

Chapter 1

Literature Review: Pasture Production Systems

1.1 Introduction

The productivity of grazed pasture depends upon climate, the fertility of the soil, the species of plants comprising the pasture and its mortality and consumption by herbivores. Fertiliser practice can alter soil fertility and facilitate changes in pasture composition (Walker, 1980). However, modifying the effects of climate is not so easy. Moisture deficits can be overcome in some regions by irrigation but, in general, farming practice adapts to the climate-induced patterns of pasture production (Bircham and Korte, 1984). Management techniques such as conservation and rationing of feed, all facilitate efficient use of herbage, but have relatively little effect on how much is or can be grown.

This literature review briefly outlines, (1) some of the biological processes involved in the production of herbage and the flexibility available to the graziers, managers or farmers to manipulate the pasture production process, (2) the broader understanding of modelling concepts and finally (3) an overview of some of the computer models; decision support systems (DSS) being more successfully used on grazing land in developed countries. Before discussing the biological process of pasture production, it is important to understand the fundamental interactions involved in the grazing management systems (interactions between plant, animal and abiotic factors).

1.2 Grazed Pastures and Their Interactions

The fundamental process in all conventional food production systems is the harnessing of the sun's energy and the supply of plant nutrients from the soil for the production of plant tissue. In an animal production system, there are two further stages: the plant must be consumed by animals, and then converted into usable animal products (Figure 1.1) (Hodgson, 1990). Each of these stages has its own efficiency (i.e. output expressed as a proportion of input) which can be influenced by management, and together these efficiencies determine the production achieved. The grazing system represented in Figure 1.1 is a simple series of the three stages, i.e. herbage growth, consumption by grazing animals (utilisation), and conversion into animal products. In fact, the three stages interact

with one another in a number of ways, the most important of which are shown in Figure 1.2. Soil and climatic factors are indicated in Figure 1.2 to show how some of the interactions between plants and animals are mediated by, or influenced by the abiotic environmental factors. These factors are not explained here as some of these are covered in pasture modelling Chapter 2 separately.

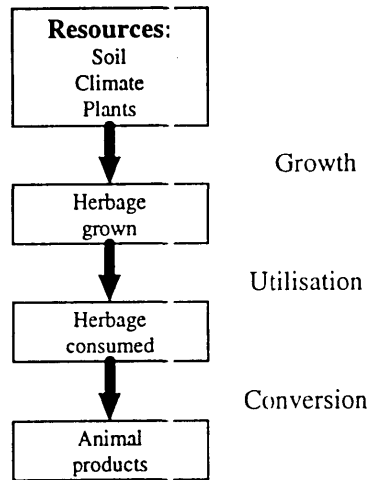


Figure 1.1 Stages of plant and animal production in grazing systems. (after Hodgson, 1990)

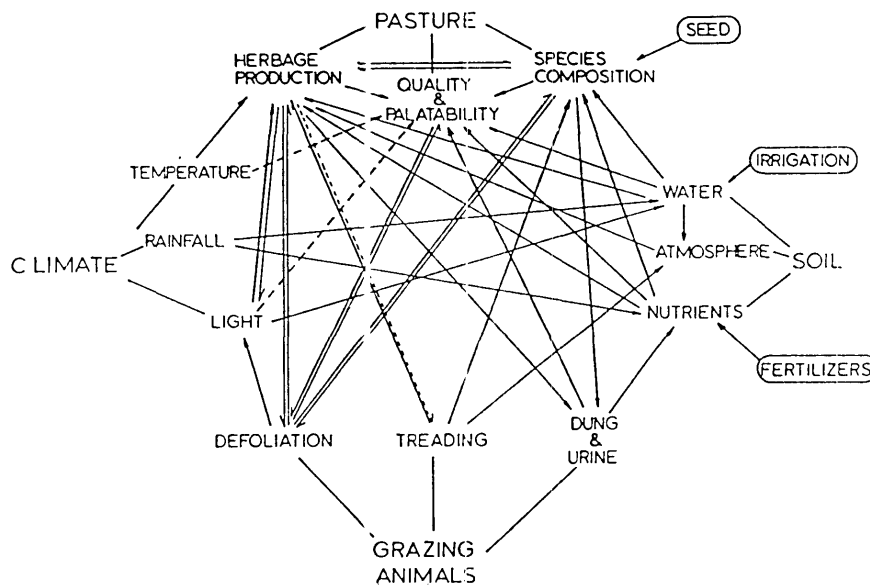


Figure 1.2 A diagram of the interactions between grazing animals and grazed pasture; only the more important effects are indicated. (after Snaydon, 1981)

1.3 Biology of Grazing Systems - Processes Involved in Herbage Production:

The biology of a grazing system mainly involves the processes of herbage production and utilisation by grazing animals which are briefly discussed below.

1.3.1 Tissue Flow in a Grazed Pasture

The herbage production (HP) in a grazed sward is a continuous process. The growth of new tissue (G) is determined by the rate of photosynthesis. The new tissue, if not consumed (C) by the grazing animals, must pass through the process of senescence (aging), death and decay (D), and eventually disappear from the sward (Bircham and Korte, 1984; Hodgson, 1990). In mathematical notation, it can be represented as:

$$HP = G - C - D \quad (1.1)$$

It is apparent from the equation (1.1) that, for a definite value of G, the value of HP and C can only be increased if less of G is allowed to senesce, die, decay and disappear (D) from the sward.

1.3.2 Measurement of Herbage Production

A brief review of this topic is contained in Chapter 3, section 3.2.2 measurement of FOO and section 3.4.2.1 of growth measurement.

1.3.3 Sward Structure

Pastures are comprised of populations of individual plant units, such as tillers, stolons, crowns, stems, etc. depending on plant species, each unit having its own associated mass (Bircham and Korte, 1984; Parsons and Penning, 1988; Smetham, 1990; Doyle *et al.* 1993). In general, these workers unanimously found that as pasture mass increases, the size of each individual increases and population of these units declines (Figure 1.3).

A rotationally grazed sward has a lower population density and larger individual units than set stocked grazed swards at comparable stocking rates (Bircham and Korte, 1984; Hodgson, 1990). Likewise, a sward predominantly grazed by cattle usually exhibits lower population density and larger individual units than those grazed predominantly by sheep. Bircham and Korte (1984) observed that any disturbance in equilibrium between the number of individuals and the size of individual units can potentially reduce HP. Such effects are typically caused by overgrazing and under-grazing.

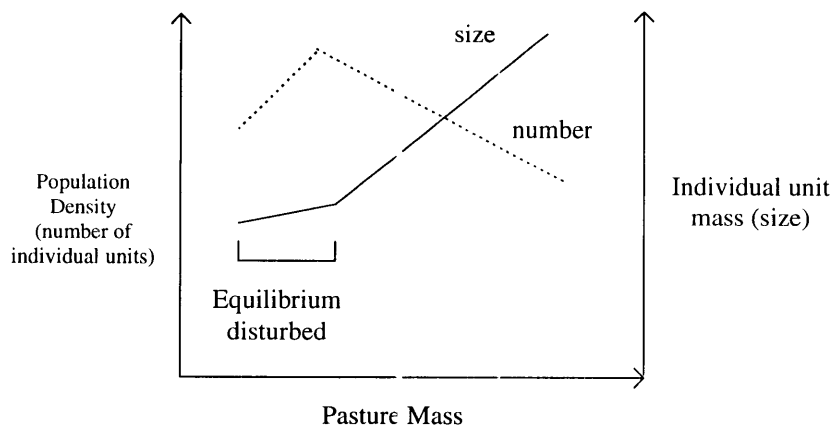


Figure 1.3 The relationships between tiller population density, individual unit size, and pasture mass. (adopted from Bircham and Korte, 1984; Korte *et al.* 1987; Hodgson, 1990; Smetham, 1990)

1.3.4 New Herbage Growth and Grazing Systems

When a well-established grass sward is cut or grazed down and then allowed to regrow, new herbage growth increases slowly at first. As reserves are mobilised to leaf area the rate of accumulation increases as more light is intercepted by an increasing area of young leaves with high photosynthetic capacity (Hodgson, 1990). When most of the incident light is intercepted by the sward, the rate of herbage accumulation decreases as shading takes effect (Figure 1.4 (a) line UG); this pattern arises from the interaction between increasing mass per tiller and decreasing tiller population (Grant *et al.* 1988). A sward maintained at a steady state by continuous grazing exhibits a constant mass (Figure 1.4 (a) line CG) and its growth cannot be inferred from a curve showing herbage accumulation

with time (Cacho, 1993). The author also inferred that a rotationally grazed sward exhibits alternating periods of slow G after defoliation followed by an increasing G rate (Figure 1.4 (a) line RG). Figure 1.4 (b) shows that G does not decline at high levels of herbage mass (HM) and in general, maximum G is achieved at 1,200-2,500 kg DM ha⁻¹ in grass dominated swards (Bircham and Korte, 1984) and these limits can be widened up to 900-3,000 in particular for perennial ryegrass dominated swards (Korte *et al.* 1987).

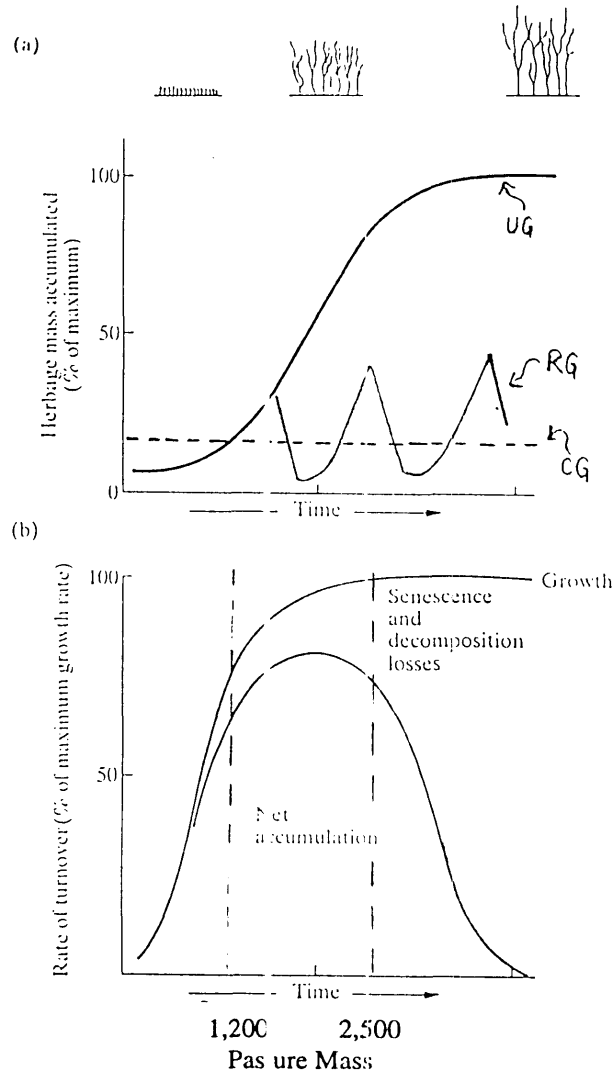


Figure 1.4 Characteristic curves for rates of new growth, herbage production, and decay versus pasture mass and time, (a) inference curves for the cumulative changes in herbage mass in a sward over time during a period of recovery growth after defoliation under the three pastoral systems; UG = ungrazed, RG = rotational grazing, and CG = continuous grazing, (b) effect of residual herbage mass on the corresponding changes in the rates of herbage growth, senescence

and net accumulation. (modified and adapted from Bircham and Korte, 1984; Hodgson, 1990; Cacho, 1993).

Climate, soil fertility, and pasture species mainly determine G. Little can be done to influence G other than by attempting to maintain green leafy pasture; grass pseudostems and clover stolons contribute little to photosynthesis compared to green lamina (Donald, 1961; Bircham and Hodgson, 1983; Bircham and Korte, 1984; Smetham, 1990). Sparse-stalky-yellow swards with little green lamina after grazing take longer to achieve maximum G than dense-leafy-green swards. It takes time for such pastures to restore the population density required to maximise light interception, i.e. total G per unit of time is reduced.

1.3.5 Herbage Production

In practical terms, G is most likely to limit herbage production (HP) in late winter and early spring, when levels of herbage mass (HM) are low (Bircham and Korte, 1984). For the remainder of the year and except during drought or at times of low population density etc., HP is not limited by G but by utilisation. This means that the amount of herbage allowed to senesce, die, decompose, and eventually disappear largely determines HP and C (kg DM/ha). These factors that determine utilisation, therefore, also determine HP.

1.3.6 Utilisation of Herbage

The term utilisation (U%) has been used to express both efficiency with which an individual paddock is grazed (i.e. pasture consumed at each defoliation as a proportion of HM originally present before commencement of grazing) and overall efficiency of a grazing system (i.e. pasture consumed over a season or year as a proportion of pasture accumulation over the same time period). Bircham and Korte (1984) noted that similar ranges of values (40-90%) are used for both. Mathematically, it can be written as:

$$U = \frac{C * 100}{HP} \quad (1.2)$$

But, this definition is not tenable to describe overall farm efficiency. Theoretically, utilisation in the overall farm system sense can be correctly defined as the percentage of new growth (G, kg DM/ha) consumed. This can be expressed as equation (1.3).

$$U = \frac{C * 100}{G} \quad (1.3)$$

Practically, however, this definition is not very useful, because of the difficulties associated with the measurement of G (Korte *et al.* 1987). The concept of utilisation as an index of the overall efficiency of a farm system is misleading, and therefore instead overall efficiency of pasture use is best expressed in terms of animal production per unit area (e.g. kg wool ha⁻¹, weaned lamb liveweight ha⁻¹, etc.) in a long-term sustainable way (Bircham and Korte, 1984; Korte *et al.* 1987).

1.3.7 Grazing Pressure

A brief overview of stocking pressure effects is presented in the stocking rate section of modelling in Chapter 2.

1.3.8 Ingestive Behaviour of the Grazing Animal

The productivity and botanical composition of pasture can be rapidly and substantially altered by grazing animals. The effects may be detrimental. Sheep tend to graze different horizons within the sward and different pasture species compared to cattle and goats (Watkin and Clements, 1978). Sheep, for example, when offered largely dry, rank compared to lush, green pasture, restrict their diet predominantly to the green herbage component (Rattray and Clark, 1984), whereas cattle are less selective.

1.3.9 Disappearance of Herbage

The proportion of new growth (G) that disappears is determined by utilisation (Korte *et al.* 1987). This is determined by many factors, such as plant species and time of year. The

rate of decay and eventual disappearance of dead herbage is regulated by temperature and moisture levels (Hutchinson and King, 1980; Bircham and Korte, 1984; Korte *et al.* 1987). Moist warm conditions favour disappearance of dead herbage since these conditions are suitable for bacterial and fungal growth, and for earthworm activity. In cold or dry conditions the disappearance rates are much reduced. This decaying process of dead tissue is essential in recycling nutrients which can be re-utilised for further plant growth.

1.4 Modelling of Pasture Systems

1.4.1 Introduction

Literally, a model can be defined as an analogue of the system being studied (Bell, 1981). That is, it is another way of depicting the system which is used to represent all and/or some aspects of the more complex system of concern. Thornley (1976) defined a mathematical model, as an equation or a set of equations which represent (s) quantitatively the assumptions or hypotheses that have been made about the real system. They can be solved, giving rise to predicted values. The model, or more correctly the assumptions that were made when constructing the model, can be tested by comparing these predicted values with measurements made on the real system. He further emphasized that the mathematical equations of a model do not provide its biological or scientific content, but simply express and interpret the hypotheses in a quantitative way, enabling their consequences to be deduced, and showing the user where to look for their verification or refutation. Verification and validation of models will be dealt with separately later in this section.

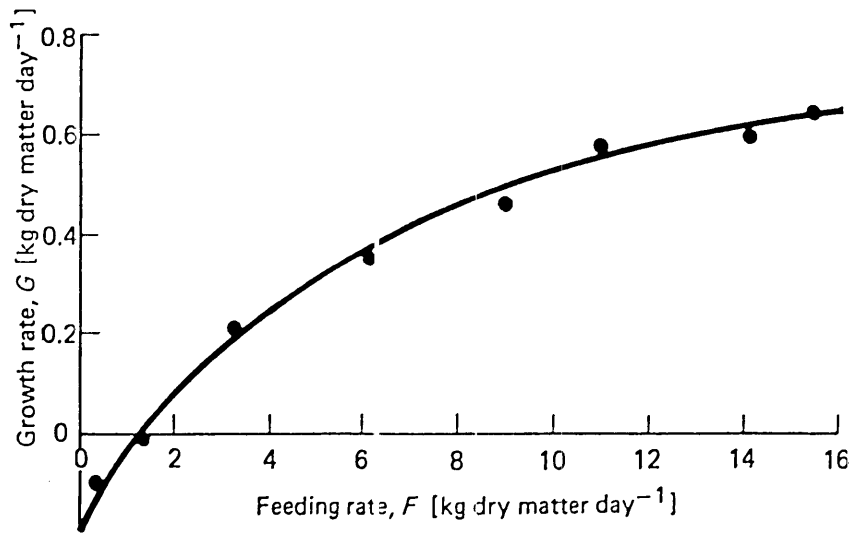


Figure 1.5 A hypothetical experiment to show the effects of varying feeding rate, F , on the growth rate of an animal, G . Experimental data, & the solid line represents a fitted equation (equation 1.4). (after France and Thornley, 1984)

In general, modelling can be broadly classified into two categories, namely static and dynamic (France and Thornley, 1984). For example, Figure 1.5 shows the type of growth curve that might result from an experiment in which an animal is supplied with feed at different rates. The data points of Figure 1.5 can be represented as:

$$G = G_1 \frac{F}{K + F} - G_2 \quad (1.4)$$

where, F = the rate at which feed is supplied to the animal.

G = the growth rate of the animal.

Here, both F and G are numerical variables. F is known as an independent variable, since the experimenter fixes F at certain values, for instance, the range of levels of feeding rate he/she wishes to cover. On the other hand, G is known as a dependent variable, since it is not under the direct control of the experimenter and its value is a consequence of the level of F that has been chosen. The quantities of G_1 , G_2 and K are called parameters. This representation is known as a static model, since it does not contain the time variable t , but

there are many useful models of this type. GrazFeed in the whole-farm simulation model for grazing enterprise (GrazPlan) is one of the examples of this type.

There is a second very important category of models, known as dynamic models; these contain the time variable t , and are often used to describe a time-course of events, most appropriate for the biological sciences. For example, the following simple equation is one of the representations of the dynamic type.

$$W = W_0 + bt \quad (1.5)$$

where, W = weight of an organism (animal or plant),

t = time

W_0 = parameter

b = parameter

Here, W_0 is the value of W at zero time ($t = 0$), and b is the slope of the growth curve.

The equation (1.5) can be drawn in Figure 1.6

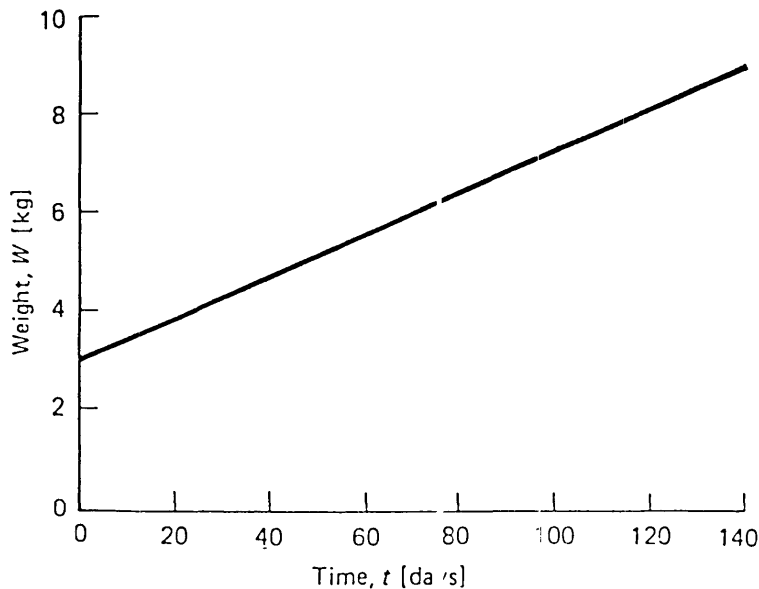


Figure 1.6 A simple dynamic growth model. It is the graphical expression of equation (1.5) which represents the weight of an organism, W , and its dependence on time t . (after Thornley, 1976).

However, it is more common to represent dynamic models by their differential form. The equation (1.5) can be re-written in this form as:

$$\frac{dW}{dt} = b \quad (1.6)$$

The equation (1.6) now explains that the growth rate, dW/dt , is equal to a constant, the parameter b . GrassGro, of the whole-farm simulation model for a grazing enterprise GrazPlan, is one example of this type. Detail of this model is presented later part of this section.

1.4.2 Significance of Models to Scientific Research and Development

The value of modelling is dependent upon the nature of the problem, the aims of the investigator and the type of model chosen (Thornley, 1976). Some aspects of general significance to modelling are listed below.

- Hypotheses expressed in mathematics while developing models can provide a quantitative description and understanding of biological problems.
- The requirement of a model can provide a conceptual framework which may help point out areas where knowledge is lacking, and might stimulate new ideas and experimental approaches.
- A model can be a good way of providing a recipe (instruction) by which research knowledge is made available in an easy-to-use form by the farm manager.
- The economic benefits of methods suggested by research can often be investigated and highlighted by an agro-economic model. For instance, the gross margin (GM) calculation option of the GrassGro model which simulates the adoption of improved methods of production.
- Modelling may lead to less *ad hoc* experimentation, as models sometimes make it easier to design experiments to answer particular questions, or to aid in verification between alternative mechanisms. Environmental comparisons and choice of lambing date simulated from the GrassGro model are some examples of this type.

- In a farming system with several components, a model can provide a way of bringing together knowledge about the parts, to give a logical view of the behaviour of the whole-farm system. For example, a long-term simulation of year-to-year variability in weather conditions and their consequent effects on pasture production from GrassGro can be a basis of managing a ewe/wether enterprise under diverse farm situations.
- The predictive power of a successful model may be used in many ways; such as identifying the priorities in research and development, management and planning. For instance, a model can be used to indicate the answers to ‘what if ...?’ questions which would be quite difficult, or sometimes not feasible in real situations. For example, what would be the consequences on animal production of halving the maintenance requirements of ruminants? or, what would be the consequences for crop yields of halving the transport resistances mechanism within-plant and so on.

1.4.3 Types of Models

The major categories of models have been briefly introduced earlier in this Chapter, and two simple models were described. However, models can be grouped into different classes in a more systematic way. France and Thornley (1984) suggested the following different ways of classifying models:

- Empirical and mechanistic models
- Static and dynamic models
- Deterministic and stochastic models:

Apart from those above, various workers have classified and defined the modelling concept and type of model in several ways but the most important concern is to match the problem, the research and/or management objectives and the type of modelling to be attempted. In much of agriculture and perhaps especially in plant and animal physiology, the users’ needs are often met by the construction of dynamic deterministic models (France and Thornley, 1984).

1.4.4 Components of Dynamic Deterministic Modelling

In a dynamic model, variables are quantities that change with time, and they can be considered under four categories: state variables, rate variables, auxiliary variables and most importantly driving variables (Thornley, 1976).

A *State Variable* is a quantity that defines the state of the system at a given point in time. For example, leaf area A and dry weight W in a plant model are typical state variables. Let the system be defined by q state variables $X_1, X_2, X_3, \dots, X_q$. These variables are independent which means that knowledge of the numerical values of some of them cannot be used to derive any of the others. In dynamic deterministic models these variables are determined by time t .

A *Rate Variable* is a quantity that defines some process within the system at a given point in time. Rates always have dimensions of quantity per unit time; they cannot be measured instantaneously as can state variables, but only over an increment of time Δt . The processes in the system occur at given rates, and these are the rates which determine how the state variable $X_1, X_2, X_3, \dots, X_q$ change with time. For instance, photosynthetic rate, respiration rate, substrate utilisation rate, transport rates, protein degradation rates, growth rates etc. in an organism (plant or animal) are some of the examples of rate variables. These can be represented by the following simple relationship:

$$\text{rate of process} = \text{function of state of system}$$

A simple example of this is equation 1.6.

Auxiliary Variables are the variables additional to the state variables in most dynamic models, and usually define the system completely. For example, if leaf area A and dry weight W are independent state variables, then the leaf area ratio, F_A , can be obtained by

$$F_A = \frac{A}{W} \quad (1.7)$$

Another example could be taken from a root-shoot partitioning model, where W_r and W_s are the dry weights of root and shoot, and are the two independent state variables of the model. The total dry weight of the plant W , can be obtained by

$$W = W_r + W_s \quad (1.8)$$

Here, W is an auxiliary variable. Sometimes, an auxiliary variable would be a rate variable, for example the specific or relative growth rate R_w can be measured by

$$R_w = \frac{1}{W} \frac{dW}{dt} \quad (1.9)$$

This type of relationship is much used in the biological sciences, and considered as a variable (total dry weight w) and a rate (total growth rate $\frac{dW}{dt}$, a process).

Driving Variables are the most important variables used in plant and animal modelling. Driving variables are the data inputs to a model which vary autonomously with time. The experimenter does not have control of these. The growth of plants and animals is driven by the environment. The quantities specifying the environment analogously may have the properties of state variables, such as temperature, humidity, rainfall, radiation, evaporation or evapo-transpiration, wind or nutritional inputs which usually have dimensions of quantity per unit time. These collectively can be written as:

$$E \equiv E(t) \quad (1.10)$$

This indicates that the environment, E , is a function of time, t . These environmental variables usually are the external inputs in the model with the assumption that, although

the environment affects the growth of plants and animals there is little effect of plants and animals on the environment.

Parameters and Constants are quantities appearing in the equations of a model that do not vary with time. Constants are described as quantities that accurately determine values which remain the same when the experimental conditions are varied. Some typical constants are the density of water, relative molecular mass of glucose, value of k in light extinction coefficient, value of C in curvilinear models.

Parameters are quantities that are often changed but are kept constant throughout a run of the model. For example, photosynthetic efficiency, the maintenance respiration coefficient (Thornley, 1976), vernalisation rate of plant species, day length for commencement of reproductive phenostage, degree-day sum for commencement of reproductive phenostage, degree-day sum for commencement of flowering, etc. (Moore *et al.* 1996; Finlayson *et al.* 1995; Cacho *et al.* 1995). These are some of the parameters used for predicting pasture phenology. The values of these parameters often vary with experimental conditions, the way in which the organisms are grown, genotypes, or other factors as well. Sometimes, certain parameters are poorly known but can be made available to fit the output of the model to experimental data by adjusting these parameters and looking at the goodness-of-fit; the process is often referred to as model calibration or validation (Blackburn and Kothmann, 1989; Stout *et al.* 1990; Cacho *et al.* 1995; Finlayson *et al.* 1995).

1.4.5 Modelling of Growth

In both plant and animal sciences, modelling of growth has been used for many years, usually to provide a mathematical summary of time-course data on the growth of an organism or part of an organism. Thornley (1976) used the term growth function in growth modelling to denote an analytical function which can be written down in a single equation. Thus, a general growth function connecting dry weight W to time t is:

$$W = f(t) \tag{1.11}$$

Where f denotes some functional relationship. Taking this basic idea into account, the equations most widely used in plant and animal growth models are the following types:

- Logistic and relatives
- Gompertz growth equation
- Richards growth equation
- Chanter growth equation
- Exponential polynomial equation, etc.

1.4.6 Computer Models of Grazing Systems

With the advancement of technology in computing science, modelling of the biological sciences has been propelled. The conventional styles of modelling are often far too complicated to solve using hand methods, particularly when these models attempt to consider a wide range of parameters to simulate whole farm systems. Now computers are viewed as a useful tool to carry out the tedious mechanics of calculation. Some of the computer programming languages that are used in modelling work are BASIC, PASCAL, ALGOL, FORTRAN, DELPHI or possibly a special purpose language such as CSMP or LP400, C or C⁺⁺. These are frequently used in formulating the software of decision support systems (DSS), for whole-farm systems or components of the whole-farm systems. The major successes with DSS on grazing lands has occurred in the more developed countries such as United States, Australia, New Zealand, South Africa etc where grazing lands support the major commodity sector. Some examples of models for grazing systems are briefly discussed below.

1.4.7 Rangeland Models:

(a) SPUR (simulation of production and utilisation of rangelands)

The SPUR model is a physically and biologically based model that includes many processes known to occur in grassland ecosystems. Among these processes are percolation of water through the soil profile, evapo-transpiration, photosynthesis, transport of C and N between

roots and shoots, and domestic animal production (MacNeil *et al.* 1985). In general, SPUR has three basic components: (1) hydrology, (2) plants, and (3) domestic animals; and also several minor additional components that include economics and wildlife. Model components were developed using current information and models including the grassland Ecosystems Level Model (EIM) and the Texas A & M (TAMU) model for beef production (Sanders and Cartwright, 1979). The detail description about the climatic data (the driving force of the model), animal parameters, soil parameters and plant parameters have been given in the SPUR User Guide (Skiles *et al.* 1987).

(b) GLA (*Grazing land application*)

This DSS was developed in the United States jointly by Texas A & M University and the US Dept of Agriculture to assist technical advisers in conservation planning on rangelands, pasture lands, haylands, grazable croplands and woodlands (Stuth *et al.* 1991). Although it was also intended to be used by farm managers and graziers, the model was chiefly used by planners and technical experts for planning and organising the existing resource information of ecosystems from the desert southwest to the forests of the northeast and from the tropics in the Caribbean to the tundra of Alaska (Stuth and Smith, 1993).

(c) RangePack

This DSS was designed and developed by Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Wildlife and Ecology in 1988 to assist Australian grazing land managers in making strategic decisions which relate to the development of their properties (Stuth and Smith, 1993). It was also intended to look at short-term tactics for implementing these strategies, and managing problem events such as drought. In addition, two additional packages have recently been released to expand the capability and support the DSS, i.e. Paddock, a spatially-based paddock planning and record module, and CLIMATE, an interactive database for easier assessment of climatic probabilities based on historical records in Australia's rangelands (Ludwig, 1990).

(d) ISPD (*Integrated System of Plant Dynamics*)

This DSS was developed by the Dept of Plant Sciences at Potchefstroom University to incorporate the whole ecosystem of rangelands in South Africa (SA). The DSS mainly focuses on habitat characteristics, vegetation dynamics, rangeland and assessment of grazing capacity for grazinglands in SA (Carlson *et al.* 1993). This unique DSS was built based on conventional database management techniques with an expert system to help overcome a limited knowledge base of extension personnel working with livestock producers. The approach used in the model may provide an innovative idea to land classification and carrying capacity assessment in resource poor countries where grazing management decision making is limited by scarce data.

1.4.8 Pasture land Models:

(a) Stockpol

This DSS was designed and developed jointly by the Ministry of Agriculture and Fisheries (MOAF) and an agri-business consultancy group and is targeted for use on grazing enterprises in New Zealand (McCall *et al.* 1991). Stockpol is a large integrated systems model; a whole-farm approach to planning is used. Although the DSS is focussed on fat lamb, wool, and beef production systems it is currently being expanded to handle red deer, goats, and dairy cattle (Stuth and Smith, 1993).

(b) GrazPlan

This DSS is built for a whole-farm simulation model for a grazing enterprise. The system was developed by CSIRO, Division of Plant Industry for sheep and cattle production systems in the temperate (high rainfall regions) and Mediterranean environments of Australian grazing lands (Donnelly *et al.* unpublished). The system consists of four individual modules: GrazFeed, MetAccess, LambAlive and GrassGro.

(i) GrazFeed

This is individually a one-day model that checks the availability of pasture to meet the nutritional requirements of livestock. It helps achieve target productivity in weaners. The program also estimates the effects of supplements in the diet.

(ii) MetAccess

This DSS allows the user flexibility to summarise and graphically display meteorological data relevant to farming. It indicates the probability of the climate being suitable for pasture, crops or management practices.

(iii) *LambAlive*

This DSS allows the grazier to assess the risk of lamb losses from bad weather if lambing dates are shifted.

(iv) *GrassGro*

GrassGro DSS takes the same model of ruminant production used in GrazFeed and links it with a dynamic model of pasture production and quality. The model of pasture growth is driven by daily weather information which is stored in GrazPlan weather files. The model does not yet implement the nutrition model of plant growth. The placement of GrassGro in the GrazPlan project is represented in Figure 1.7.

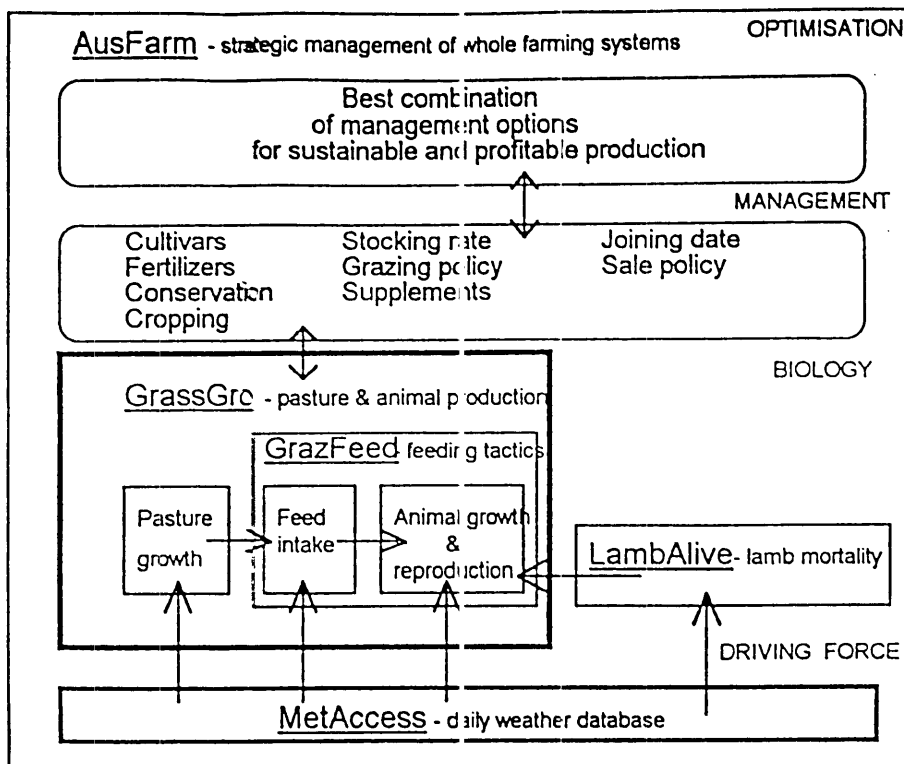


Figure 1.7 *GrassGro and its place in AusFarm, a whole-farm simulation project.* (adapted from J. Donnelly, A. Moore & M. Freer, unpublished. A discussion document 'Using the GrassGro DSS' at Tamworth and Cowra, 1994)

GrassGro is designed to evaluate:

- Prediction of animal production as influenced by pasture availability
- Prediction of year-to-year variability in pasture supply
- Matching animal demand for energy and protein to pasture supply

- Comparisons of pasture species and environments
- Wether flocks for wool production
- Ewe flocks for wool and/or prime lamb production
- Steer fattening and beef cow enterprises
- Choice of joining and weaning dates
- Simple supplementary feeding policies
- Comparisons of stocking rate
- Gross margin calculations with fixed costs and prices

1.4.9 Models, Predicted Data, and Experimental Data

Thornley (1976) proposed the way to explore the relationship between the experimental system that is being studied and a model of the system, and mathematics is considered. A way in which these can be related is presented in Figure 1.8. A similar procedure can be applied to evaluate and validate computer models of the whole-farm systems or its components. Apart from this evaluation procedure, a model can also be tested for its sensitivity analysis by changing some of the parameters used in the model.

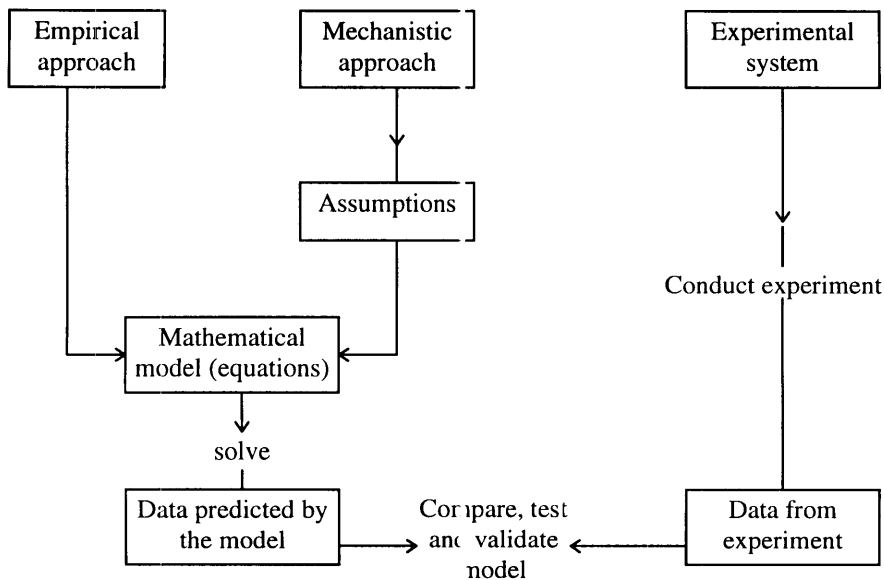


Figure 1.8 Procedures of evaluating a mathematical or a computer model. (adapted from Thornley, 1976)

1.4.10 Conclusions

Climate, soil fertility and pasture species are the major determinants of new herbage growth. Maximum herbage production is achieved by avoiding the extreme of over-grazing, which reduces new herbage growth, and under-grazing which increases loss due to decay and decomposition. Integrated management systems offer some scope for increasing herbage production during periods of feed deficit; by minimising the period during which herbage growth is restricted by low pasture mass and feed surplus; by maximising utilisation (Sheath and Bryant, 1984).

Because of the complexity of grazing systems many computer systems model have been developed.

There are several limitations associated with DSS development and these have been explored by Stuth and Smith (1993). One of the problems is how to measure the success of a system once distributed. Obviously, if an organisation sponsors a DSS, there should be immediate internal adoption of the system. Those systems targeted for direct use by land holders/managers are best measured in terms of number of people using the system, land area impacted, durability of the decision and sustainable use of the system. However, some systems may naturally become obsolescent as the knowledge that they provide is internalised by users to the point that computer-based systems are no longer needed.

Other issues relating to the success of DSS include geographical relevance, validation of biological responses, and verification of heuristic (i.e. helping to discover) based predictions. For example, if the geographical range of a DSS is broadened, modellers are forced to search out the relevant properties of all the ecosystems which are encompassed in the model. This process causes the system to lower effectiveness in predicting precision about the region-specific problems. It is possible that designers can develop the region-specific system and thereby can narrow down the requirements needed by the system but transportability to other ecosystems is then severely limited.

Success of a DSS requires the biological processes that are encompassed in the system have been sufficiently validated. However, the major limitation to validation is the financial and human resources needed to test a wide range of environmental conditions. On the other hand, as a DSS includes an increased variety of conditions, universal validation becomes increasingly more difficult. In these circumstances, greater reliance has to be placed on “expert verification”; an assessment of the degree of “reasonableness” of a predicted outcome.

The measurement of the success of a DSS is now an emerging issue that will require a greater maturity in the process of developing and implementing information technology in grassland ecosystems.

Wilson and Morren (1990) and Stuth *et al.* (1991) outlined some of the future prospects of DSS of natural resource ecosystems management. In a broader sense, DSS is not the end of the story but only the beginning of a new era in which information technology will have profound impacts on the way resource managers access and analyse information. This trend will require the way that science is conducted to be restructured in the future. Biological, economic, and social sciences will need to merge with information science to produce users (practitioners) who can react effectively to the unified information world.

In a relatively narrow sense, DSS can be used at a policy, or on-farm level. DSS are becoming an integral part in natural resource management as policy level funding agencies need greater depth of analysis, preferably in less time (see also *significance of model...*), while managers require a greater analytical outcome, particularly where decisions relate to long-term and short-term risks associated with weather variables and market conditions.

Chapter 2

Parametrization of the GrassGro Model for Use with Three Pasture Types

2.1 Introduction

Approximately 80% of the degraded pastures on the Northern Tablelands of New South Wales (NSW) consist of native pasture grasses (Robinson and Archer, 1988; Lodge *et al.* 1990). More than 700 grass species from 150 different genera have been reported occurring in NSW (Lodge *et al.* 1990). This includes both natives, which were present in Australia before European settlement and naturalised species that have been introduced from overseas and are capable of distributing and regenerating themselves without human assistance (Lodge *et al.* 1990). Whilst annuals are common, many are warm season perennials which are susceptible to frost, whilst only a small proportion are cool season perennials (Lodge *et al.* 1990). Some of the common species occurring in the temperate pastures are: *Andropogon virginicus*, *Aristida ramosa*, *Bothriochloa macra* (Robinson and Archer, 1988; Lodge *et al.* 1990), *Chloris gayana*, *C. ventricosa*, *C. truncata*, *Eragrostis curvula*, *Panicum* spp., *Paspalum dilatatum*, *Holcus lanatus*, *Danthonia linkii*, *Eleusine tristachya*, *Agrostis* spp., *Avena fatua*, *Bromus* spp. and *Briza minor* (Hamilton, 1973; Cook, 1974; Robinson and Archer, 1988; Lodge *et al.* 1990).

The modelling exercise undertaken here consisted of developing parameters to simulate the growth and feed on offer (FOO) of the three pasture types, i.e. phalaris dominant, phalaris-white clover and degraded, which includes a mixture of annuals and warm season perennials. A schematic of the GrassGro model showing the parameters modified for each pasture type is presented in Figure 2.1

2.2 Parameters for Phalaris (Phalaris aquatica) and white clover (Trifolium repens) growth rates

Phalaris has been described (Lazenby and Swain, 1973) as being “the most adaptable grass used in improved pastures in Australia” in that it is compatible with legumes, able to

persist where the rainfall is as low as 430 mm; a deep rooted species with a crown below the soil surface. All of these factors contribute to the plants persistence under both moisture stress and intensive grazing. The authors obtained a yield of approximately 11,200 kg ha⁻¹ from pure swards at Armidale, with moisture non-limiting and nitrogen applied annually @ 224 kg ha⁻¹.

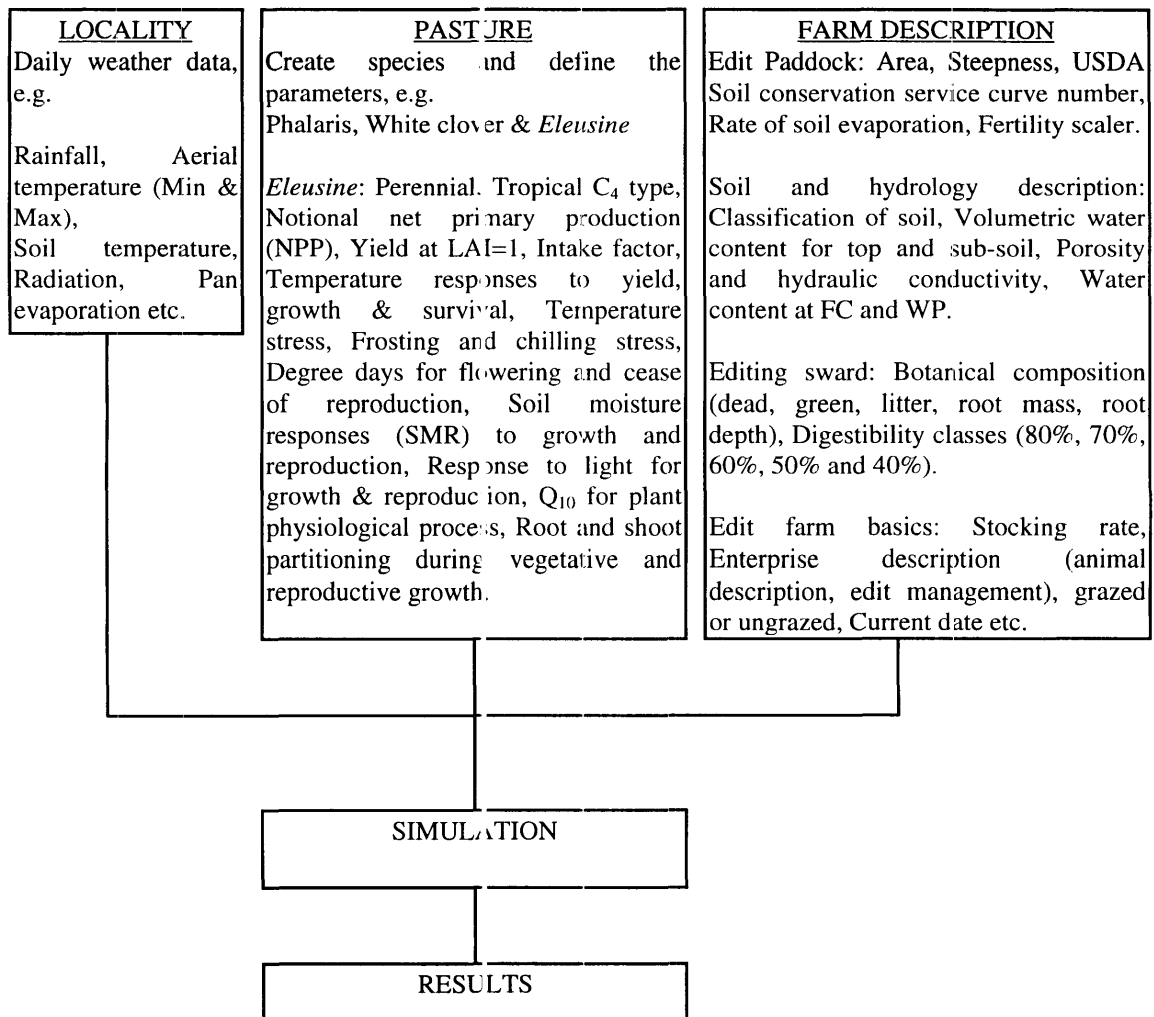


Figure 2.1 Schematic of GrassGro indicating parameters considered in the following section.

Herbage of phalaris is palatable when young, the leaves especially having good feeding value; acceptability and digestibility of the plant falls during summer particularly when temperatures are high accompanied by low rainfall.

White clover, on the other hand, is sown on the Northern Tablelands in preference to subterranean clover in areas where rainfall exceeds 760 mm. It is considered one of the most successful legumes in temperate regions where soil moisture is not a limiting factor.

The ability of phalaris and white clover to cohabit in pastures is one of the major agronomic attributes of these plants. They form a suitable combination both morphologically and qualitatively in a grazing system. The growth rhythms of the two plants has been well demonstrated by Lazenby and Swain (1973) under moisture non-limiting conditions. Askin *et al.* (1987) found that the higher the proportion of clover in a pasture, up to 35%, the greater will be the growth of stock on that sward. In addition, nitrogen fixation is related to the amount of clover growth in the pasture.

A basic determinant of the proportion of clover in a pasture is the level of phosphorus and nitrogen in the soil. A newly established pasture will contain up to 50-70% white clover of the total pasture herbage weight. However, an increased level of mineralised nitrogen in aged pasture decreases the clover content, because the competitiveness of associated grass becomes greater as the available soil nitrogen level increases (Hoglund *et al.* 1979).

For the comparison of results (simulated vs measured) of both the phalaris and phalaris-white clover pastures, the growth and quality parameters supplied with the model were accepted. Credible values for pasture growth from the model can only be expected for a particular species when all the stipulated parameters have been estimated with sufficient precision. The parameters used in the GrassGro model to simulate pasture growth and feed on offer (FOO) are shown in Appendix 1.

2.3 Degraded Pasture Growth Rate

The 'degraded' pasture at the Big Ridge site 2 at "Chiswick" was found to be composed of annuals and many summer perennial species. This shift in pasture composition is consistent with the findings reported by various workers (Hamilton, 1973; Lazenby and Lovett, 1975; Cook *et al.* 1976; Archer and Robinson, 1988) and is typical of many overgrazed pastures in the temperate pastures of the Northern Tablelands.

Although a wide range of species, both summer annuals and perennials, are found in such degraded pastures, only a few of them, such as *Eleusine tristachya*, *Danthonia linkii*, *Eragrostis curvula*, and *Chloris truncata* are predominant at the Big Ridge 2 site and contribute significantly to the feed on offer (FOO) available for grazing.

Because of the need to simplify the parameters for the native grass species in the model to simulate their growth rhythm and complexity of the model, the degraded pasture was defined as consisting of *Eleusine tristachya*, *Danthonia linkii* and annual clovers (e.g. *Trifolium glomeratum*, *T. cluster*, and *T. dubium*). This simplification is considered valid as these species contribute most to the pasture over time.

Eleusine tristachya was the dominant grass species in the degraded pasture of the experiment at the Big Ridge 2 site, "Chiswick". This belongs to the *Poaceae* family, is similar to crow's foot grass (*E. indica*) but smaller in stature with 1-3 spikes in the flowerhead (Burbidge, 1966; Lodge *et al.* 1990), densely arrayed in a comb-like fashion in two parallel rows (Burbidge, 1966). It possesses an indeterminate flowering characteristic, and usually flowers during summer-autumn (Burbidge, 1966).

Although this grass can behave as a short-lived perennial, it is more often regarded as an annual (Lodge *et al.* 1990, Hutchinson and King, 1993). However, the information obtained through several researchers (R.D.B. Whalley, pers. comm; G J. Blair, pers. comm) regarding its life cycle, it is commonly viewed as a warm season perennial species. Due to a lack of published information about the species, some information has been deduced from other common warm season perennials such as redgrass (*Bothriochloa macra*) and/or windmill grass (*Chloris truncata*) and partially through African lovegrass (*Eragrostis curvula*). In terms of carbon assimilation pathway in the photosynthetic process, they are all in the C₄ category and with comparable growth habits (McWilliam, 1978).

Bothriochloa is one of the most common species encroaching into sown pastures on the Northern Tablelands during the process of degradation (Cook *et al.*, 1974). This species, together with ryegrass (*Lolium perenne*), white clover (*Trifolium repens*) and others followed the same established pattern of seasonal pasture production with the highest yields during the October - March period, and the lowest in the six months April through to the September (Cook *et al.* 1978; Robinson and Archer, 1988).

The high annual yield of *Bothriochloa* is made less attractive by the fact that only 22% of this growth was leaf material (Robinson and Archer, 1988). As previously noted, the palatability of such species to stock is substantially diminished by the high stem content (up to 55% in summer; 26% annually).

Cook *et al.* (1976) found that, under low fertility and moisture stress conditions, *Bothriochloa* can produce 4,400 kg DM ha⁻¹. Under conditions of high fertility and in the absence of moisture stress, the yield recorded by Archer and Robinson (1988) was as high as 10,600 kg DM ha⁻¹ annually.

Pasture production in the Cook *et al.* (1978) experiment varied during the year as the prevailing ambient temperature and soil moisture conditions changed. The peak production of redgrass dominant pasture was measured at 64 kg DM ha⁻¹ d⁻¹ with the application of superphosphate @500 kg ha⁻¹ in the spring of 1972. This rate of production for redgrass dominant pasture was found to be considerably less than the irrigated ryegrass swards in the Armidale environment (Colman *et al.* 1974). However, it is known that under comparable non-limiting growth conditions, C₄ plants produce more DM than C₃ plants (McWilliam, 1978). This view is supported by the evidence that the maximum specific activity of the primary carboxylating enzymes in C₄ plants is found at temperatures close to those giving maximum rates of photosynthesis in tropical and sub-tropical plants (Phillips and McWilliam, 1971). Further evidence produced by several authors (Phillips and McWilliam, 1971; Lazenby and Swain, 1972; Cook *et al.* 1976) showed that the maximum growth rate of tropical species is very much higher than that of temperate species (Figure 2.2).

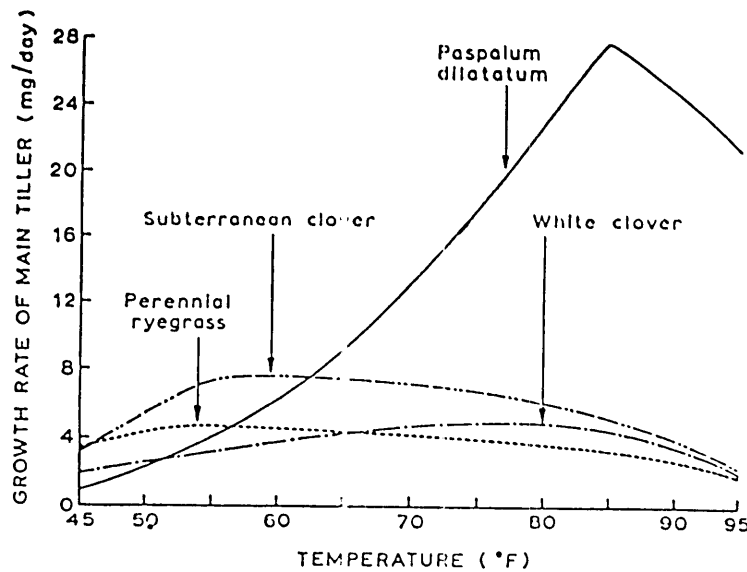


Figure 2.2 Effect of ambient temperature on the growth rate of main tiller of temperate and tropical pasture plants. (adapted from Mitchell, 1956, in Lazenby and Swain, 1973)

On the basis of above information, and due to the sub-tropical latitude of the Armidale region, a maximum growth rate of $500 \text{ kg DM ha}^{-1} \text{ d}^{-1}$ can be expected from the *Bothriochloa* dominated sward used as a surrogate of *Eleusine*. However, the potential production would be restricted by the cool night temperatures (Vickery, 1981). Unfortunately, this figure was not accepted by the model so it was then reduced to $400 \text{ kg DM ha}^{-1} \text{ d}^{-1}$. The maximum yield of C_3 plant species in the temperate region can go up to $180 \text{ kg DM ha}^{-1} \text{ d}^{-1}$ (Vickery, 1981).

(a) Intake Factor

The GrassGro modellers (Moore *et al.* 1996) did not supply details of how the intake factor in the model was established. The intake factor for a particular species could be established in a number of ways, for example palatability, which is the way the plant materials are relished by the grazing animals as it changes over time, stage of growth and soil fertility (Jones, 1995). Similarly the intake factor could vary with the canopy structure

of a sward; rosettes being more prone to biting with a bigger mass having a greater intake factor than prostrate or resupinate types.

Another factor which can affect intake is the poisoning effect of the plant, for example prussic acid poisoning which sometimes reduces the palatability and so the intake factor (Narayanan and Dabadghao, 1972). No justification could be made for changing the intake factor so it remained unchanged for *Eleusine*.

(b) Temperature

In general, grass species can be divided into two groups (tropical and temperate) according to their growth response to temperature; (Figure 2.2 and Figure 2.3). One important feature of tropical pasture plants that distinguishes them from temperate species is their higher temperature range for growth and development (McWilliam, 1978). In general, tropical plants have an optimum upper and lower temperature limit for growth 10°C higher than that of temperate grasses (Lazenby, 1972; McWilliam, 1978). However, a wide variation in temperature tolerance and requirement exists between species within the group and between ecotypes within species. Thus, depending on the species and its adaptation, plants may become more or less dormant in mid-summer (temperate grass species) or winter (tropical species) or during periods of temperature or water stress (Phillips and McWilliam, 1971; McWilliam, 1978). During these stress conditions, plants exhibit a temporary cellular resistance (hardening) mechanism to heat or cold, and utilise the temperature change for initiation of germination and reproduction (Lazenby, 1972). In general, the photo-period or day-length experienced during the spring and early summer is a major physiological trigger in the initiation of flowers in temperate pasture plants and is a key factor in controlling the time of flowering (McWilliam, 1978), whilst in tropical plants, the total degree days (°D) irrespective of day-length, is the major determining factor of the time of flowering (Vickery, 1981).

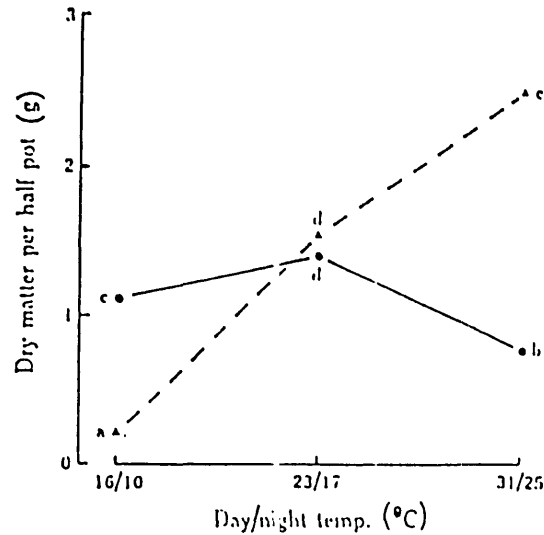


Figure 2.3 Effect of temperature on the mean yield of C4 and C3 plant species when grown in monoculture. *Bothriochloa macra* (▲) and *Lolium perenne* (●). (adapted from Cook *et al.* 1976)

Temperature is a major factor controlling the distribution and diversity of pasture plant species and many examples of clonal variation are available with respect to temperature and adaptation within populations to local thermal conditions. Also, the influence of temperature on net photosynthesis is well known and the response of various pasture species has been documented by Beinhardt (1962), Lazenby and Lovett (1975) and Cook *et al.* (1976). In these reports (Black, 1971), the species with higher rates of photosynthesis are those of tropical origin and they are associated with their higher temperature requirement. Black (1971) suggested that the presence of the C₄ photosynthetic system in the tropical grasses confers on these plants a superior ability to fix CO₂ at high temperature compared with the temperate grasses and both temperate and tropical legumes which possess the C₃ photosynthetic pathway. It can be seen from Figure 2.2 that the rate of growth per tiller in tropical grasses is three times that of C₃ species.

The optimum temperature for growth, as measured by dry matter increase for most temperate grasses, such as *Lolium perenne* (Cook *et al.* 1976, Vickery, 1981), *Dactylis glomerata* and *Phalaris aquatica* (Lazenby and Swain, 1972; McWilliam, 1973; Vickery, 1981) lies between 20 - 23°C. Information from these sources suggested that the growth rate declines markedly below 10°C although some growth still occurs at 5°C. The experiment conducted by Cook *et al.* (1976) showed that ambient temperatures above 23°C resulted in a reduction in growth in the temperate species e.g. *Lolium perenne* (Figure 2.3). Most of the temperate grass species, such as *Dactylis glomerata*, *Phalaris aquatica*, *Festuca arundinacea* and *Lolium* spp. usually reduce growth and production rates above 30 - 35°C. However, these ranges may vary slightly with the geographic origin of the particular ecotypes.

For tropical grasses, Vickery (1981) showed the optimum temperature for growth and DM production is higher, often above 30°C, a fact supported by Cook *et al.* (1976). The latter also found *Bothriochloa macra* showed a linear increase in the mean DM production with increasing temperature regime ranging from 16/10 to 31/25°C (day/night temperature). At the highest temperature regime *Bothriochloa* outyielded ryegrass whereas at the lowest temperature regime, ryegrass exhibited superior performance (Figure 2.3). Despite the fact that the tropical species have a high production potential, low night temperatures, which are a feature of temperate climates, retards their growth. By contrast, temperate species usually show improved growth when night temperatures are significantly lower than day temperatures (Vickery, 1981).

In conclusion, *Bothriochloa*, as a surrogate of *Eleusine* pasture has a temperature response pattern with an optimum at 35°C where growth is 95% of maximum which falls to 5% of maximum at both 10°C and 40°C.

(i) **Temperature Stress**

The time between the various phases of plant growth is strongly temperature dependent. The temperature summation rule, or degree-day hypothesis, which is often used to predict phase duration will be discussed later. Temperature stress includes effects due to both

high and low temperatures, including frosting and chilling stress. Under these stresses, plant growth may be affected indirectly by temperature. These stresses are outlined below.

(ii) Chilling Stress

Johnson (1991) defined the chilling stress as cooling subtropical and tropical plants to temperatures in the 0-10°C range which may have a severe effect and result in death. Levitt (1980) reported that the extent of injury due to chilling stress depends both on the temperature and duration. The latter also suggested that the effects of chilling stress may be reversible, but again this is related to the duration and intensity of exposure. Sudden chilling may be fatal to the plant as it can cause the membranes to fracture (Johnson, 1991). Johnson (1991) also argued that temperate species are generally not susceptible to chilling injury at temperatures of 0°C. This is thought to be due to the fact that these species have a higher proportion of unsaturated fatty acids in the membrane lipids which prevent membranes solidifying. Plants may be able to develop resistance to chilling injury by increasing the proportion of unsaturated fatty acids in the membranes. However, plants which are grown in warm conditions and suddenly transferred to chilling conditions may be damaged or killed, whereas if they are allowed to acclimatise slowly, they may be able to survive in the same conditions.

(iii) Frosting/Freezing Stress

Some plants can survive extremes of temperature to the region of -40°C, however this is not relevant to Australian agriculture these plants being important only in arctic regions (Levitt, 1980). Levitt believes that in such cases, the water behaves as ultrapure water, lacking nucleating sites where ice formation can begin. He also argued that the hardened tissues can be cooled slowly to these temperature ranges. Such plants must be able to survive periods of dormancy induced by the extreme temperatures. *Bothriochloa* and/or *Eleusine* can be categorised as 'tender plants' which may be killed at the first touch of frost so this class was used in the model.

(iv) Degree Days

The total degree days ($^{\circ}\text{D}$) irrespective of day length, is the major determining factor for physiological and reproductive changes in tropical plants (Vickery, 1981). *Eleusine* takes about 70 days to come to 50% flowering, and ceases its reproduction in about 120 days after the onset of spring, which are at approximately 1000 and 2000 $^{\circ}\text{D}$ respectively and so possesses an indeterminate flowering characteristics. The reproductive trigger was calculated to be about 150 $^{\circ}\text{D}$. Temperature summation of degree day or day-degree was calculated using the following equation.

$$^{\circ}\text{D} = \frac{[(t_1 - th) + (t_2 - t_1)]}{2} \quad (2.1)$$

where, t_1 = maximum temperature at the day ($^{\circ}\text{C}$)

t_2 = minimum temperature at the day ($^{\circ}\text{C}$)

th = threshold temperature or base temperature of the species ($^{\circ}\text{C}$)

(modified from Constable, 1976; Johnson, 1991)

In the model the threshold temperature (th) for *Eleusine* was assumed to be 5 $^{\circ}\text{C}$. In cotton, day-degrees are based on 12 $^{\circ}\text{C}$, threshold temperature (Constable, 1976). Cotton takes about 2000 $^{\circ}\text{D}$ to reach maturity. In the temperature summation, ' t_2 -th' was assumed to be 0 when it gives a negative value.

(c) *Soil Moisture Response*

The overall effects of moisture stress on pastures are well recognised. Numerous reports in the literature show that water deficits limit yield and that irrigation increases yield, the degree of response varying with the severity, duration and more importantly, timing of stress (e.g. Johns, 1972). Moderate water deficiencies can lead to reduced plant growth but the time of deficit can have marked effects, particularly if it occurs during the period of tillering (Vickery, 1981). These workers postulated that severe water deficits caused by prolonged drought are often associated with substantial plant death within the pasture, and if this is intensified by accompanying heavy grazing, substantial reduction in plant cover may result. However, the situation is usually different with plant species of Mediterranean

origin. For example, when moisture stress is associated with high temperature, as in summer, *Phalaris aquatica* L. becomes dormant during these periods and thus avoids such conditions (Ketallaper, 1960; Johns, 1972).

El-Sharkway and Hesketh (1964) determined the point at which water deficit reduces the photosynthetic capability of various plants. Murata *et al.* (1966) showed an abrupt decrease in net photosynthesis in a number of plants generally coincides with a soil moisture tension of about -1.0 bars; following the decrease in net photosynthesis there was a decrease in the moisture content of the leaves. Among the species tested in the experiment, these workers found red clover (*Trifolium pratense*) and lucerne (*Medicago sativa*) were the most resistant to moisture stress whilst Italian ryegrass (*Lolium multiflorum*) and cocksfoot (*Dactylis glomerata*) were among the most susceptible species.

Tropical and temperate species vary in their water use efficiency (WUE). Black (1971) and Hatch (1971) suggested that tropical species with the C₄ pathway can close stomates to conserve water without restraining photosynthesis which enables them to produce more DM per unit moisture transpired than the temperate species. In terms of WUE (expressed as a transpiration ratio of water used per unit of DM produced), native or degraded pastures generally show transpiration ratios of about 2000 g water/g DM whilst the introduced pastures species, for example, *Phalaris* show average ratios of about 1000 and during periods of active growth the ratios may go down as low as 500 (Vickery, 1981).

Despite the high efficiency of these highly productive introduced pasture species, the C₄ pathway of tropical grasses can better withstand stressful soil moisture conditions. This is supported by the fact that during the process of pasture degeneration accompanied by droughts, most of the introduced pasture species have been reported to be replaced by summer-growing grasses, such as *Bothriochloa macra*, *Themeda australis*, *Aristida ramosa*, *Eleusine tristachya* and others (Cook *et al.* 1976; Cook *et al.* 1978; Robinson and Archer, 1988; FitzGerald *et al.* 1995; Archer, 1995). This pasture degeneration phenomenon has been further supported by Begg (1959) who observed that *B. macra* was

found to be the most common species encroaching on sown pastures on the Northern Tablelands of NSW. In his report, Egg suggested that the slower rates of depletion of soil moisture beneath *B. macra*-dominant pastures compared with improved *Phalaris tuberosa*-*Trifolium repens* pastures would be a major determinant of the rate of replacement. Cook *et al.* (1976) compared the responses of *Lolium perenne* and *B. macra* to two moisture treatments involving either moisture stress or non-stress conditions *in-vitro*. *Bothriochloa* always out performed *L. perenne* under conditions of moisture stress.

The *Phalaris* the soil moisture response curve in the model is 0.3, *Trifolium* 0.6, and *Lolium* 0.3 (dimensionless factor) (Moore *et al.* 1996). Based on the above evidence a value of 0.2 was chosen for *Bothriochloa* as a surrogate for *Eleusine*-dominant pasture.

(d) Light Intensity Effects and Extinction Coefficient

Light regimes in pasture canopies are influenced by atmospheric conditions, and by the nature, size, and structure of the sward canopy. As light passes through a sward canopy of chlorophyll-bearing tissue, it is altered in quality and progressively attenuated in quantity (Donald, 1961). The increase in infra-red radiation with depth in canopies can potentially have profound effects on pasture growth and development (Ludlow, 1978). Indeed, there are many situations in which light may be the only factor for which there is competition, as in well fertilised crops under irrigation or in high rainfall regions (Donald, 1961). Donald (1961) expressed the view that such conditions would be more and more common in world agriculture, because of the extension of irrigation and the elimination of nutrient limitations through vigorous application of fertilisers.

Ludlow and Wilson (1971) suggested that even in regions where there is acute competition for water during the dry part of the year, light may nevertheless be the sole basis of competition during the wet season, for example during the winter in Mediterranean climates. On a regional basis, light may be the dominant factor of competition in the cereal crops of northern Europe, in the fertilised summer pastures of the sub-tropics, in the tea estates of Ceylon and in clover-rich pastures growing at high latitudes in New Zealand.

On the other hand, Australian agriculture is an exception, as the light is not a critical limiting factor of plant growth (Lovett, 1973). Ludlow (1978) in his report illustrated the effect of light, and competition for it, among pasture plants. As he suggests, growth and development changes, such as flowering, in some temperate pasture plants are solely governed by daylength. He also suggested that shading reduces photosynthesis and growth and alters plant development and the distribution of DM. Moreover, most pasture plants are 'sun' plants that have a limited capacity to adapt to shaded conditions. He also argued that shade tolerance plays only a minor role in competitiveness for light compared with the ability to gain preferential access to incident radiation which is determined primarily by height of the plant species. He noted that a combination of legumes, with more or less horizontal or diaphanous leaves, and grasses with erect leaves would appear to provide a pasture canopy that minimises the differences in competitiveness between grasses and legumes, and promotes stability in botanical composition. This view is also supported by Salisbury and Foss (1969). Therefore, before changes of canopy structure to improve efficiency of light utilisation are contemplated, the consequences on the relative competitiveness of species needs to be determined.

(i) *Theoretical Considerations of Light Intensity*

The theoretical analysis of light, leaf area and growth have been discussed by the Japanese workers, Monsi and Saeki (1953), and others such as Davidson and Philip (1958). These workers point out that light interception by a sward canopy has an exponential relationship, which is simply an adoption of Beer's law, whereby:

$$I = I_0 e^{-kL} \quad (2.2)$$

Where, I = Light intensity beneath a leaf area index of L;
 I_0 = Light intensity above the crop;
 L = Leaf area index at the point of measurement;
 k = Coefficient of extinction.

(adapted from Donald, 1961)

This indicates a sharp decline in light intensity from the surface of the crop downwards. The same idea has been put forward by various other workers and their consensus of the light models all deal with the degree of attenuation in the sward and, in essence, relate to the extinction coefficient, k (Rhodes and Stern, 1978).

Sheehy and Cooper (1973) suggested that the extinction coefficient has been found to vary between varieties of grass species, and even between ecotypes within a variety. It is suggested (Donald, 1963) that the legumes, such as clovers possessing a planophile structure of leaf canopy, may have the lower biological potential than grasses. However, for certain of the legumes this may be partly due to the delayed onset of growth in spring (Rhodes and Stern, 1978). From experimental observations and theoretical predictions, it can be extrapolated that communities with erect foliage would have the higher extinction coefficient, and therefore are the most productive under managements that provide a high average LAI.

In the GrassGro model *Phalaris* has a light extinction coefficient 0.06 - 0.90 (Moore *et al.* 1996). This being so then *Eleusine* (and/or *Bothriochloa*) would be close to 0.65 - 0.70 because of the slightly more planophile nature of its foliage. However, the light intensity effect in both the cases would be expected to be the same (see Appendix 1).

(e) Q_{10}

Salisbury and Ross (1969) defined the Q_{10} as a value expressing the effects of temperature on physiological processes. According to them, this quotient is obtained by dividing the rate of a reaction measured at one temperature by the rate measured at a temperature 10° (centigrade or kelvin scale) lower. They also suggested that if it is impossible to measure the rates at temperatures exactly 10°C apart, the following equation can be used to calculate the value from rates measured at any two temperatures:

$$Q_{10} = (k_2/k_1)^{10/T_2 - T_1} \quad \text{or} \quad \log Q_{10} = (10/T_2 - T_1) \log k_2/k_1 \quad (2.3)$$

where, T_1 = lower temperature

T_2 = higher temperature

k_1 = rate at lower temperature

k_2 = rate at higher temperature

They conferred that the reactions with high activation energies have greater Q_{10} values than those with smaller activation energies. They found most chemical reactions have Q_{10} 's between 2 & 3. The workers involved in the development of the GrassGro model (Moore *et al.* 1996) have presented Q_{10} values: 2.00 for the deterioration of digestibility (DU) and 1.5 for root losses (%) in *Phalaris*, white clover, perennial ryegrass, lucerne, sub-clovers, annual grasses, fescue, medics, and annual clovers. No reason could be found to alter the Q_{10} values for *Bothriochloa* and/or *Eleusine* pasture for the temperate environment in which the simulation was made.

(f) Root and Shoot Partitioning During Vegetative and Reproductive Growth

It is generally recognised mineral deficiencies lead to a relatively greater proportion of plant growth being partitioned to the roots, and this leads to common statements such as, 'the plant is seeking nitrogen' (Johnson, 1991). Johnson suggested that similar responses are observed for other mineral nutrients and water. This present discussion will restrict attention to nitrogen. To quantify the root:shoot partitioning between three pasture types, e.g. degraded, phalaris, and phalaris/white clover, the median quadrat technique was used by colleagues at the experimental site every 60 days (starting in June 1994) to collect samples of above and below ground biomass. In summer, they recorded that the feed on offer (FOO) of green material in the degraded pasture was significantly higher than in the other two pastures.

In contrast to the tops, DM yield of the rhizomes and roots in the phalaris dominant and phalaris/white clover pasture types was always found to be higher than in the degraded pasture. This clearly indicates that phalaris and white clover have a much larger root:shoot ratio than the degraded pasture. The study indicated that there was an increase in the nitrogen concentration of the tops from spring to summer for all pastures, but the

proportional increase was higher for the degraded pasture than for the other two pastures. However, in contrast to the tops N concentration, the N concentration of the rhizomes and roots in the phalaris dominant phalaris/white clover was higher than in the degraded pasture. The same trend was observed for root and rhizome biomass.

Based on the above, the maximum allocation for root:shoot ratio for the *Eleusine* (degraded) pasture was set at 1.60 at the start of reproduction, 1.00 at 50% flowering, growth factor for translocation 0.60, maximum specific rate of translocation 1.00%; whereas in case of phalaris the figures supplied with model were 3.00, 1.00, 0.60, and 1.0 respectively (see Appendix 1).

2.4 Description of Paddock, Enterprise and Sward

The following information was used to set up parameters and state variables for the soil in the paddocks, and to parametrise the species growing in the swards.

2.4.1 Edit Paddock

(a) Area of Paddock:

The degraded pasture consisted of two plots, each of 0.53 ha, the total area for this pasture was set at 1.06 ha in the model.

The total area of the phalaris and phalaris/white clover pasture was 0.8 ha each. The model would not accept areas less than 1 ha so this was used.

(b) Steepness

McLeod (1995 pers. comm.) measured a slope of 3.4° for the three pasture types. In the model, this corresponded to a 'gentle slope'.

(c) The Soil Conservation Service Curve Number

This value is a parameter used in the U.S.A., Dept of Agric - Soil Conservation Services (USDA - SCS) run-off equation (Moore *et al.* 1996). The value ranges from 50-99.

Higher values represent a higher likelihood of run-off. For the simulation run, it was fixed at 65 because of the gentle slope of the paddocks and the ground cover present.

(d) *The Stage of Soil Evaporation*

This parameter controls the rate of soil evaporation once water is no longer freely available at the soil surface (Moore *et al.* 1996). It ranges between 2 and 5 and is related to the soil texture. Considering the soil type, a value of 3.8 was assigned for the simulation.

(e) *Fertility Scaler*

Mineral nutrition for plant growth and development has not been explored in the model (Moore *et al.* 1996). The fertility scaler acts as a 'growth limiting factor' analogous to the temperature and soil moisture limiting factors. A value of 1 indicates no growth limitation, while a value of 0 indicates no growth.

The Northern Site Team (1995, unpublished) reported that the phalaris/white clover pasture had the higher soil carbon content than the other two pastures. However, they observed there was no significant difference between the degraded and the phalaris dominant pastures. There was a similar trend for the soil nitrogen with total soil nitrogen in the phalaris/white clover pasture being significantly higher than in the other two pastures, with no significant difference between the degraded and the phalaris pastures. In their discussion, they concluded that the long-term differences in pasture productivity and therefore the carbon and nutrient return in plant residues and from grazing sheep can explain the majority of the differences in total soil carbon and nitrogen content between the three pasture types.

The carbon content and nitrogen reserve are generally the major determinants of the soil fertility status of cropping lands (Johnson, 1991). Total soil mineral nitrogen in the phalaris-white clover pasture was significantly higher than in the other two pastures, and there was no differences between the degraded and the phalaris dominant pastures. On average the amount of nitrogen was in the range of 7.7-18.4 mg kg⁻¹ in the 0-5 cm layer. As noted earlier a similar trend was reported from earlier studies at the experimental site

for the carbon content in the three pasture types. Similarly, the subsoil (5-20 cm) nitrate was significantly higher in the phalaris-white clover pasture than in the other two pastures. The high nitrate content in the subsoil of the phalaris-white clover pasture was most likely due to mineralisation of nitrogen fixed by white clover.

Based on the above the fertility scaler values were set at 1.0, 0.8, 0.8 for the phalaris/white clover, phalaris and degraded pasture respectively.

2.4.2 Soil and Hydrology Description:

(a) Soil Classification

The major soil type of the Big Ridge 2 site is a Grey Brown Podsollic (Greenwood and Douglas, 1994). Greenwood and Douglas (1994) estimated soil texture by the hand moulding method and based on their findings the following textural classes were used in the simulation.

Degraded pasture 'sandy clay loam' for the top soil layer (0-240 mm) and 'clay loam' for sub-soil layer (240-1200 mm); phalaris pasture- 'sandy clay loam' for the top soil layer (0-200 mm), and 'clay loam' for sub-soil layer (200-1200 mm); and phalaris/white clover - 'clay loam' both for the top soil (0-260 mm) and sub-soil layer (260-1800 mm).

(b) Hydrology

A hydrological study was conducted by CSIRO, Division of Soils at the Big Ridge 2, Chiswick Site in July 1994. Volumetric water content (%), field capacity (FC) and permanent wilting point (WP) were measured in each of the six paddocks. All the measurements were made on cores 60 mm deep and 85 mm diameter. The suction imposed for the measurements ranged from 10 cm (\approx -1kPa) to 15000 cm (\approx -1500 kPa).

Table 2.1 Volumetric soil water content at different suctions for the three pasture types.

Pasture type	Av. vol. water content (%)	Suction (cm)	Equivalent kPa
degraded	45.4	10	≈ -1
	43.7	30	≈ -3
	41.6	50	≈ -5
	37.5	100	≈ -10 (FC)
	12.2	15000	≈ -1500 (WP)
Phalaris	46.8	10	≈ -1
	43.2	30	≈ -3
	39.7	50	≈ -5
	35.0	100	≈ -10 (FC)
	12.0	15000	≈ -1500 (WP)
Phalaris/white clover	56.0	10	≈ -1
	48.0	30	≈ -3
	45.0	50	≈ -5
	43.0	100	≈ -10 (FC)
	13.0	15000	≈ -1500 (WP)

Based on the above evidence, water content at FC (e.g. -5--10 kPa) and at WP (e.g. -1500 kPa) were set at 37.5% and 12.2% for the degraded; 35.3% and 12.0% for the phalaris dominant; and 43.7% and 13.0% for the phalaris/white clover pasture.

(c) Porosity

There was no separate information available for the total porosity of soils in any of the three pasture types. It was assumed that the volumetric water contents at the saturation point (suction 10 cm or -1 kPa) were the total porosity for the particular pasture soil type. Thus, the total porosity calculated was 45.4% for the degraded pasture soil, 46.8% for phalaris and 56.0% for phalaris/white clover pasture soil.

(d) Hydraulic Conductivity

The Northern Site Team measured sub-surface hydraulic conductivity using a well permeameter on August 29-31, 1995 and found considerable variability across the site.

This variability is due to the soil textural and structural variation. The team reported that the effect of soil structure on hydraulic conductivity seems to be stronger than the effect of texture. For example strata 2 and 3 in paddock 6 consists of well structured medium clay in the B-horizon. The values of hydraulic conductivity measured in these locations were much higher (17-23 mm h⁻¹) than in paddock 3 strata 1, and paddock 2 strata 3. The two locations also contain medium clay in their B-horizon, but are not well aggregated (The Northern Site Team, 1995 unpublished)

It is suggested that the B-horizon held more water than the A-horizon between FC (-5 to -10 kPa) and WP (-1500 kPa). The B-horizon has a higher clay content resulting in a predominance of fine pores that require large suction (low potential) for water to be removed. Saturated hydraulic conductivity decreased with depth due to increasing clay content. Based on these measurements, the saturated hydraulic conductivity used in the model for the three pasture types was 15-18, 13-15, and 17-23 mm h⁻¹ for the degraded, phalaris/white clover, and phalaris dominant pastures respectively.

(e) Top soil and Sub-soil Moisture

Mcleod (1995 unpublished data) found high variability in soil structure and the soil types across the paddocks and found that volumetric water content varied significantly between and within the treatments.

The general trend of the top and the sub-soil moisture in treatment 3 (i.e. phalaris/white clover) shows higher soil moisture content both for the top and sub-soil layers. This fact is attributed to the higher clay content in paddock 5 (i.e. treatment 3) through the profile.

Based on these findings average values of 23% and 49% for top and sub-soil moisture were assigned for the degraded, 16% and 35% for phalaris, and 24% and 52% for phalaris/white clover pasture soils respectively.

2.4.3 *Editing Sward*

For sward editing, the data of green and dead herbage from the 1995, BOTANAL measurements was used to estimate green and dead dry matter (DM kg ha⁻¹) over time and 25% of the standing dead herbage for each period was assumed to be litter dry matter. In practice, the amount of litter depends on the integrated effects of several factors such as sheep treading (i.e. stocking rate), temperature, moisture, humidity, size and magnitude of rain drops, hailstones etc. (Salisbury and Ross, 1969; Davies, 1993) and resistance of individual plant species to these factors (Davies, 1993). For example *Eleusine* would be expected to be far more resistant to these effects than phalaris and clover. However, because no quantitative data was available, the same proportion of litter dry matter was applied to all pasture types.

(a) *Root Mass*

Normally, in ungrazed pastoral systems, root mass is proportional to the green tops dry weight (Salisbury and Ross, 1969; Davies, 1993) and almost equal to dead plus green dry matter. However, this “rule of thumb” does not apply to grazed pastures. A study conducted by the Northern Site Team in 1994/95 showed that the phalaris and the phalaris/white clover pastures exhibited a similar pattern of growth below and above ground, but they were significantly different to the degraded pasture. In the degraded pasture, the ratio of root (roots + rhizomes) to shoot (green + dead) was maintained near 1:1 whilst in the phalaris and phalaris/white clover, it was almost 3-3.5:1. Therefore, these values were applied to calculate the root biomass for the three pasture types.

(b) *Digestibility Classes*

The model requires that the amount of DM (kg ha⁻¹) of at least the five digestibility classes, i.e. 80%, 70%, 60%, 50% and 40% for each of the green, dead, and litter components. The estimated digestibility of white clover *in vivo* has been found by Archer and Robinson (1988) to be higher than that of green phalaris and fescue during summer and autumn (P<0.05), but similar in winter due to regular seasonal fluctuations in the organic matter digestibility (OMD) of green leaves of the grasses. The authors found that within the summer perennial group, the quality of green leaves was consistently high for fresh growth

in the spring, but fell during the summer. They found *Bothriochloa* to be an exception which remained equivalent in nutritive value to the year-long green native grass species. However, when these authors made a comparison of *Bothriochloa* and phalaris, the former always had lower digestibility and was lower in nitrogen content. This indicates that among the three pasture types, the cegraded pasture would always have slightly lower values for the higher digestibility classes and higher values of lower digestibility classes than that of phalaris and phalaris/white clover. Because of lack of quantitative data, the values were not changed in the model.

Once the total values for green, dead, and litter are fixed in the paddock, the model automatically calculates the amount for the different digestibility classes.

2.4.4 Edit Farm Basics

(a) Stocking rate

The rate at which a pasture is stocked is perhaps the most important single factor in grazing management which affects the production of the animals from the pasture, the profitability of the enterprise and often the longevity of the pasture. Stocking rate affects production in four ways. According to Edwards (1980), Bircham and Korte (1984) and Smetham (1990), within the limits of the potential of the pasture and the animal, the lighter the stocking rate the better will each grazing animal perform. Secondly, the production per hectare from the pasture will increase with increased stocking rate up to a certain point after which production declines. Thirdly, the optimum economic return will vary depending on the stocking rate, the cost of livestock, other fixed and variable costs and the price of the product. When the other costs are fixed, the optimum economic return will be obtained at a stocking rate somewhere between the maximum production per animal and the maximum gain per ha. Fourthly the condition of the pasture, and consequently its ability to produce and to continue producing herbage, as well as the botanical composition of mixed pastures, are determined by the stocking rate applied over the whole or portion of the season.

Taking these points into account, the paddocks in the simulation were continuously stocked with stocking rates being adjusted to the availability of pasture. The following Table 2.2 shows the stocking rates (DSE ha⁻¹) used in the simulation on the three pasture types.

Table 2.2 Stocking rates (DSE ha⁻¹) of wether for 1994/95

	1994	1995										
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Degraded	3.8	3.8	5.7	3.8	3.8	3.8	3.8	3.8	3.8	5.7	5.7	5.7
Phalaris	10.0	10.0	20.0	10.0	10.0	10.0	10.0	10.0	10.0	12.5	12.5	12.5
Phal/wc	10.0	10.0	20.0	10.0	10.0	10.0	10.0	10.0	10.0	12.5	12.5	12.5

(b) Enterprise Description

The following parameters were used to describe the production enterprise in the simulation.

Enterprise type	Wether
Animal breed	Med. Merino
Standard reference weight	45 kg
Potential fleece weight	5 kg
Maximum fibre diameter	24 μ
Adult mortality rate	2% per year
Current date	21 march, 1995
Peak number of stock	3 and 8 adults (5.7 and 20 DSE ha ⁻¹)
Liveweight	43.2 kg (conceptus-free)
Greasy fleece weight	2200 g
Animals are	Castrated