

Chapter 1 Introduction

1.1 The Need for Improving Graziers' Management

Increasing demands for sustainable and profitable development and utilisation of grazing lands have caused an unprecedented need to improve farmers' management. In Australia, for instance, the highly variable climate (White and Howden 1991; White *et al.* 1993), the continual degradation of high quality and productive perennial pastures (Archer *et al.* 1993; Archer 1995; Peart 1995), high interest rates (McWilliam 1993) and the demand of quality and consistency of livestock production in the world's markets (*Australian Agriculture 1994-95*) raise costs and limit the opportunities to expand farms. The challenge for farmers therefore is to develop and implement sustainable and profitable grazing systems which can be integrated, on a whole farm basis, to consistently meet production targets and product specifications (Archer 1995). This will require farmers to improve their management to ensure that they are able to objectively plan and monitor pasture production and livestock performance to meet the demands of specific markets.

1.2 The Need for Computerised Decision Support Systems

Management implies decision-making. Decision-making within the context of a grazing system is complex and involves interactions between soil, plants and grazing animals against a background of climatic and market variability. To make the right decisions, farmers should have insight into the potential impact of various decisions on the farm. Estimates of these impacts are often difficult to obtain using traditional sources of information because of the difficulties that farmers face in bringing the wide range of relevant information together in an objective way. Thus, an alternative technology for information processing must be pursued to assist farmers making the right decisions.

With the power of the technology enabling a huge volume of data processing, computers have become an essential part of information processing. Furthermore, the ability to automate information processing has enabled an expansion in the use of formalised information (Davis and Olson 1985). As a consequence of the advent of computer technology, and the dramatic increase in information use of grazing management, interest in the use of computerised decision support systems (DSSs) has increased (Stuth and Lyons 1991). These systems assist farmers in dealing with complex planning problems by allowing exploration of alternatives and selection of appropriate strategies (Foran *et al.* 1990). Computerised DSSs, therefore, are becoming increasingly popular tools which support farm management.

1.3 Need for Evaluating Model Performance

Today, more than 25 years after the appearance of computer modelling in grazing systems (Rickert 1993), a large number of computer models varying in complexity and purpose has been developed and employed for a diverse range of tasks. Examples of these are educating the next generation of primary producers and consultants (Clewett *et al.* 1991), improving productivity and sustainability by better matching of livestock requirements to forage supplies (McDonald and Bell 1995) and providing a basis for selecting management options with respect to forecasts of market and climatic conditions (Stafford Smith and Foran 1991). However, the rapid expansion of modelling has not been without controversy. A key question is the degree of agreement between the model and the real system concerned. The question is often called the problem of evaluation (France and Thornley 1984). Despite the importance of evaluating models within real systems, only a small proportion of existing models have been properly evaluated and compared with data from field experiments.

The evaluation process is critical to the success of any model as it is only through this process that model performance can be validated. Furthermore, the evaluation process permits the identification of weakness in model concept, process equations and specific input parameters which might result in a consistent pattern in the difference between the model and the real system to be identified, and thereby allowing improvement in the model.

Thus, it is essential that the performance of models be evaluated against real data. Comparing a model's prediction with *independent* measurements collected from a real system (i.e., data sets used for evaluation should be different from data sets used to guide decisions regarding algorithms used in the model) is one way to evaluate the model's performance (Grant 1986).

1.4 The GrazFeed Model

The computer package GrazFeed, which was developed by Drs. Freer, Donnelly and Moore (CSIRO Division of Plant Industry), is a nutritional management system for grazing animals. It is designed as a simple way of applying the recommendations in *Feed Standards for Australian Livestock: Ruminants* (SCA 1990) to grazing animals and now forms part of the basic structure of the GrazPlan package (Freer and Moore 1994). It can be used with any type of pasture except semi-arid rangelands and is also suitable for any breed of sheep or cattle (Freer and Moore 1994). An example of the output from a complete run is presented in Appendix 1.

The model requires inputs including the current condition of the pasture and animals on it. Pasture information includes green and dead biomass and their *in vitro* digestibility as well as legume content. From this information, the program prepares a suggested distribution of herbage between six digestibility classes ranging from 80% to 30% and the protein concentration of each

class, which may then be adjusted by the user. Intake of pasture is then predicted from functions of available herbage and its digestibility (Freer and Christian 1983). The intake module is based on the assumption that animals will preferentially select material of higher digestibility; this is the motivation for the representation of the pasture as six digestibility classes. The animal nutrition module implements the Australian Feeding Standard for Ruminants (SCA 1990). Finally the program provides an estimate of the animal production obtainable from the pasture and attempts to show the extent to which production might be improved through supplementation. As a result of the routine use of GrazFeed to determine supplement requirements, NSW Agriculture has claimed an annual benefit of \$7.5 million to the NSW grazing industry (Freer and Moore 1994).

The review of literature in Chapter 2 discusses in detail environmental factors affecting pasture production and quality, factors determining sheep intake, the utilisation of energy and protein for sheep weight gain and wool growth. The approaches used by the GrazFeed model to predict sheep intake and production are also presented along with these discussions. Chapters 3 and 4 present the results of comparisons of the model's predictions with data obtained from the field experiments which were conducted on improved and native pastures in the high rainfall region of Australia, respectively. Chapter 5 contains an evaluation of the model's performance on different seasonal pastures in Xinjiang province of north-west China. Chapter 6 then ties these evaluations into a concluding discussion, also pointing out areas which warrant further research.

Chapter 2

Review of Literature

2.1 Introduction

Many grazing system models have been developed to predict pasture and animal productivity and evaluate management strategies (see for instance: Stuth and Lyons 1991, 1993; White and Howden 1993; McAleer and Jakeman 1993). The developers of the models have attempted to make them as biologically logical as possible with more mechanistic functions being incorporated as better understanding has evolved of the underlying processes.

Among the existing models, a few models like GrazFeed contains selective grazing logic. The intake module assumes that animals preferentially select material of higher digestibility, and the effect of substitution of supplement for pasture is taken into account. Intake of pasture is predicted from functions of herbage availability and digestibility as well as animal breed, age and physiological state (Freer and Christiar 1983). It also concerns the effect of a deficiency of rumen-degradable protein on intake (see Section 2.4.2.2). The animal nutrition module implements the Australian Feeding Standard for Ruminants (SCA 1990). Thus, the concept of the GrazFeed model appears to be soundly based; this is the motivation for evaluating the performance of the GrazFeed model rather than other models.

In the review of literature which follows, the environmental factors that affect the pasture production and quality are discussed first. Thereafter, the factors that determine the intake of feed by sheep and the approaches used for predicting the intake, sheep weight gain and wool growth are discussed in detail.

Unless otherwise indicated, the variables describing the properties of feed are quantities per kg of dry matter (e.g. MJ kg⁻¹ DM; g kg⁻¹ DM), and digestibility is in decimal form (e.g. 0.65 rather than 65%). Mathematical symbols used in this chapter are listed in Table 2.1.1.

Table 2.1.1 Mathematical symbols used in this chapter

Symbol	Description	Units
<i>Feed</i>		
ADF	Acid detergent fibre	g ADF kg ⁻¹ DM
CF	Crude fibre	g CF kg ⁻¹ DM
DM	Dry matter	kg DM kg ⁻¹ feed
DMD	Dry matter digestibility	kg digestible DM kg ⁻¹ DM expressed as a percentage
DMI	Dry matter intake	kg DM sheep ⁻¹ day ⁻¹
DOM	Digestible organic matter	kg
DOMD	DOM in feed DM	kg DOM kg ⁻¹ DM expressed as a percentage
DOMI	Digestible organic matter intake	kg DOM sheep ⁻¹ day ⁻¹
MADF	Modified acid detergent fibre	g MADF kg ⁻¹ DM
N	nitrogen	g N kg ⁻¹ DM
NDF	Neutral detergent fibre	g NDF kg ⁻¹ DM
OM	Organic matter	kg OM kg ⁻¹ DM
OMD	Organic matter digestibility	kg DOM kg ⁻¹ OM expressed as a percentage
<i>Animal</i>		
BW	Bodyweight, weight of fleecè-free animal on feed	kg sheep ⁻¹
BWC	Bodyweight change	kg sheep ⁻¹
EBC	Empty bodyweight change	kg sheep ⁻¹
EBG	Empty bodyweight gain	kg sheep ⁻¹ day ⁻¹
EBW	Empty bodyweight, liveweight minus the contents of the gastro-intestinal tract	kg sheep ⁻¹
FWC	Greasy fleece weight change	kg sheep ⁻¹
LWC	Liveweight change	kg sheep ⁻¹
SA	Animal surface area	m ²
SFW	Standard Fleece Weight	kg sheep ⁻¹ year ⁻¹
SRW	Standard Reference Weight	kg sheep ⁻¹
W	liveweight, weight of animal, including fleece, on feed.	kg sheep ⁻¹
W _{clean}	Clean wool growth	g sheep ⁻¹ day ⁻¹
<i>Energy</i>		

DE	Digestible energy	MJ kg ⁻¹ DM
DEI	Digestible energy intake	MJ sheep ⁻¹ day ⁻¹
E _{cold}	Additional energy required in cold stress	MJ sheep ⁻¹ day ⁻¹
E _{graze}	Additional energy expenditure in grazing	MJ sheep ⁻¹ day ⁻¹
ER	Energy retained by sheep as body tissue	MJ sheep ⁻¹ day ⁻¹
EVG	Energy content of empty body gain	MJ kg ⁻¹ EBG sheep ⁻¹ day ⁻¹
GE	Gross energy	MJ kg ⁻¹ DM
GEI	Gross energy intake	MJ sheep ⁻¹ day ⁻¹
k _g	Efficiency of use of NE for gain in growth and fattening	dimensionless
k _m	Efficiency of use of ME for maintenance	dimensionless
ME	Metabolizable energy	MJ kg ⁻¹ DM
MEI	Metabolizable energy intake	MJ sheep ⁻¹ day ⁻¹
ME _m	ME required for maintenance	MJ sheep ⁻¹ day ⁻¹
ME _p	ME required for production	MJ sheep ⁻¹ day ⁻¹
MH	Metabolic heat production	MJ sheep ⁻¹ day ⁻¹
M _s	M _w minus, for the unweaned lamb, ME in milk intake	MJ sheep ⁻¹ day ⁻¹
M _w	MEI minus estimated ME used for pregnancy and /or lactation	MJ sheep ⁻¹ day ⁻¹
q _m	ME as fraction of GE	Dimensionless
<i>Protein</i>		
CP	Crude protein, being total N × 6.25	g kg ⁻¹ DM
CPI	Crude protein intake	g sheep ⁻¹ day ⁻¹
CPLS	Crude protein leaving the stomach	g kg ⁻¹ DM
ECP	Endogenous crude protein	g kg ⁻¹ DM
MCP	Microbial crude protein	g kg ⁻¹ DM
NAN	Non-ammonia nitrogen	g kg ⁻¹ DM
NPN	Non protein nitrogen	g kg ⁻¹ DM
OMADR	Organic matter apparently digested in the rumen	g kg ⁻¹ OM
RDP	Rumen degraded protein	g kg ⁻¹ DM
UDP	Undegraded dietary protein	g kg ⁻¹ DM
U _t	UDP intake minus half the protein secreted in milk or retained in conceptus	g sheep ⁻¹ day ⁻¹

2.2 Environmental factors affecting pasture productivity

2.2.1 Introduction

Effects of environmental factors on pasture productivity have been studied extensively. The background for this interest is the great impact pasture productivity, which is very much under the control of the environment (Lovett 1972), has on grazing animal performance. Several reviews (Weihing 1963; Whittaker 1970; Wheeler and Hutchinson 1973) have indicated that climatic factors including rainfall, temperature light and soil factors including soil moisture and nutrient elements are prime environmental determinants of pasture productivity.

2.2.2 Rainfall

The general relationship between pasture production and annual rainfall on various types of grazing lands have been discussed by Whittaker (1970) who indicated that forage production curvilinearly increases with increasing annual rainfall.

But of more importance than mere total amount of rainfall is its seasonal distribution and its effectiveness. The dry matter production by native or improved pastures and its distribution through the year is heavily dependent on the amount and distribution of rainfall. Examples based on experiments on various pasture types have been reviewed by Wheeler and Hutchinson (1973) in detail and needs no elaboration here.

In his review of effective rainfall, Johns (cited in Lovett 1972) defined effective rainfall as its ability to supply evaporative demand. In experiments with a number of pasture types on a similar soil type on the Northern Tablelands, Egg (1959) found that soil moisture availability varied according to pasture species. However the general pattern was similar- December, January, April and May being the months of greatest soil moisture stress. Thus although most of the rain fell in the period from December to May, rainfall from June to November was more effective in maintaining available soil moisture.

2.2.3 Temperature

Whilst temperature, like precipitation, is subject to diurnal and annual fluctuations, the annual limits of temperature, its seasonal distribution and reliability are relatively well defined and relatively constant.

Optimum, minimum and maximum temperatures for plant growth vary widely between species and within species according to the stage of development and physiological condition of the plant and the duration and rate of exposure to a particular temperature regime (Lovett 1972). Working with the temperate grass *Lolium multiflorum* Weihing (1963) demonstrated a high

correlation ($r = 0.84$), between changes in rate of growth and changes in daily mean temperature and indicated an optimum growth temperature of 18.3°C for this species. However, a study by Field (1974) shows that the optimal growth temperature for a legume is range from 10 to 27°C . When legumes were harvested at a fixed morphological stage, the greatest yield was commonly recorded in the lowest temperature regime, provided the minimum temperature exceeded 10°C (Smith 1970).

In general the range of temperatures in which growth is active can be related to the climatic zone in which a species originated. Most pasture species of temperate origin do not grow appreciable at mean daily temperatures less than about 6°C . Their optimum growth is usually achieved at temperatures below 27°C , and they grow poorly at temperatures around 35°C (Evans *et al.* 1964).

2.2.4 Light

The relationship between light and pasture growth rates has been reviewed a number of times (see for instance: Brown and Blaser 1968; Cooper 1970; Harris 1978). From these reviews, it is generally agreed that both for grass and legume pastures, maximum production depends on seasonal light intensity and temperature and is greatest during periods when temperatures are moderate and radiation inputs are high, and lower in late summer, autumn and winter.

2.2.5 Soil factors

The extent to which soil factors determine pasture production will depend upon related or interacting climatic factors such as rainfall, temperature and light. The review of this section concentrates on the manner in which particular soil factors influence pasture productivity. However, it should be understood that the relationship between particular soil properties and plant growth may be quite different in different regional climates.

2.2.5.1 Soil moisture

In general, production of legume pastures has been found to be strongly correlated with available water in soil and increases linearly as the amount of water applied increases up to field capacity. Under moisture stress, the number of stems per plant, the number of basal buds, the number of shoots per plant, plant height and top weight are substantially reduced (Cowett and Sprague 1962; Perry and Larson 1974). However, under higher levels of moisture, legume yields tends to level off or decline (Wahab and Chamblée 1972).

In contrast to the production of temperate legumes, the production of temperate grasses is generally less affected by soil moisture. An experiment (Johns 1972) showed that while the three

grasses phalaris, tall fescue and perennial ryegrass all substantially outyielded white clover under dryland conditions, the white clover plots produced far more than the grass plots when irrigated.

2.2.5.2 Soil acidity

An experiment examining quantitative influence of soil acidity on plant growth in uniform environments was conducted by Griffett *et al.* (1966) on a mixed birdsfoot trefoil, legume and timothy pasture in New York State. It revealed a marked change in productivity and composition. The results show that legumes require a pH in excess of 5.8 to attain maximum percent composition of legumes in the pasture, this coincides with maximum yield of the pasture. The effect of pH on pasture composition and productivity was also demonstrated for moderately and imperfectly drained fragipan soils where soil type was an additional interacting factor.

2.2.5.3 Soil nutrient elements

Effects of regional variations in soil nutrient elements on pasture production are difficult to quantify. There is considerable evidence that mineral deficiencies or imbalances in soil limit pasture productivity in both temperate and tropical environments (Wild 1958; Henzell *et al.* 1966; Bouma 1972).

a) Nitrogen

Nitrogen effects on pasture production vary widely among pasture species. In pure tropical or subtropical grass swards large responses in dry matter yields have been obtained with low rates of nitrogen application (Bryan and Sharpe 1965; Henzell *et al.* 1966). However, several experiments (see for instance: Simpson 1965; Colman 1972) indicated that the productivity of temperate grass pastures is generally less affected by nitrogen than the productivity of tropical or subtropical grass pastures.

b) Sulfur and phosphorus

Sulfur exists in soils largely in the organic form but the immediate source for plant uptake is inorganic sulfur, which occurs principally in the adsorbed form with small proportions as water-soluble sulfur (Freney and Williams 1980). Responses of pasture production to sulfur have been reported on various types of pastures (see for instance: Anderson and Spencer 1950; Rossiter 1952; Walker *et al.* 1956; Andrew 1977; Spencer and Glendining 1980).

A review by Wild (1958) shows that nearly all soils in Australia are deficient in phosphorus and there are widespread recorded production responses of nearly all pastures to phosphorus (Bouma 1972).

2.3 Environmental factors affecting pasture quality

2.3.1 Introduction

Environmental factors not only influence pasture productivity but also pasture quality. Reviews have indicated several environmental factors relating to light, temperature, wind, soil moisture and soil fertility that are important factors affecting the nutritive quality of pasture herbage. Because under most grazing conditions digestible energy is the only likely nutrient to be limiting animal production (Freer and Moore 1994) the main emphasis of this section is given to changes in dry matter digestibility.

To discuss particular environmental factors which influence the nutritive quality of pasture herbage, it is necessary to firstly outline general seasonal changes in pasture herbage quality.

2.3.2 General seasonal changes

The changes in dry matter digestibility with season for pasture herbage grown in tropical and temperate regions have been studied extensively. It is generally accepted that dry matter digestibility is the highest in spring, then falling to a low value in mid-late summer, increasing slightly in autumn and decreasing again in winter (Hacker and Minson 1972; Strickland 1973; Fletcher 1976; Langlands and Holmes 1978; Powell *et al.* 1978; Reed 1978; Andrews and Crofts 1979). Van Soest *et al.* (1978) selected perennial grasses from different latitude regions and indicated that both the spring maximum and the summer minimum dry matter digestibility become progressively lower with change of region from high to low latitudes.

2.3.3 Light

2.3.3.1 Light intensity

The intensity of light experienced by pastures vary widely between sites and seasons (see for instance: Cooper and Tainton 1963). A study by Sakurai (1963, cited in Wilson 1984) suggested that the herbage digestibility of grasses which experience high insolation is lower than those of grasses which experience a low light intensity, however, other studies are contrary to this finding. The experiments conducted by Graza *et al.* (1965), Deinum *et al.* (1968), Masuda (1977) and Wong (1978) to examine the effect of light intensity on herbage dry matter digestibility indicate that herbage dry matter digestibility of both tropical and temperate grasses is decreased by reducing the light level under which plants are grown. The decrease in dry matter digestibility of these grasses over a wide range of light intensities was mostly small (1-5 percentage units) except for the experiment of Wong (1978) in which green panic (*Panicum maximum* var. *trichoglume*) swards grown under 60 or 40 percent shade for 2-4 months were 10-12 percentage units lower in dry matter digestibility than swards grown in full sunlight. In the same experiment,

Wong found no effect of shade on the dry matter digestibility of the legume *Siratro* (*Macroptilium atropurpureum*).

2.3.3.2 Daylength

Daylengths which initiate flower and stem development in grasses will lead eventually to a sward of low digestibility and probably poor intake by animals. The few experimental studies of the effects of daylength on dry matter digestibility or cell wall content (Bowman and Law 1964; Allinson 1971; Mannelje 1975) indicate that, excluding effects associated with flowering, the effect of daylength on tissue dry matter digestibility is usually small and inconsistent.

2.3.4 Wind

Several studies show that the leaves of plants grown under high wind velocities have a tendency to develop xeromorphic features of greater vascular development, more sclerenchyma and thicker cuticles (Whitehead and Luti 1962; Grace and Russell 1977). Thus plants grown under such conditions could have lower tissue digestibility due to the increase of xeromorphy but no experimental measurements of wind effects on herbage digestibility have been made (Wilson 1984).

2.3.5 Temperature

2.3.5.1 General temperature regime

Compared with temperate pasture species, tropical pasture species generally have lower dry matter digestibility, especially the grasses (Minson and McLeod 1970). A study determining the relationship between mean growth temperature and dry matter digestibility (Minson and McLeod 1970) indicates that herbage dry matter digestibility decreases approximately one percentage unit with 1°C increasing in growth temperature.

Many experiments have shown that high temperature has a strong detrimental effect on the dry matter digestibility of both tropical and temperate grasses (Deinum *et al.* 1968; Wilson and Ford 1971, 1973; Deinum and Driven 1975, 1976; Wilson *et al.* 1976) but a much smaller effect on the dry matter digestibility of legumes (Garza *et al.* 1965; Smith 1969; Wilson and Minson 1980). The observations of the overall small differences in dry matter digestibility between tropical and temperate legumes (Minson and Wilson 1980) and the small seasonal changes in dry matter digestibility for many legumes (Minson and McLeod 1970) may be partially explained by the small temperature response of these legumes.

2.3.5.2 Frost

Frost causes significant damage to pasture in many of the sub-tropical areas of the world. Most tropical pasture species have only a low frost tolerance (50 percent tissue death at -1 to -4°C) and show little or no capacity to harden during autumn (Ludlow 1980), thus frost causes considerable death of above ground herbage. Although temperate pasture grasses can tolerate temperatures down to -25°C (Ludlow 1980), frost damage can still be significant in temperate pasture regions (Reid *et al.* 1967; Langlands and Holmes 1978). Nutritive quality of grasses declines rapidly under frosting (Milford 1960) and as does the quality of tropical legumes, many of which shed their leaves after frosting (Milford 1967). Frost-killed leaves which remain on the plant often decline rapidly in dry matter digestibility (Wilson and Marnettje 1978) and nitrogen content (Muldoon and Pearson 1977). Consequently, the lower quality of frost-killed herbage results in a marked decline of voluntary intake and poorer animal performance (Reid *et al.* 1967).

2.3.6 Soil

2.3.6.1 Soil moisture

a) Drought

Reviewing the literature, there are two opposite viewpoints on the effects of moisture stress on herbage dry matter digestibility. Some believe that intermittent droughts of light to moderate severity are detrimental to forage quality (see for instance: Sakurai 1963, cited in Wilson 1984). However, others accept that low soil moisture has either no effect or increases the digestibility of the pasture or of leaf or stem material (Dent and Aldrich 1963; Van Soest *et al.* 1978). Moisture stress slows growth and delays stem development resulting in leafier swards of higher digestibility (Vough and Marten 1971; Perry and Baltensperger 1979).

There is evidence that in younger leaves ageing is delayed by water stress (Ludlow and Ng 1974) and the decline in nitrogen content and dry matter digestibility (Wilson and Ng 1975) are slower than for leaves on plants kept well-watered, indicating that the aging or maturation of tissue is not necessarily hastened by drought. With low soil moisture the progress of plants to later stages of development may be markedly retarded (Calder and Macleod 1968).

In general, the changes in tissue composition associated with water stress are favourable to pasture quality. Increases in the concentration of nitrogen (Gifford and Jensen 1967; Wilson and Ng 1975), most minerals (Rahman *et al.* 1971; Gerakis *et al.* 1975) and soluble carbohydrates (Blaser *et al.* 1966; Ford and Wilson 1981) are recorded.

b) Relative humidity and evaporative demand

It has been suggested that plant water deficits due to high evaporative demand may be a contributing factor to the lower dry matter digestibility of herbage grown in areas of high temperatures (Minson and McLeod 1970). An experiment examining the effect of relative humidity on herbage quality (Wilson *et al.* 1976) indicates that there was no effect of humidity on dry matter digestibility. Generally, the effect of differences in humidity or evaporative demand on tissue characteristics which may be associated with herbage quality are relatively small and inconsistent (Wilson 1973, 1984).

c) Excess water

Peterschmidt *et al.* (1979) reported that over-wet conditions had no consistent effect on dry matter digestibility or crude protein in *Medicago sativa*. In grasses these conditions gave herbage of lower crude protein and higher cell wall content, but had no effect on lignin content (Pate and Snyder 1979).

2.3.6.2 Soil fertility

In general, effects of soil fertility on the nutritional quality of pastures are small and inconsistent (Wilson 1984).

a) Nitrogen

Reviews by Minson (1973) and Wilman (1975) indicate that the effect of nitrogen fertilisation on herbage dry matter digestibility is complex and variable. Nitrogen may have positive, nil or negative effects on herbage dry matter digestibility. It often increases dry matter digestibility in young tissues and early regrowth (Whitney 1974; Gomide *et al.* 1969) but decreases dry matter digestibility of mature tissues (Donaldson and Rootman 1977).

b) Phosphorus and potassium

The majority of evidence indicates that phosphorus and potassium fertilisation have little direct influence on herbage dry matter digestibility but may improve nutritive quality indirectly by stimulating rapid new growth of severely nutrient deficient plants or by alteration of botanical composition of the pasture (see for instance: Miller *et al.* 1961; Reid and Jung 1965; Calder and MacLeod 1968; Rehm *et al.* 1977; Hannaway and Reynolds 1979).

c) Other nutrients

In general, other nutrient elements have been little studied with respect to their effect on pasture quality. The experiments examining the effect of fertiliser sulfur and fertiliser calcium on herbage quality (Reid and Jung 1965; Rees *et al.* 1974; Rees and Minson 1976, 1978; Goh and

Kee 1978; Odom *et al.* 1980) indicate that sulfur and calcium affect herbage dry matter digestibility differently in different types of pasture.

2.4 Prediction of Feed Intake

2.4.1 Introduction

The accurate prediction of feed intake is critically important for the successful application of a grazing system model, since livestock performance is principally dictated by nutritional status (Blaxter *et al.* 1956; Freer and Christiar 1983). Consequently, the prediction of voluntary feed intake in ruminants has been given much attention over recent decades. The aim of this section of the literature review is to indicate the factors that determine the intake of feed by sheep and to present the existing mathematical functions that may be used to predict feed intake. The approaches used by GrazFeed to predict intake are also discussed in some detail.

In the scientific literature, the commonly accepted theory of feed intake regulation has usually been based upon the explicit or implicit assumption that an animal seeks to obtain a genetically determined maximum growth and production rate and therefore a required maximum nutrient intake; the frequent failure of animals to achieve a maximum nutrient intake is the consequence of constraints imposed on the intake process. This theory has been supported by more recent publications of various research groups (see for instance: Minson 1982a; Van Soest 1982; Forbes 1986a; Weston and Popp 1987; NRC 1987). However, recently this assumption has been criticised by Ketelaars and Tolkamp (1992). They stated that animals apparently accept a submaximum growth and production rate rather than maximum growth and production rate. Therefore, the following literature review is intended to cover both the commonly accepted theory of feed intake regulation in ruminants and the new findings which have been obtained by Ketelaars and Tolkamp.

2.4.2 Animal factors affecting intake

Potential feed intake is a function of animal genotype, physiological state and health status. Animal factors affecting feed intake have been reviewed by Forbes (1980), Freer (1981), Weston (1982, 1985) and De Jong (1986). All these reviews are in accordance with the view that animal factors have been thought to affect intake partly *via* differences in the physical capacity to ingest feed (differences in gut size and digesta retention times) and partly *via* differences in nutrient requirements.

2.4.2.1 Animal size

As mentioned above, feed intake is limited by a combination of the animal's demand for nutrient requirements and its physical capacity for feed, both of which are proportional, in a

general way, to the size of the animal. Whilst most researchers in ruminant nutrition agree with such a view, there are two different opinions with regard to the effect of size on intake in the literature. Kleiber (1961) and Blaxter *et al.* (1966a) have stated that feed conversion in ruminants is independent of size because intake is proportional to maintenance requirements. With increasing size, maintenance requirements per unit of bodyweight decrease, so feed intake relative to bodyweight decreases to the same extent. Van Soest (1982), on the other hand, has argued that gut size acts as a limiting factor for intake and that therefore, intake of a given roughage will be a constant fraction of bodyweight irrespective of species size. However, what is undisputed between these authors is the fact that with increasing size, feed intake generally increases. However, there is as yet no agreement on a quantitative relationship between intake and size.

The quantitative relationship between intake and liveweight of sheep demonstrated by ARC (1980) is expressed in Equation 2.4.1. The equation is based on published data on the dry matter intake of more than 100 coarse roughage diets. It can be seen that the intake of herbage increases linearly with weight, there being no upper limit.

$$\text{DMI} = 104.7q_m + 0.307 W - 15.0 \quad (2.4.1)$$

where:

DMI = dry matter intake ($\text{g kg}^{-1} W^{0.75} \text{day}^{-1}$)

W = animal liveweight (kg)

q_m = metabolizable energy as fraction of gross dietary energy.

This equation, expressed as a relationship between dry matter intake (kg day^{-1}) and liveweight, for diet with metabolizable energy as fraction of gross dietary energy (q_m), is shown in Figure 2.4.1. However, in most cases, for sufficiently large values of liveweight, intake reaches a maximum or actually begins to decline (Arnold *et al.* 1977; Sibbald *et al.* 1979). Also, between breeds differences in intake have been well documented (e.g. Blaxter *et al.* 1966a, b; Christian *et al.* 1978; Freer 1981). Thus, the equation of ARC (1980) has only limited applicability for the prediction of intake (Freer and Christian 1983; Ketelaars and Tolkamp 1992).

Freer and Christian (1983) state that the best approach for predicting intake is from two variables: (i) the standard reference weight (SRW) of the animal (that is, the weight of the animal when it reaches mature skeletal size), and (ii) the current size of the animal relative to its mature size. SCA (1990) adopts the approach of Freer and Christian (1983). Equation 2.4.2 is recommended by SCA (1990) to predict dry matter intake (kg day^{-1}) of a non-lactating animal from the values of SRW and relative size. A detailed description of this approach can be found in Chapter 6, SCA (1990). Equation 2.4.2 is also illustrated in Figure 2.4.1, which is based on the outputs of the GrazFeed model, where it can be compared with the corresponding predictions by the ARC (1980). Experimental results of Langlands (1972, 1973), Langlands and Donald (1975)

and Williams *et al.* (1976) indicate that intakes predicted from the GrazFeed model appear to be much closer to empirical measurements than intakes predicted from ARC (1980).

$$\text{DMI} = 0.04 (\text{SRW}) Z (1.7-Z) \quad (2.4.2)$$

where:

DMI = dry matter intake (kg DM day⁻¹)

Z = relative size (with a maximum value of 1.0)

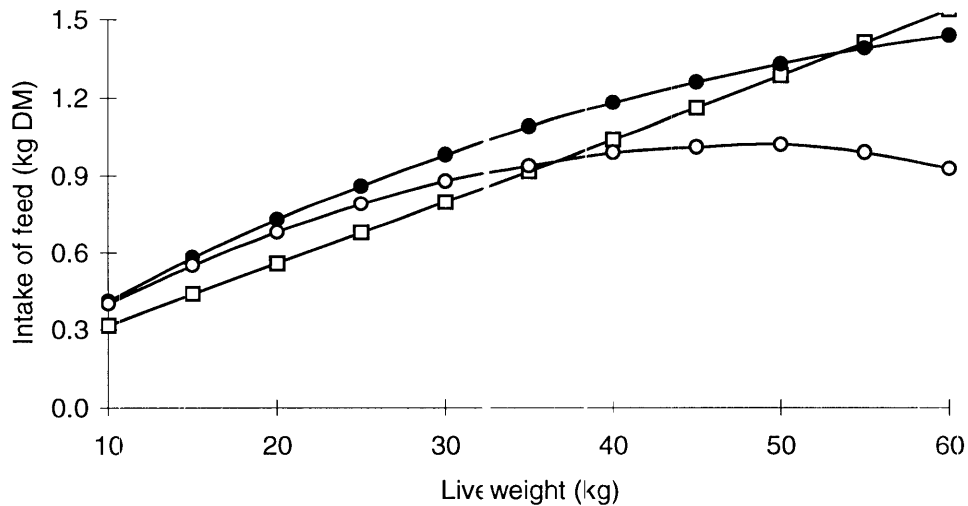


Figure 2.4.1 Comparison of the calculated intakes from ARC (1980) (□—□, $q_m = 0.65$) with the predicted intakes from the GrazFeed model (○—○, for small Merino; ●—●, for medium Merino). The detail of inputs for the GrazFeed model are described in Appendix 2.

2.4.2.2 Physiological state

a) Pregnancy

Knowledge of the changes in intake accompanying changes in pregnancy and lactation is extensive, yet of a more descriptive than explanatory nature. The view that the additional energy demand of pregnancy as a result of the development of the foetus, is generally accepted (ARC 1980). However, there is no evidence for an increase in feed intake throughout pregnancy and a decrease in intake is commonly observed a few days before parturition (Forbes 1971; Weston 1982; Forbes, 1986a, b). It is suggested that the possible cause is the competition for space between the gut and the gravid uterus (Forbes 1986a). However, observations made by Weston (1988a, b) indicated that the changes in rumen volume are not consistent with changes in the size of the gravid uterus. Hence, intake during pregnancy has not been well explained.

b) Lactation

Generally, lactating sheep consume more feed, irrespective of its quality, than non-lactating animals (Ketelaars and Tolkamp 1992). Differences up to 60% have been observed (Davies 1963; Corbett 1968; ARC 1980). The idea that intake follows from a balance between the demand for nutrients and the constraints imposed by gut size has been documented by Van Soest (1982), Forbes (1986b) and Weston (1988a, b). The essence of their ideas is that higher requirements induce the lactating animal to accept a higher rumen fill or produce a more rapid digesta turnover and this allows a higher intake. However, there is no convincing evidence to support the above idea (Ketelaars and Tolkamp 1992).

To calculate $DMI_{lactation}$, the approach of Freer and Christian (1983) has been adopted by SCA (1990). Equation 2.4.3 calculates the factor m which is used as a multiplier on the right hand side of equation 2.4.2 when predicting the $DMI_{lactation}$.

$$m = 1.0 + 0.025 n T^{1.4} \exp(-0.05 T) \quad (2.4.3)$$

where:

n = 1.0 for a ewe with 1 lamb, or 1.35 for a ewe with twins.

T = the time from parturition (days)

2.4.2.3 Health status

The presence of disease and parasitic infestation reduces feed intake; parasitic infestations are of particular relevance to grazing animals (see for instance, the reviews by Baile and Forbes 1974; Steel and Symons 1979; Dargie 1980; Forbes 1986a). Tests with different intestinal parasites indicate a complex pattern of responses depending on the level of infection and the development of resistance (Steel and Symons 1979). As a result, at present there is no quantitative description of the effects of disease and parasitic infestation on intake.

2.4.3 Effect of pasture nutritional characteristics on intake

2.4.3.1 Digestibility

There is abundant evidence (e.g. Balch and Campling 1962; Campling 1970; Bines 1971; Freer 1981; Minson 1982a; Hodgson 1982; Dulphy and Demarquilly 1983) to support the view that intake is limited primarily by the rate of the disappearance of digesta from the gut. This rate depends both on the chemical and physical properties of the herbage, and on the microbial activity in the rumen. In calculations however, intake is often related to digestibility because this quantity is a much more readily estimated characteristic, and it is largely determined by the same factors that determine the rate of disappearance of digesta from the gut.

The commonly accepted view about the role of feed digestibility in regulating intake may be summarised as follows: there is no single relationship existing between feed digestibility and intake but rather separate relationships depending on whether intake is controlled by rumen fill or

by nutrient requirements for maintenance and growth (Weston and Hogan 1973; Forbes 1977; Minston 1982b; Van Soest 1982; Forbes 1986a; NRC 1987). Therefore, organic matter intake is expected first to increase and then to decrease with increasing digestibility as illustrated in Figure 2.4.2.

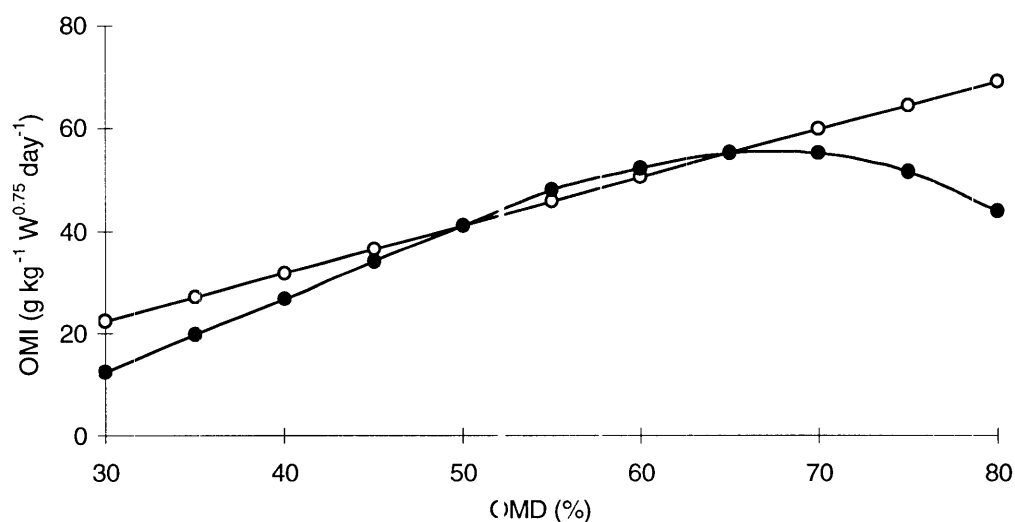


Figure 2.4.2 The relationship between OMI and OMD of the feed, calculated from Ketelaars and Tolkamp (1992), ○—○; and the commonly accepted view about the role of OMD on OMI, ●—●, the turning point is usually assumed to occur between 0.65 and 0.75 OMD.

However, the above intake relationship has recently been criticised by Ketelaars and Tolkamp (1992). From 831 types of roughage, they collected information on composition and intake by mature wether sheep. These roughages included grasses and legumes from temperate and tropical regions with organic matter digestibility varying from 0.30 to 0.84 and with nitrogen content in the organic matter from 0.3 to 5.6%. Feeds were fed either fresh or dried, in the long form or coarsely chopped. After analysing these published data, they found that the intake relationship commonly accepted does not apply to this compilation of intake data and the relationship between intake and digestibility can be expressed as Equation 2.4.4, illustrated in Figure 2.4.2, where it can be compared with the commonly accepted intake relationship. Hence, Ketelaars and Tolkamp (1992) concluded that intake increases linearly with increasing digestibility rather than reaching a plateau level. This conclusion is in accordance with the reviews of Hodgson (1977), Freer (1981) and SCA (1990), which have demonstrated linear relationships between digestibility and voluntary intake over the full range of maturity to be found in pasture plants.

$$\text{OMI} = -5.6 + 0.9349 \text{ OMD} \quad (2.4.4)$$

where:

OMI = organic matter intake (g kg⁻¹ W^{0.75} day⁻¹)

OMD = digestibility of organic matter (%)

2.4.3.2 Nitrogen (or protein) and mineral content

Reviews such as the ARC (1984) and SCA (1990) have clearly shown that the intake of feed may be depressed if the feed is deficient in certain chemical constituents, particularly those which are essential nutrients for the rumen microbial population. The quantitative relationship between intake and nitrogen (or protein) content which is expressed as equation 2.4.5 has been described by Ketelaars and Tolkamp (1992) after analysing the results of feeding trials with 831 different forms of roughage. Equation 2.4.5 and the relationship between intake and nitrogen content which is generated by the GrazFeed model are illustrated in Figure 2.4.3, where both agree that nitrogen content appears to be positively correlated with organic matter intake. However, there is no agreement on the extent to which nitrogen content affects intake, particularly at low nitrogen contents in the organic matter.

$$\text{OMI} = 33.6 + 8.1959 \text{ N} \quad (2.4.5)$$

where:

OMI = organic matter intake ($\text{g kg}^{-1} \text{W}^{0.75} \text{day}^{-1}$)

N = nitrogen content of organic matter (%).

Other nutrient deficiencies can also cause a reduction in intake. For example, increases in intake from increasing nitrogen content will not occur if insufficient sulfur is present in the feed; it has been suggested that a minimum concentration of about 0.15 per cent sulfur is necessary (Minson 1982a). Under some conditions intake has also responded to other minerals such as sodium (Minson 1982a), phosphorus (Playne 1969), cobalt (Marston *et al.* 1938), and selenium (McLean *et al.* 1962).

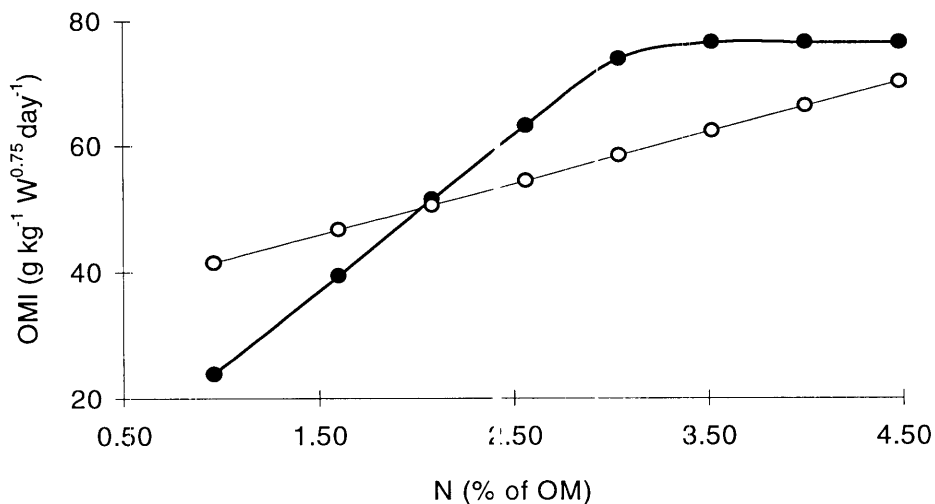


Figure 2.4.3 The relationship between OMI and N content of the feed, calculated from Ketelaars and Tolkamp (1992), ○—○; and created by the GrazFeed model, ●—●, for diets with

dry matter digestibility of 0.80. The inputs used for the GrazFeed model to create this graph are presented in Appendix 3.

2.4.4 Effect of pasture physical characteristics on intake

The effects of pasture physical characteristics on intake, especially the effects of herbage availability, sward structure and grazing selection, have been studied extensively.

2.4.4.1 Herbage availability

A number of studies have investigated the relationship between intake and pasture abundance, and have found that intake is severely reduced at low abundance and tends toward an asymptote for sufficiently abundant pasture (Freer 1981). It is this type of relationship that is generally included in models of grazing systems.

A more detailed understanding of the effect of availability on intake can be obtained by considering separately the time spent grazing and the rate of intake (which can be further divided into the rate of taking bites and the quantity of intake per bite) (Allden and Whittaker 1970). The detailed relationship of rate of intake to grazing time and herbage availability is illustrated in Figure 2.4.4. It shows that, as the amount of available herbage present declines, the animal's intake is initially unaffected; then the rate of intake decreases when accessibility of the herbage available imposes limitations on the rate at which the animal can prehend its feed; however, the animal is able to partially compensate for the reduced amount of intake by an increase in grazing time. As the animal extends its period of grazing the compensation becomes progressively more incomplete and the total intake would be expected to decrease dramatically. This relationship of rate of intake and grazing time to herbage availability is inconsistent with the experimental findings of Black and Kenney (1984) and Forbes and Hodgson (1985).

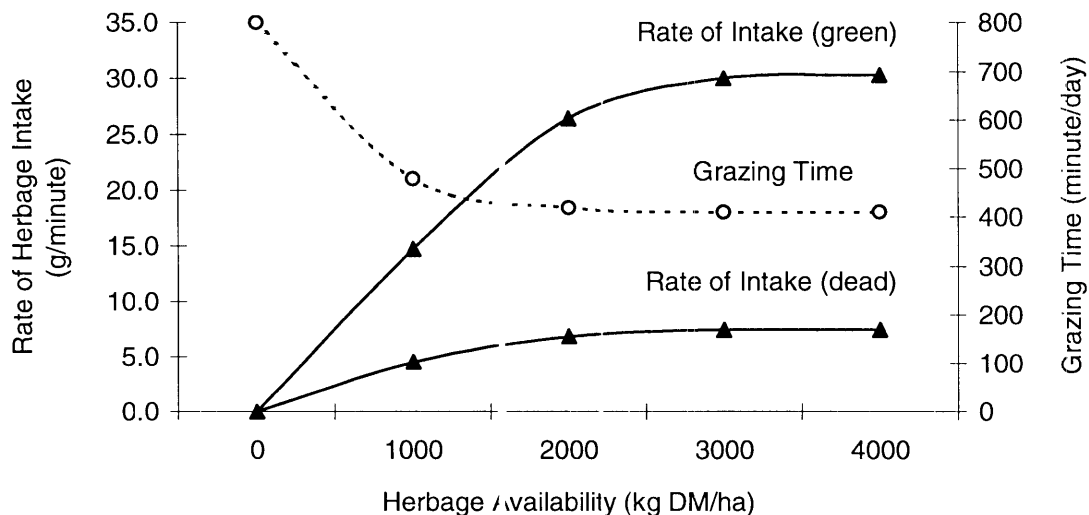


Figure 2.4.4 Relation of rate of intake of both dry and green herbage (▲—▲) and of grazing time (○-----○) to herbage availability (source: Alden and Whittaker 1970).

2.4.4.2 Sward structure and selective grazing

Pastures present the grazing animal with a mixed population of herbage plants. Not only structural features influence the amount of intake, but also differences in smell, taste and moisture content influence the amount of intake (Hogan *et al.* 1987). Alden and Whittaker (1970) found that intake rate was more closely related to tiller height than to herbage mass in the situations they studied. Using artificially constructed pastures, Kenney and Black (1984) showed that the rate of intake of pasture increased as the height and density of the sward increased. Also it has been shown that in clover pastures, grazing animals had a higher intake rate than where grazing a pasture dominated by grasses (Hogan *et al.* 1987).

It is generally accepted that the diet of grazing sheep may be of quite different composition from that of the grazed pasture. Freer (1981) notes that sheep select legumes in preference to grasses, green material in preference to dry material, and leaves in preference to stems. Forbes and Hodgson (1985) found a much larger percentage of leaf in the diet of their sheep than in the pasture. It is not clear in general, however, which plant characteristics most determine preference. Models assume that it is digestibility that determines preference.

2.4.5 Environmental factors affecting intake

Amongst environmental factors affecting intake, the effects of temperature and daylength especially, may be important determinants of feed intake of grazing animals.

2.4.5.1 Temperature

The effects of thermal stress on feed intake have been well documented by many publications of various research groups (Weston 1982; Forbes 1986a; Kennedy *et al.* 1986; Young 1987). A decrease of temperature to below the lower critical level or an increase of this critical value following shearing raises intake of both growing and pregnant sheep, but the response depends on the extent of insulation and level of metabolic activity of the animal and the quality of the feed.

Feed intake decreases immediately when an animal is under heat stress. After adaptation, heat and cold stress have different effects on digesta retention time, digestibility, pituitary activity and basal metabolism. After removal of heat stress it takes some time before intake recovers (Weston 1982; Forbes 1986a; Kennedy *et al.* 1986; Young 1987).

There has been much study of various aspects of thermal stress and animal performance (for instance, the publication discussed above), but, there are no well established bases for

quantitative definitions of effects on feed intake under grazing conditions because the flexibility of grazing behaviour allows animals to mitigate the effects of temperature extremes.

2.4.5.2 Photoperiod

The effect of photoperiod on feed intake has been well demonstrated by recent publications (Blaxter and Boyne 1982; Weston 1982; Forbes 1986a; Young 1987; Gettys *et al.* 1989). From these it is apparent that increasing photoperiod increases feed intake capacity of ruminants. However, again there are no well established bases for quantitative definitions of the effect of photoperiod on intake.

2.4.6 Effect of supplementary feeding on intake

In grazing systems the provision of additional feed may influence intake according to the nature of the nutrients provided and the ease with which the animal is able to prehend its feed (itself a function of the size and spatial dispersion of the plant pool). Therefore, the responses of intake of the grazing animal to supplementary feeding may be erratic and inconsistent (McClymont 1956).

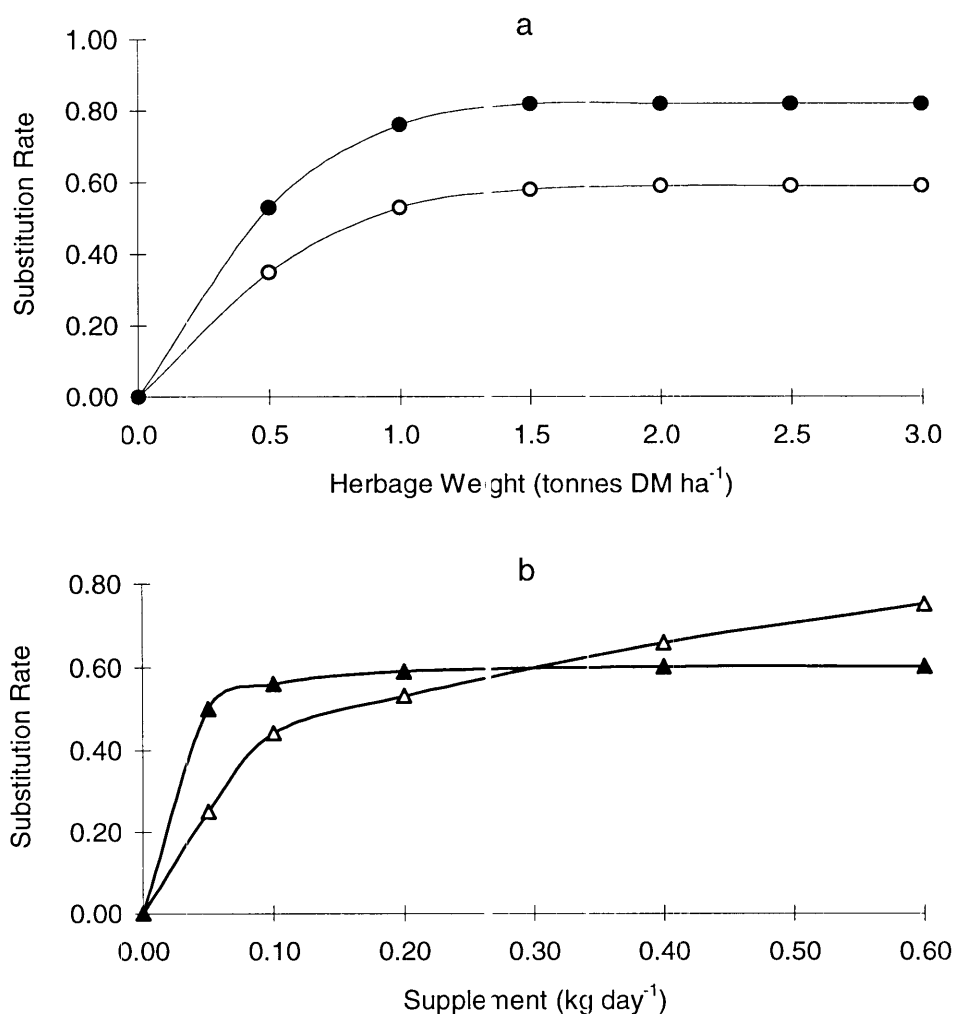


Figure 2.4.5 (a) relationship between substitution rate and pasture quantity and quality (mean digestibility 0.70, ●—●, and 0.50, ○—○) for 0.2 kg maize supplement with 0.90 digestibility. (b) relationship between substitution rate and supplementary quantity and quality (digestibility 0.60, ▲—▲, and 0.90, △—△) on pasture with mean digestibility of 0.50 and 1.0 tonne dry matter per ha. The detail of information used for the GrazFeed model to create the above graphs is presented in Appendix 4.

2.4.6.1 Energy-rich supplements

When animals grazing pastures are supplemented with energy-rich concentrates, their intake of herbage is depressed (Allden and Jennings 1962, 1969; Holder 1962; Langlands 1969; ARC 1980). The extent of the reduction of herbage intake (expressed as substitution rate) depends on supplement and pasture both in terms of quality and quantity. As shown in Figure 2.4.5, with higher quality supplements or higher quality abundant pasture, substitution rates are closer to 1.0, but on pastures of only 50 per cent digestibility, it is as low as 0.6; when the weight of pasture and the supplementary amount fall so do the substitution rates. The relationships presented in Figure 2.4.5 are in accordance with the findings by Allden and Jennings (1962), Langlands (1969) and Milne *et al.* (1981).

2.4.6.2 Protein and non protein nitrogen (NPN) supplements

The review in section 2.4.3.2 of this thesis shows that feed intake increases with increasing protein or nitrogen content of diets which is in accordance with the view of Morris (1958). He indicated that protein and nitrogen supplementation of sheep fed low protein roughages under pen conditions resulted in increased feed intakes. However, Allden (1981) stated that similar studies on intake appear not to have been carried out on grazing animals. On the other hand, Edwards *et al.* (1987) reported that the herbage intake of grazing weaner sheep was increased by continuous access to a high-protein supplement such as a lupin block.

2.5 Prediction of Animal Production in Grazing Sheep

2.5.1 Introduction

In his study of the effects of nutrition on grazing animal production, Beever (1993) pointed out that the level of animal production will be governed principally by the quantity of nutrients and, in particular, the amount of energy consumed by the animal. Consequently, to achieve high rates of animal performance, provision of high quality forage, particularly high protein content forage, is essential. Once feed enters the rumen, ruminant animals use their unique digestive system to digest the feed and release nutrients. The nutrients are then absorbed by the animal to drive its basic functions and used for maintenance, growth, pregnancy, lactation, and wool production. If,

on the other hand, the intake of nutrients, particularly energy, is insufficient for these needs, the animal may break down some of its body tissue to make up part of the deficiency.

This section concentrates on the prediction of sheep productivity with emphasis on bodyweight gain and wool growth. To understand these approaches, a review of the nutritional value of feeds is necessary.

2.5.2 Nutritional value of feed

Efficient animal production matches animal requirements for production with the nutritive value of the feed available (Low and Andrews 1987). Consequently, the nutritional value of feed has been studied extensively, in particular, the energy and protein values of feeds having received much attention. A large number of equations have been published for predicting energy and protein values of feeds (e.g. Minson 1982b, ARC 1980; MAFF 1984; SCA 1990).

2.5.2.1 Energy values of feeds

a) Gross energy (GE)

With most feeds eaten by ruminants the GE value reflects that of carbohydrates such as cellulose (about 17.6 MJ kg⁻¹ DM). The GE value increases with increasing concentrations of protein (about 24 MJ kg⁻¹ DM) and fat (about 39 MJ kg⁻¹ DM), but decreases as its ash content rises. This may be due to either a change in the natural mineral content of the feed or to contamination with soil or other extraneous inorganic material (SCA 1990). The GE of most ruminant feeds is approximately 18.4 MJ kg⁻¹ DM (MAFF 1984; ARC 1980; SCA 1990).

b) Digestible energy (DE)

Values for the DE content of DM reported by Moir (1961), Minson and Milfold (1966) and Michell (1974) ranged from less than 17 to about 19 MJ kg⁻¹ DM. Generally, a value of 18.4 MJ kg⁻¹ digestible DM is appropriate when DMD is 0.60 or greater, and 18.0 MJ kg⁻¹ for lower DMD (SCA 1990).

Reviews by Kellaway (1969) and Michell (1974) have demonstrated linear relationships between energy content of digestible plant organic matter (MJ kg⁻¹ DOM) and crude protein (CP) contents of plant DM (g kg⁻¹). The following equation 2.5.1 of Terry *et al.* (1974, cited in SCA 1990) is generally applicable to all foodstuffs.

$$\text{MJ kg}^{-1} \text{ DOM} = 17.33 + 0.0124 \text{ CP g kg}^{-1} \text{ DM} \quad (2.5.1)$$

c) Metabolizable energy (ME)

ME is the amount of energy provided by the feed that is available for metabolism by the animal's tissues. It is widely used to describe the energy values of feed and the energy needs of the animal. Reviews have indicated that ME is influenced by several factors relating to feed (Margan *et al.* 1987), level of feeding (ARC 1980), animal species (Doyle and Egan 1980) and animal physiological state (Graham 1980; Blaxter *et al.* 1966c). Many equations have been used to calculate the Metabolizable energy per kg feed DM (M/D). Some equations used in the literature are shown in Table 2.5.1.

Table 2.5.1 Equations for calculating the M/D from the composition dry matter (%)

Parameter	Equations for M/D	Reference
DMD	$0.193 \text{ DMD} - 0.661$ (all forages)	Moir (1961)
	$0.156 \text{ DMD} - 0.535$ (all forage)	WADA* (in SCA 1990)
	$0.153 \text{ DMD} - 1.057$ (tropical forages)	Minson (1984)
	$0.184 \text{ DMD} - 2.506$ (temperate forages)	Armstrong (1964)
DOMD	$a \text{ DOMD}^{**}$	MAFF (1984)
	$0.184 \text{ DOMD} - 1.827$ (tropical forages)	Minson (1984)
DOMD & OM	$0.178 \text{ DOMD} + 0.834 \text{ OM} - 17.9$	RRI (1984)
CP	$0.268 \text{ CP} + 7.573$ (temperate forages)	Armstrong (1964)
	$0.260 \text{ CP} + 4.653$ (tropical forages)	Minson (1984)
CF	$17.573 - 0.238 \text{ CF}$ (temperate forages)	Armstrong (1964)
ADF	$16.654 - 0.241 \text{ ADF}$ (tropical forages)	Minson (1984)
ADF & N	$83.58 - 0.824 \text{ ADF} + 2.62 \text{ N}$ (all forages)	Oddy <i>et al.</i> (1983)

*WADA = Western Australian Department of Agriculture.

** $a = 0.14$ for straws; 0.15 for hays and artificially dried grass; 0.16 for green forages.

2.5.2.2 Protein value of feeds

a) Crude protein (CP)

The simplest expression of protein content of feed is the traditional CP percentage. Values are usually obtained by multiplying Kjeldahl nitrogen by 6.25.

The CP fraction of feed includes not only true protein but also a wide range of compounds containing no amino acids - ureides, nitrate and ammonia. When the feed is low in protein but contains sufficient CP, amino acids may be provided to the animal indirectly when the animal ingests microbial protein synthesised in the rumen using the CP. Any dietary true protein may or may not be digested in the rumen. When undigested in the rumen, protein is termed 'escape' or 'bypass' protein. This type of CP is of significance as a supplement (Nolan, pers. comm.). It is generally agreed that CP provides a useful guide to the potential contribution of feed to supply amino acids for ruminants where all other nutrients are adequate.

b) Microbial crude protein (MCP)

While the feed particles are being digested in the rumen, some of the protein is released into the rumen fluid and broken down by enzymes from the micro-organisms. The ammonia

produced when proteins are degraded is then used by the microbes for their own growth and multiplication, forming MCP.

Reviews of ARC (1980, 1984) and Corbett (1987) have shown that the quantity of CP synthesised by microbial growth is related to the dietary energy expressed as organic matter apparently digested in the rumen (OMADR) or fermented organic matter, or more directly expressed as DOMI or ME since OMAADR is a fraction of DOMI (Ulyatt and Egan 1979; ARC 1980; Corbett *et al.* 1982).

The ARC (1980) adopted a mean value for MCP yields of 188 g CP kg⁻¹ OMAADR, subsequently revised (ARC 1984) to 200 g CP kg⁻¹ OMAADR.

c) Rumen degradable protein (RDP)

The dietary protein that breaks down in the rumen is called rumen degradable protein (RDP). Studies by Webster *et al.* (1982) found that RDP of forages can be calculated from their CP (g/kg DM) and MADF (g kg⁻¹ DM) or CF (g kg⁻¹ DM) and derived the following equations:

$$\text{RDP} = 0.9 (\text{CP} - 0.1 \text{MADF})/\text{CP} \quad (2.5.2)$$

$$\text{RDP} = 0.9 (\text{CP} - 0.125 \text{CF})/\text{CP} \quad (2.5.3)$$

d) Crude protein leaving the stomach (CPLS)

The total N in digesta minus the N present as ammonia is termed non-ammonia nitrogen (NAN). The NAN contains the nitrogenous substances, the amino acids and may be described (Hogan and Weston 1981) as the crude protein leaving the stomach (CPLS = 6.25 NAN). Corbett (1987) indicated that CPLS has three components, in descending order of magnitude these are MCP, UDP and endogenous crude protein (ECP). Thus:

$$\text{CPLS} = b_1 \text{DOMI} + b_2 \text{CPI} + \text{ECP} \quad (2.5.4)$$

where:

b_1 = the MCP yield g kg⁻¹ DOMI.

b_2 = the fraction of the CPI that not been degraded during passage through the rumen.

2.5.3 Calculation of ME requirements for maintenance

2.5.3.1 The common equation

Maintenance requirements for metabolizable energy (ME_m) are considered as the sum of basal metabolism energy (which includes a requirement for wool growth), basal urinary energy, energy expended in work which includes feeding, ruminating and walking, and energy expended in cold stress (ARC 1965). To calculate ME_m, the approach of Corbett *et al.* (1987) has been

adopted by SCA (1990). Their equation shown in equation 2.5.5 is derived from the equation which was developed by Graham *et al.* (1976).

$$ME_m = \frac{S \cdot M(0.26W^{0.75} \exp(-0.03A))}{k_m} + 0.09MEI + \frac{E_{graze}}{k_m} + E_{cold} \quad (2.5.5)$$

where:

- S = 1.0 for female and castrates or, 1.15 for entire males (rams)
M = 1 + (0.23 × per cent diet DE from milk) = 1 + (0.26 – Bα) with B = 0.015 for suckled lambs and kid goats, and α is week of life. Minimum value of M is 1.0
W = liveweight (kg)
A = age in years, with a maximum value of 6.0, when exp(-0.03A) = 0.84
k_m = net efficiency of use of ME for maintenance
MEI = total ME intake (MJ sheep⁻¹ day⁻¹)
E_{graze} = additional energy expenditure of a grazing animal compared with a similar housed animal (MJ sheep⁻¹ day⁻¹)
E_{cold} = additional energy expenditure in cold stress by animals in below lower critical temperature environments, MJ sheep⁻¹ day⁻¹.

2.5.3.2 Efficiency of use of ME in feed for maintenance (k_m)

The equations used for calculating k_m are shown in Table 2.5.2. For solid feed it is generally agreed that k_m increases slightly with increasing quality of feed. Milk diets are normally considered separately and assigned a fixed k_m value. With the exception of the k_m value given by White *et al.* (1983), there is little variation about a value of k_m for milk diets of 0.85 (Table 2.5.2). The study by Graham (1980) showed that k_m did not vary with age of animal.

Table 2.5.2 Equations and values for k_m

Reference	k _m for milk diet	k _m for solid feed
ARC (1980)	0.85	0.35 q _m + 0.503
Christian <i>et al.</i> (1978)	0.84	0.246 DOMI/DMI + 0.546
France <i>et al.</i> (1983)	0.85	0.70
Graham <i>et al.</i> (1976)	0.84	0.30 q _m + 0.546
White <i>et al.</i> (1983)	0.80	0.244 DEI/GEI + 0.546
MAFF (1975)	0.85	0.016 M/D + 0.55
SCA (1990)*	0.85	0.02 M/D + 0.5

*As mentioned in 2.5.2.1 b, feeds generally have an average gross energy content of 18.4 MJ/kg DM, consequently, according to the equation expressed by the ARC (1980), SCA (1990) wrote its equation for calculating k_m in M/D form.

2.5.3.3 Energy expenditure at pasture (E_{graze})

The value of E_{graze} varies with grazing conditions including the availability and digestibility of feed, weather, topography and interactions between these factors.

The efficiency of ME used for muscular work is uncertain (Graham 1985) but, generally it is assumed (e.g. ARC 1980) to be the same as the efficiency of use for maintenance, k_m .

Corbett (1987) reported that the non-cold stressed ME_m is about 20%-50% greater than the requirement of similar housed animals depending on grazing conditions. This conclusion is supported by direct measurements (Corbett 1981) and by experimental results (Langlands *et al.* 1963). To calculate E_{graze} , the approach of Corbett *et al.* (1987) has been adopted by SCA (1990) who have modified the equation of Corbett *et al.* (1987) by eliminating the k_m term; thus the following prediction equation has been derived:

$$E_{\text{graze}} = [(0.05 \times \text{DMI} (0.9 - D)) + (0.05T/(GF + 3))] W \quad (2.5.6)$$

where:

DMI = dry matter intake from pasture, kg sheep⁻¹ day⁻¹, excluding supplementary DM

D = digestibility of the dry matter (decimal)

T = 1.0 or 1.5 or 2.0 respectively for level, undulating or hilly terrain

GF = availability of green forage, tonnes DM ha⁻¹ (quantity when cut to ground level). If GF is so low that, in effect, dead forage only is available to animal it is suggested that total forage be used in place of GF

W = animal liveweight (kg).

2.5.3.4 Energy expenditure in cold stress (E_{cold})

a) Effect of climate on E_{cold}

Climatic conditions which cause body temperature to rise alter energy and nitrogen metabolism (Graham *et al.* 1959). Quantitative definition of the effects of ambient temperature and wind speed on heat loss has been well documented (e.g. Joyce and Blaxter 1964; Mount and Brown 1982; SCA 1990). Below a certain ambient temperature (the lower critical temperature), heat production rises as temperature falls.

Although the phenomenon that heat loss by the animal is increased during, and for some time after rainfall, has been widely observed, quantitative description of the effects of rainfall on heat loss is difficult because there is little information on the relationship between rainfall and the extent to which the fleece becomes wet (SCA 1990). The quantitative relationship between rainfall and total insulation devised by Frøer (in SCA 1990) is shown in equation 2.5.7.

$$I_{\text{total}} = I_t + [1 - 0.3 (-1.5 R/F)] I_e \quad (2.5.7)$$

where:

- I_{total} = total insulation value in rain
 I_t = tissue insulation, °C m² day MJ⁻¹
 I_e = external insulation, °C m² day MJ⁻¹
 R = rainfall, mm day⁻¹
 F = fleece depth, mm.

b) Calculation of E_{cold}

The detailed relationships for calculating E_{cold} from fleece length, wind speed, rainfall (equation 2.5.7) and temperature have been presented by SCA (1990) and are expressed in the following equations. Values of the variables in equations for calculating E_{cold} are shown in Table 2.5.3:

$$E_{\text{cold}} = [AS (T_{\text{lc}} - T_{\text{a}})] / (I_t + I_e) \quad (2.5.8)$$

where:

AS = animal surface area which can be calculated with the equation:

$$AS \text{ (m}^2\text{)} = 0.09 W^{0.66}$$

T_{lc} = animal's lower critical temperature, °C

T_{a} = ambient (air) temperature, °C.

Table 2.5.3 Values of the variables in equations for predicting heat loss by animals and their lower critical temperatures (source: SCA 1990)

Variable	Symbol	Units	Value
Evaporative loss	E	MJ (m ² day) ⁻¹	1.3
Tissue insulation	I_t	°C m ² day MJ ⁻¹	1.3
Coat insulation per mm depth	z	°C m ² day MJ ⁻¹	0.141
Radius	r	mm	120 (adult) 50 (lamb)
Body temperature	T_b	°C	39
Animal surface area	AS	m ²	0.09 kg W ^{0.66}

* I_t increasing from 0.64 (newborn) by 0.033 °C m² day MJ⁻¹ to 1.6 (max) at 28 days old.

c) The lower critical temperature (T_{lc})

The T_{lc} for an animal varies with its thermal insulation or resistance to heat flow to the environment, and with its rate of metabolic heat production (MH, MJ sheep⁻¹ day⁻¹) in

thermoneutral conditions (SCA 1990). The resistance to heat loss is governed by two factors: I_t and I_e . SCA (1990) calculated T_{lc} by the following equation:

$$T_{lc} = T_b + (E/AS) (I_e) - [(MH/AS) (I_t + I_e)] \quad (2.5.9)$$

where:

T_b = animal body temperature, °C

MH = metabolic heat production in thermoneutral conditions, can be calculated with the equation of SCA (1990): $MH = \sqrt{ME_m + (MEI - ME_m) (1 - k_g)}$. MJ sheep⁻¹ day⁻¹.

d) External insulation (I_e)

Wind reduces I_e and thus increases heat loss to the environment. This effect can be described by the equation of Joyce *et al* (1966), after conversion to °C m² day MJ⁻¹ from Mcal, SCA (1990) presents the following equation:

$$I_e = [r/(r + F)] [1/(0.481 + 0.326 v^{0.5})] + r \log_e [(r + F)/r] (z - 0.017 v^{0.5}) \quad (2.5.10)$$

where:

r = the radius of the animal, mm

F = fleece depth, mm

v = air velocity, km h⁻¹

z = the thermal insulation mm⁻¹ fleece.

2.5.4 Weight gain and loss

2.5.4.1 Weight gain

a) Factors affecting the composition of gain

Reviews have indicated several factors relating to animal and growth rate that may affect the composition of weight gain.

It has generally been found that weight gain in small animals consists of a higher proportion of protein and less fat, and consequently has a lower fat content than weight gain in heavier animals. ARC (1980) claims, furthermore, that the increase in fat content of weight gain with increasing empty bodyweight is well approximated by a linear function.

Breed is a second factor that can affect the composition of weight gain. Searle and Graham (1982) suggest at a given weight, sheep of smaller mature size have fatter bodies, therefore have a higher fat content of weight gain. This suggestion is consistent with the finding of McClelland *et al.* (1976).

The differences between sexes in the composition of weight gain have been documented by Christian *et al.* (1978) and ARC (1980). Generally males have a lower fat content of weight gain than females, and castrates having intermediate values.

The review of MAFF (1984) indicated that faster growth rates lead to lower fat contents of weight gain. However, ARC (1980) discusses the effect of growth rate on the fat content of gain and concludes that there is insufficient evidence for taking this into account.

b) Calculation of the composition of gain

i) *the common approach*

The commonly used approach to calculate weight gain is exemplified by White *et al.* (1983). The Metabolizable energy available for bodyweight gain is intake minus the requirements for maintenance and production (only lactation in this particular case). Multiplying by the efficiency gives the net energy retained (ER, MJ/day) by the animal as body tissue, expressed in equation 2.5.11. Then, ER is converted to empty body gain (EBG, kg day⁻¹) by dividing the energy content of empty weight gain (EVG, MJ kg⁻¹ EBG day⁻¹). Finally, EBG is converted to liveweight gain (LWG) by multiplying the conversion between LWG (kg day⁻¹) and EBG (equation 2.5.12). The conversion between LWG and EBG has been recorded as varying with the breed, sex and the rate of gain or loss. The conversions given in the ARC (1980) are LWG = 1.09 (EBW + 2.9) for the weaned sheep and LWG = 1.09 EBW for other categories of sheep.

$$ER = k_g (MEI - ME_m - ME_p) \quad (2.5.11)$$

$$LWG = c \text{ EBG} = c (ER/EVG) \quad (2.5.12)$$

where:

c = the conversion between LWG and EBG.

This approach is adopted by Edrsten and Newton (1975, 1977), Christian *et al.* (1978), France *et al.* 1983 (for sheep on solid feed), Geisler and Neal (1979), ARC (1980) and SCA (1990).

ii) *equations for calculating the composition of EBG*

The SCA (1990) presents the following equations to predict the composition of EBG:

$$EVG = (6.7 + R) + (20.3 - R) / [1 + \exp(-6(P - 0.4))] \quad (2.5.13)$$

where:

P = (current W kg) / SRW kg with ξ RW as the value assigned to the particular type of animal

R = adjustment for the rate of gain or loss.

The R can be calculated either from empty body change (EBC) or ME intake:

$$R = [(EBC)/(4 SRW^{0.75})] - 1 \quad (2.5.14)$$

$$R = 2 [NEC/NE_m] - 1 \quad (2.5.15)$$

where:

NE_m = net energy for maintenance calculated with equation 2.3.2, $MJ day^{-1}$

NEC = net energy available for gain = $k_g (MEI - ME_m)$, or for intakes less than ME_m , 0.8 efficiency of use of energy from loss in W , it is $1.25 k_m (ME_m - MEI)$.

$$Fat: (MJ/kg EBG) = (1.7 + 1.1 R) - (23.6 - 1.1 R)/[1 + \exp(-6(P - 0.4))] \quad (2.5.16)$$

$$Protein: (MJ/kg EBG) = (5.0 - 0.1 R) - (3.3 - 0.1 R)/[1 + \exp(-6(P - 0.4))] \quad (2.5.17)$$

Given that the energy contents of fat and protein are $39.3 MJ kg^{-1}$ and $23.6 MJ kg^{-1}$ respectively, then

$$Fat: (g/kg EBG) = (43 + 28 R) + (601 - 28 R)/[1 + \exp(-6(P - 0.4))] \quad (2.5.18)$$

$$Protein: (g/kg EBG) = (212 - 4 R) - (140 - 4 R)/[1 + \exp(-6(P - 0.4))] \quad (2.5.19)$$

c) Efficiency of use of ME in feed for weight gain (k_g)

The efficiency k_g is defined as the increase in body energy retention per unit increase in Metabolizable energy from feed available for weight gain (Wallach *et al.* 1986). It is apparent that several factors relating to animal, feed and growth rate may affect k_g . The expressions for k_g from the literature are presented in Table 2.5.4.

For solid feeds it is generally agreed that k_g increases with increasing quality of the feed. Milk diets are normally considered separately and assigned a fixed value. It can be seen that there is little variation about a mean value of k_g for milk diets of 0.70 (Table 2.5.4).

Besides the animal and feed factors, rate of intake or growth rate may affect k_g . Studies by Edelsten and Newton (1975) and Sibbald *et al.* (1979) indicated that k_g is a continuously decreasing function of intake which is in accordance with the view of ARC (1980).

Table 2.2.4 Expressions for efficiency of use of ME in feed for weight gain (k_g)

Reference	k_g for milk diet	k_g for solid feed
Graham <i>et al.</i> (1976)	0.69	$0.03 + 0.81 M/D$
Christian <i>et al.</i> (1978)	0.69	$0.03 + 0.664 (DOMI/DMI)$
ARC (1980)	0.70	$0.78q_m + 0.006$
MAFF (1984)	0.70	$0.0435 M/D$
SCA (1990)	0.70	$0.042 M/D + 0.006$

2.5.4.2 Weight loss

Body energy is mobilised when energy intake is insufficient to cover energy losses. Reviews by Searle and Graham (1972), Blaxter *et al.* (1982) and White *et al.* (1983) indicate that the composition and energy value of liveweight loss in a sheep of any given type and liveweight are similar to that of its liveweight gain. Consequently, the approach adopted by the SCA (1990) to calculate the ME from metabolism of animal body tissues is by 'reverse use' of equation of 2.5.13.

The energy from liveweight loss will not be used with 100% efficiency. Although the efficiency of use of the energy for maintenance varies from 0.70 (Sibbald *et al.* 1979) to 0.93 (France *et al.* 1983), an efficiency of 0.8 is commonly suggested (e.g. Marston 1948; Flatt *et al.* 1965; SCA 1990).

2.5.5 Wool growth

Wool growth of sheep is subject to an annual rhythm in response to photoperiod. The magnitude of seasonal variation in wool growth rate is breed-dependent. Nutrition, physiological status and animal size also influence rates of wool growth (Coop 1953; Bigham 1969; Bigham *et al.* 1978; Corbett 1979; Sumner 1979; White *et al.* 1979; Sumner and Rattray 1980).

2.5.5.1 Protein requirement for wool growth

In the nutritional studies of wool growth, emphasis is placed on the quantity and quality of the amino acid supply and its use (SCA 1990).

Wool protein differs from other body proteins particularly because of its high sulfur-amino acid (SAA) content. Lindsay *et al.* (1980) found that the SAA comprised only 0.035 of the total amino acids actually absorbed from forage diets, whereas they are 0.09 to 0.15 of the total in wool (Reis 1979). There are many reports of increased wool growth in response to additional

SAA provided as supplements protected from ruminal degradation or administered parentally (Reis 1979).

Although knowledge of protein requirements for wool growth in particular circumstances is extensive, there appears to be no general predictive equation in the literature, partly because of lack of quantitative information relating wool growth to absorbed protein and partly because the ability to grow wool varies greatly between breeds of sheep and between animals of one breed.

2.5.5.2 Energy requirement for wool growth

Wool growth is sensitive to amino acid supply and also depends to some extent on energy intake (Black *et al.* 1973; Graham 1982).

The review of Corbett (1987) indicates that gross energetic efficiencies of wool growth are generally found to be in the range of 10 to 20 g clean dry wool per kg DOMI (approximately 0.02 to 0.04 MJ/MJ ME). However, the only study in which estimates of the net efficiency of use of ME for wool growth (k_{wool}) (Graham and Searle 1982) showed that k_{wool} was 0.16-0.19, and it accounted for 10% of ME_m .

Based on information reviewed by Corbett (1979), the SCA (1990) assumed that wool growth decreases progressively as gestation develops, and that decreases during lactation are proportional to milk yield which is consistent with the finding of Oddy (1985). Accordingly, the equations proposed by ARC (1980) to calculate the wool growth were modified by SCA (1990) to account for the effects of pregnancy and lactation. The modified equations are shown in equations 2.5.20 and 2.5.21. Both of them are presently in the GrazFeed model.

$$W_c = 8 \text{ ME}_w (\text{SFW}/\text{SRW}) \quad (2.5.20)$$

$$W_c = (\text{SFW}/\text{SRW}) / (5 M_s + 0.7 U_l) \quad (2.5.21)$$

where:

W_c = Clean wool growth, g sheep⁻¹ day⁻¹

ME_w = total ME intake, MJ sheep⁻¹ day⁻¹, minus estimated ME use for pregnancy and/or lactation

SFW = the Standard Fleece Weight for an adult sheep (2 years old +) of given type (breed, strain, sex). It is the annual greasy fleece production (kg) expected in a year with good climatic conditions for pasture growth, and for ewes is the production expected if they had neither borne nor reared a lamb. The value to be chosen corresponds to the weight of the 12 month fleece as shorn, with a clean scoured yield of 0.6-0.7. It is a constant for any given genotype, but is reduced for ages of less than about 2 years with the expressions:

$$1 + \exp(-C.33t))z^{0.67}$$

where:

t = age in months

z = the relative size of the animal

SRW = the Standard Reference Weight of sheep, kg

M_s = M_w minus, for the unweaned lamb, the ME in milk intake, MJ sheep⁻¹ day⁻¹

U_t = intake of UDP minus half the protein secreted in milk or retained in conceptus, g sheep⁻¹ day⁻¹.

2.6 Conclusion to Review of Literature

The effects of environment including climatic and soil factors on pasture production and quality were discussed in sections 2.2 and 2.3 of this review. It has been shown that the interrelationships between the factors controlling pasture production and quality are complex. Although in general, the amount and seasonal pattern of pasture production and quality are determined largely by temperature and rainfall or soil moisture, other factors including soil acidity and nutrient elements may also be important determinants of pasture production and quality in some circumstances.

The effect of the numerous factors including nutritional and physical characteristics of pasture, animal and environmental factors, and supplementary feeding on the intake of the grazing animal, as well as the approaches to predicting the intake were discussed in section 2.4. Scientists disagree as to how a grazing animal's intake is affected by these factors, especially the pasture characteristics. However, in general, experimental evidence does not seem sufficient to choose unequivocally between the possibilities presented. These disagreements in intake regulation imply the complex nature of the factors which determine intake. This complexity further indicates that present information is inadequate for developing a general predictive equation for intake (Freer 1981), and universal intake models are not likely to be attainable.

A number of different approaches to predicting feed energy and protein values, k_m and k_g that have been proposed in the literature were reviewed and discussed in section 2.5. Considerable variance in predicting these values between approaches implies that currently it is difficult to obtain one model to handle all types of grazing situations. As discussed, the equations which have been adopted by SCA (1990) to predict ME_m , E_{graze} , E_{cold} , weight gain and loss as well as wool growth are based on a wide range of data, and appear to be soundly based. However, it should be noted that the equations given in these sources can not be universally valid.

The information from this chapter is essential to enable a comprehensive and objective evaluation of the performance of the GrazFeed model when comparing with the observations from the field experiments reported in chapters 3, 4 and 5. The reviews of existing knowledge on the environmental factors that affect pasture production and quality, the factors that determine the intake of feed by sheep and the approaches that are used to predict the intake and sheep

productivity can assist in the identification of the reasons which may cause discrepancies between model prediction and experimental observation.

Chapter 3

Comparison of animal performance on improved pastures using experimental data and GrazFeed

3.1 Introduction

In his review of the efficiency of pasture/livestock operations, Scott (1995) indicated that the closer pasture productivity is matched to the demands of livestock, the more efficient the grazing industry and the higher the profits will be. Successful management of pastures must balance the grazing animals requirements with the seasonal and annual fluctuation in pasture production (Scott 1995). The grazing industry needs to use all available means to assist the producer to close the feed gap as much as possible. Research in recent years has demonstrated that computerised decision support systems have the potential to assist in farm planning (Dick 1994).

Improved pastures which can provide a longer productive season, higher quality and quantity of pasture available are a very important resource for both wool and meat production in the high rainfall zone of Australia. The GrazFeed model, which implements the Australian Feeding Standard for Ruminants (SCA 1990) has the potential to help graziers closely match pastures with the requirements of stock in this region (see for instance, McDonald and Bell 1995). However, before any model can be used to make management decisions they must be validated for the ecosystem in which they are being used. A valid model is one where the model output agrees with observed ecosystem data (Manklin *et al.* 1975). Thus, the predictions of GrazFeed need to be compared with experimental observations to determine the usefulness and limitations of each approach on improved pastures in the high rainfall zone of Australia. The objective of this study was to evaluate the GrazFeed performance in predicting sheep bodyweight change and wool growth on improved pastures in the high rainfall zone.

3.2 Materials and Methods

3.2.1 Experimental site

The experimental site was located on Big Ridge 2, Chiswick, the CSIRO Pastoral Research Laboratory, Australia, at 31°31'S 150°39'E. The site is at an altitude of 1046m and is gently undulating. The Big Ridge 2 site has been maintained for grazing trials since the 1960s. The site has been subjected to four severe droughts (1965, 1982, 1993 and 1994) and a wide range of set stocking (0-30 sheep/ha). The range of set stocking rates over the last 30 years has gradually produced three different pastures: 'degraded', phalaris and phalaris/white clover.

Two replicates of each of the three pasture treatments ('degraded', phalaris and phalaris/white clover) are arranged in the paddock diagram in Figure 3.2.1 below. Each plot has three equal strata to allow stratified sampling. Characteristics of the experiment are summarised in Table 3.2.1.

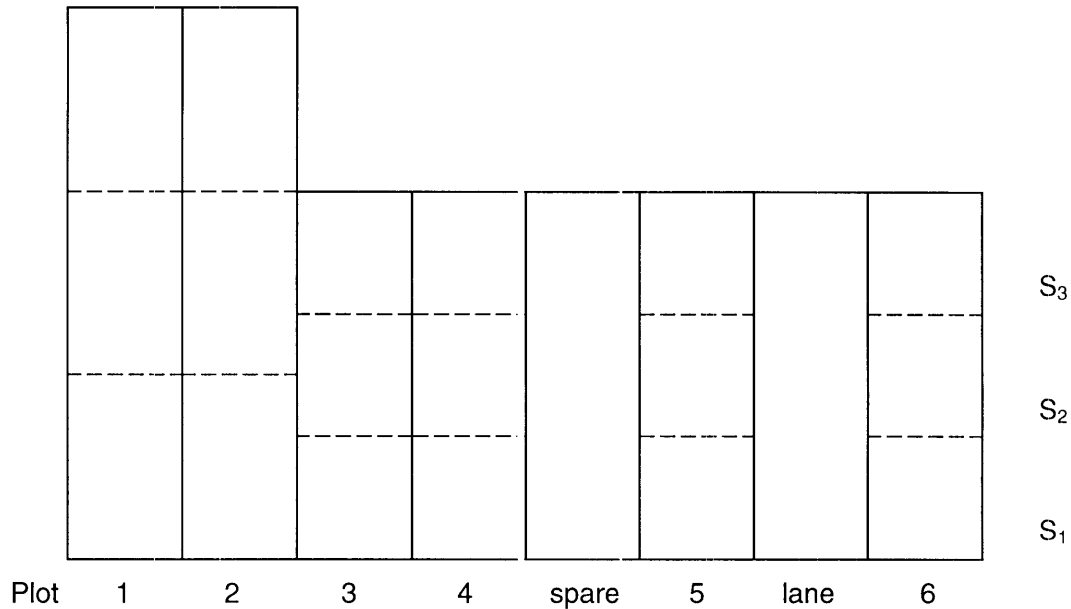


Figure 3.2.1 Layout of treatment plots at Big Ridge 2, Chiswick, Armidale.

Table 3.2.1 Characteristics of the experimental sites at Big Ridge 2, Chiswick, Armidale.

<i>Characteristics</i>	<i>Pasture Type</i>					
	<i>Degraded</i>		<i>Phalaris</i>		<i>Phalaris/White Clover</i>	
Plot number	1	2	3	6	4	5
Area (ha)	0.6	0.6	0.4	0.4	0.4	0.4
SR* (sheep ha ⁻¹)	3.8 – 5.7	3.8 – 5.7	10 – 20	10 – 20	10 – 20	10 – 20

* SR = Stocking rate

3.2.2 Measurements

3.2.2.1 Pastures

a) Sampling

Pasture samples were taken at approximately 30 day intervals (starting on December 14, 1994). At the commencement of the experiment, three fixed diagonal transects (30 m long) were established representing three strata in each plot. During each sampling, 10 sampling positions

were located and defined by a marked rope stretched along the transect. The Rising Plate method was used to estimate the weight of herbage at the each marked sampling position and percent of green herbage and the percent of legume were assessed by visual estimation.

Before commencing sampling, one additional sampling position within each of the three strata in each plot was marked randomly. The meter readings of the additional sampling positions was recorded separately. At the end of sampling, the herbage on the additional sampling positions was harvested to ground level and taken to the laboratory for separation and analysis.

b) Herbage mass and *in vitro* digestibility

The cut samples were washed in cold water to remove soil then dried in an oven at 65°C for 48 hours and weighed to obtain the herbage biomass. Following drying, the cut samples were separated into green and dead and grasses and legumes and weighed separately. After completing the experiment, a total of 36 (3 readings/time × 12 times) meter readings with associated calibration cuts were made in each of the six experimental plots. These 36 readings were separated into two groups: spring/summer (December 1994 to February 1995, and September 1995 to November 1995) and autumn/winter (March 1995 to August 1995). The seasonal curvilinear regressions of herbage biomass on meter reading, as well as the linear regressions of the percent of green herbage and legume content on their visual estimates at each of the experimental plots were then computed. Thus, the biomass of green herbage and the percentage of legume at each sampling time in every plot was determined by taking the average of the biomass of green herbage and the percentage of legume at each sampling position, were computed by the corresponding regression. The biomass of dead herbage was calculated by subtracting the green biomass from the total herbage biomass.

Prior to *in vitro* digestibility analyses, the three green herbage samples in each plot were bulked into one sample, as was the dead herbage samples. The bulked samples were ground to pass a 1 mm sieve and well mixed. The herbage *in vitro* digestibility was analysed at the University of New England by near infrared reflectance spectroscopy (NIR). NIR determines *in vitro* digestibility by detecting reflectance of longwaves from the sample and is calibrated with samples of known *in vitro* digestibility similar to those being tested (Minson 1987).

The measurements made at each sampling time in each plot were: biomass of green and dead herbage, percentage of legume, and *in vitro* digestibility of green and dead herbage.

3.2.2.2 Animals

In the experiment, small 16 months old Merino wethers were set-stocked through the whole experimental period. Although the stocking rate in each of the six plots varied with the pasture conditions, the experimental sheep were always grazed on the experimental pastures. Animal liveweight data was recorded at approximately the same time as the pasture

assessments. The dye-banding technique was employed approximately every 60 days (starting on December 14, 1994). Greasy fleece yield was partitioned to provide fleece weight over the experimental time by sectioning the staples at the dye-bands and measuring length and diameter of the six sections. Greasy fleece weight at each sampling time was assumed to be directly proportional to the volume of staple at that time and was calculated as follows:

$$V_n = [3.1416 * (D_n / 2)^2] * L_n$$

$$P_n = (V_1 + V_2 + \dots + V_n) / \text{Total segment volume } (V_1 + V_2 + \dots + V_6)$$

$$FW_n = P_n * \text{Greasy fleece yield}$$

where:

V_n = Volume of n

P_n = Proportion of the staple volume at sampling n time to total segment volume

FW_n = Fleece weight at sampling n (kg)

The sheep were shorn on November 9, 1995 and the greasy fleece yield recorded.

3.2.2.3 Climate

The data for rainfall, air temperature, and wind speed were available from a meteorological station at the experimental site.

3.2.3 Evaluation processes

The parameters in the animal component of the model which control feed intake, daily weight gain and fleece growth rate were adjusted to reflect both the sheep breed and specific attributes of the animals employed in the experiment. The weight of a mature ewe in average condition was 40.0 kg, and her potential greasy fleece weight in a good year was 3.5 kg (D. Wilkinson, *pers. comm.* 1995).

Since the dye-banding was not performed at each animal liveweight measurement, the spline function (Atkinson 1993) in Matlab software was applied to estimate the fleece weight at the measuring dates for which the observed greasy fleece weight was not available. An example of the use of this function to estimate fleece weight at the sampling day is illustrated in Figure 3.2.2. Estimates of sheep bodyweight required by the model were determined by subtracting their greasy fleece weight from their liveweight.

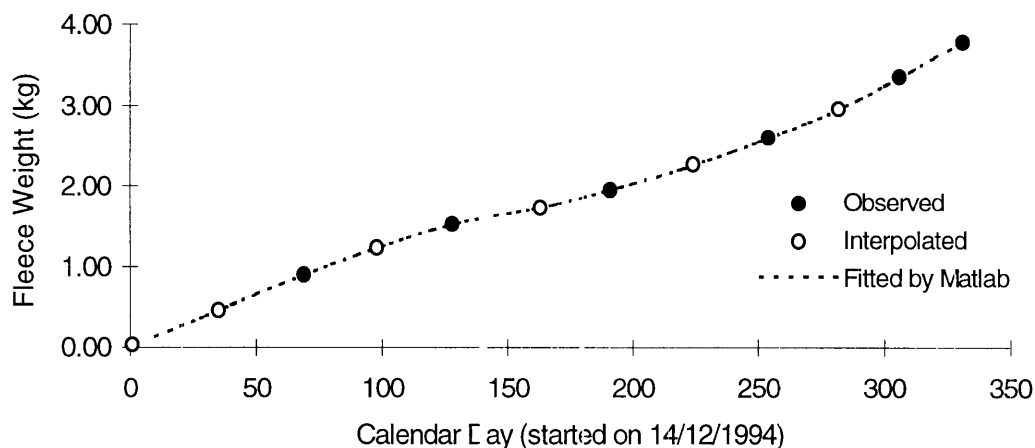


Figure 3.2.2 Function used for interpolating the staple length at the times when dye-banding was not performed.

After testing the sensitivity of the model's animal predictions to variations in climatic data using the climate record at the experimental site during the whole experimental period, it was apparent that the climatic factors had no influence on the model's animal predictions. Hence, the climatic data were disregarded in the model's run.

The model was provided with details of pasture and animal variables found at the days when pasture and animal measurements were conducted. Based on this information the model generated predictions of sheep daily weight gain and greasy fleece daily growth on the days when pasture and animal measurements had been made. Based on these point predictions of sheep daily production, the spline function in Matlab software was used to estimate the sheep's daily production over the whole experimental period. An example of using the Matlab to interpolate sheep daily production is presented in Figure 3.2.3. The animal production changes between the period of two consecutive measurements was determined by summing the daily animal productions between them. These animal production changes were compared with the corresponding observations.

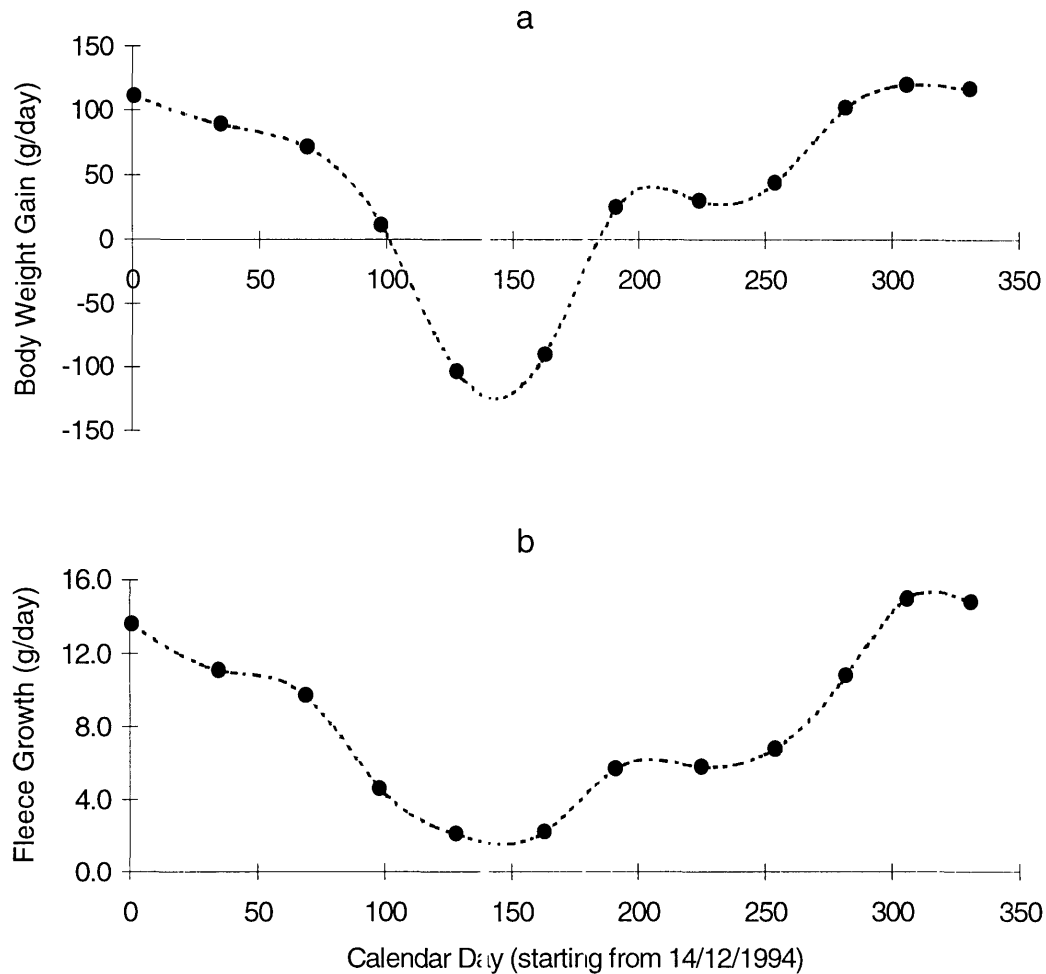


Figure 3.2.3 Function used for interpolating the sheep daily (a) bodyweight change (b) fleece weight change over the experimental time, ● predicted by GrazFeed, - - - fitted by Matlab.

Both graphical and statistical procedures were employed to assess the performance of the model. The observed and predicted sheep performances were plotted over time, along with the corresponding pasture data. This permitted a visual assessment of the model performance under different pasture conditions and helped to highlight any consistent discrepancies. In addition, the field observations were regressed against the model predictions, allowing the degree of variation in the observations accounted for by the model predictions to be assessed. Where bias was present in the predictions, the slope and intercept of the linear regression of the observations against the predictions can be used to quantify the nature and extent of the discrepancy.

3.3 Results

3.3.1 Pasture

The monthly climatic data recorded throughout the experiment is shown in Figure 3.3.1. The seasonal changes in green herbage biomass and digestibility, dead herbage biomass and

digestibility, and legume content on the six experimental plots over the experimental period are shown in c, d and e respectively of Figures 3.3.2, 3.3.3, 3.3.4, 3.3.5, 3.3.6 and 3.3.7.

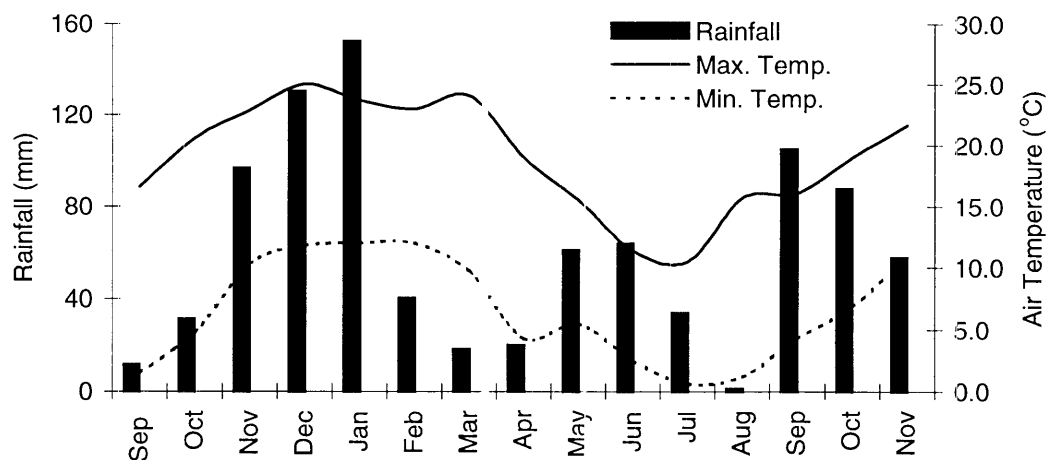


Figure 3.3.1 The total monthly rainfall and maximum and minimum monthly air temperatures for the experimental period (December 1994 to November 1995) at Big Ridge 2.

Substantial variation in pasture biomass was observed, both over time, between stocking rates and between pasture types. Only 11 mm of rain fell in early spring (September) 1994 (Figure 3.3.1), resulting in a late start to the growing season and reduced pasture growth rates, consequently, low green herbage biomass was present in the three pastures, especially for the phalaris dominant and the phalaris/white clover pastures. In contrast, there was good rainfall in spring 1995 leading to an accumulation of green herbage biomass at the end of spring 1995, almost double that recorded in the early summer of 1994 (c of Figures 3.3.2, 3.3.3, 3.3.4, 3.3.5, 3.3.6 and 3.3.7).

Total green herbage biomass for the phalaris and phalaris/white clover pastures was less than the total dead biomass, except in the spring/summer. Total green herbage availability for the degraded pasture was less than the total dead biomass, except in the summer 1994 and spring 1995. In summer 1994 and spring 1995 the biomass of green material in the degraded pasture was much higher than in the other two pastures. In general, the biomass of green herbage at other times was less in the phalaris dominant and the phalaris/white clover pastures than in the degraded pasture.

There are two reasons for the degraded pasture having the higher green herbage biomass in the summer 1994 and spring 1995 compared to the other two pastures. Firstly, the stocking rate in the degraded pasture was much lower than in the other two pastures, such that much less of the feed on offer was consumed. The other reason was that the degraded pasture was dominated by annual or biennial species, which grow predominantly in the late spring and summer.

There was virtually no persistence of white clover at the beginning of the experiment in the phalaris/white clover pasture due to the severe drought in 1994. White clover was surface sown onto the phalaris/white clover pasture on May 23, 1995. Good spring rainfall in 1995 resulted in rapid white clover growth. As a result, 48% and 46% of white clover was present at the end of the experiment in Plots 4 and 5 respectively.

3.3.2 Bodyweight change

The observed patterns of sheep bodyweight change (BWC) (a of Figures 3.3.2, 3.3.3, 3.3.4, 3.3.5, 3.3.6 and 3.3.7) reflect both the seasonal conditions and rates of stocking. BWCs were observed to fluctuate by as much as 8.0 kg (Plots 5 and 6) within a year, with the widest fluctuation over the experimental period occurring at the phalaris dominant and phalaris/white clover pastures. A wide variation in the response to stocking rate was observed in autumn (March and April) 1995. The sheep in the two lower stocked plots lost less than 1.3 kg bodyweight whereas sheep in the higher stocked Plot 5 lost more than 2.6 kg, with the highest loss of 3.7 kg recorded in Plot 5. The model was, therefore, required to predict changes in BWC which varied considerably both in magnitude and in the general pattern of change.

3.3.2.1 The degraded pasture

As can be seen from Figures 3.3.2a and 3.3.3a, the model successfully predicted the BWCs in different seasonal conditions on the degraded pasture. The model predictions always fell within one standard deviation of the observed BWC on the degraded pasture plots. With the exception of the first two BWC observations of BWC on the two plots, the model predictions were very close to the observed BWCs.

The conclusions drawn from the visual assessment are supported by statistical tests. Almost 96 % and 95% of the observed variation in BWC was accounted for by the model at Plots 1 and 2, respectively (Figure 3.3.8). The slope and intercept of the linear regression of the observations against the predictions can be used to test if there was any tendency for the model to over- or under-predict. An accurate model is characterised by a slope of one and an intercept of zero (Dent and Blackie 1979). The tests showed that the slope did not differ significantly from one, nor did the intercept differ from zero on the two degraded pasture plots (Table 3.3.1), suggesting that there were no bias in the model's prediction of the sheep BWC for the degraded pasture.

3.3.2.2 The phalaris dominant pasture

A visual inspection of the model predictions of BWC compared with the field observations generally reveals a good agreement over time for the phalaris dominant pasture (Figures 3.3.4a and 3.3.5a). With the exception of two observations in Plot 3 and one observation in Plot 6, the

model predictions always fell within one standard deviation of the observed BWC. Some of the largest discrepancies occurred at the beginning of the experiment and in the autumn of 1995. The model had a tendency to under-predict the BWC at the beginning of the experiment and the end of autumn 1995 and overpredict BWC in mid autumn 1995 on the two plots. However, there was no consistent bias in the predictions over the experimental period.

When the observed BWCs were regressed against the predictions, the model was found to account for 91% and 93% of the variation in the observations on Plots 3 and 6, respectively (Figure 3.3.8). Tests of the slope and intercept of the regression line were not significant for the two plots (Table 3.3.2), suggesting that there were no major biases in the predictions of the model.

3.3.2.3 The phalaris/white clover pasture

In contrast to the model's good performance with the degraded and phalaris pastures, the model's performance with the phalaris/white clover pasture was not successful. As can be seen from Figures 3.3.6 and 3.3.7, the majority of model predictions were greater than one standard deviation away from the observed BWC on the two phalaris/white clover plots. Some of the largest discrepancies appear to occur in mid summer 1994, mid autumn 1995 and spring 1995. With the exception of two predictions on each of the two phalaris/white clover plots, the model always overpredicted BWC.

The conclusions drawn from the visual assessment are supported by statistical tests. Almost 90% and 87% of the observed variation in BWC were accounted for by the model on the Plots 4 and 5 respectively (Figure 3.3.8). However, the intercept of the regression line for Plot 4 differed significantly from zero, and the slope and intercept of the regression line for Plot 5 differed significantly from one and zero, respectively (Table 3.3.3) suggesting that there were major biases in the model's predictions of BWC on the phalaris/white clover pasture.

3.3.3 Greasy fleece weight change

Both seasonal conditions and pasture types caused substantial variation in sheep greasy fleece weight change (FWC) over the experimental period (see Figures 3.3.2, 3.3.3, 3.3.4, 3.3.5, 3.3.6 and 3.3.7). FWCs were observed to fluctuate by as much as 0.3 kg (Plot 6), with the most rapid fleece growth in spring and summer and the slowest fleece growth in late autumn 1995. The average sheep greasy fleece yield was less for the degraded pasture than on the phalaris/white clover and phalaris dominant pastures.

There are insufficient data to determine the reason why the sheep on the degraded pasture have lower fleece yield, but it may have been due to two effects. Firstly, the legume content in the degraded pasture was significantly lower than in the other two pastures in spring 1995, thus the protein quantity and quality might have limited wool growth of the sheep on degraded pasture.

The other reason was the differences in sulfur content between the soils of the three pasture types. The study of nutrient cycling conducted by Chen *et al.* (1995) on the same experimental site from May 1995 to August 1995 showed that the sulfur content of the phalaris/white clover and phalaris dominant pasture soils was higher than that in the degraded pasture. This lower sulfur content of the degraded pasture soil may result in lower sulfur content of the herbage which may have limited the wool growth on the degraded pasture.

The effect of stocking rate on the sheep FWC was confounded by differences in the pasture types discussed above.

3.3.3.1 The degraded pasture

A visual inspection of the model predictions of FWC compared with the field observations generally reveals a good agreement for both of the degraded plots (Figures 3.3.2b and 3.3.3b). With the exception of two predictions on each of the two plots, the model predictions of FWC always fell within one standard deviation of the observed FWCs. Some of the largest discrepancies occurred in the autumn and winter of 1995. However, there was no consistent bias in the predictions over the experiment time.

The conclusion drawn from the visual assessment is supported by the results of the statistical analysis (Figure 3.3.9). The model accounted for 91% and 87% of the observed variations in FWC on the Plots 1 and 2, respectively. The tests of the slopes and intercepts of the regression lines of Plots 1 and 2 were not significant (Table 3.3.1), suggesting that there were no major biases in the prediction of FWC.

3.3.3.2 The phalaris dominant pasture

As can be seen from Figures 3.3.4b and 3.3.5b, the model provided a poor prediction of FWC over the experimental time for the phalaris dominant pasture. The majority of the model predictions of FWC was greater than one standard deviation from the corresponding observations. Errors in prediction were evident over time. The model had a tendency to seriously under-predict FWC in mid/late autumn 1995 on Plot 3, and in mid/late autumn and early winter 1995 on Plot 6. For the other experimental periods, the model always overpredicted FWC.

When the observed FWCs were regressed against the predictions, the model was found to account for 91% and 96% of the variation in the observations on Plots 3 and 6, respectively (Figure 3.3.9). However, tests of the slope and intercepts of the regression line both for Plots 3 and 6 were significant (Table 3.3.2), indicating that the model was a biased predictor of FWC for the phalaris dominant pasture.

3.3.3.3 The phalaris/white clover pasture

The observed and predicted FWC over the time for the phalaris/white clover pasture are plotted in Figures 3.3.6b and 3.3.7b. As with the model's performance at the phalaris dominant pasture, the model did not predict FWC for the phalaris/white clover pasture as well as for the degraded pasture. The majority of the model predictions of FWC was greater than one standard deviation from the corresponding field data. Some of the largest discrepancies occurred in late autumn and early/mid winter 1995 on Plot 4 and in summer 1994, winter and spring 1995 on Plot 5.

The model was found to account for 90% and 88% of the observed variation on Plots 4 and 5, respectively (Figure 3.3.9). However, there was strong evidence in the tests of the slope and intercept of significant bias in the model's prediction for the two plots (Table 3.3.3).

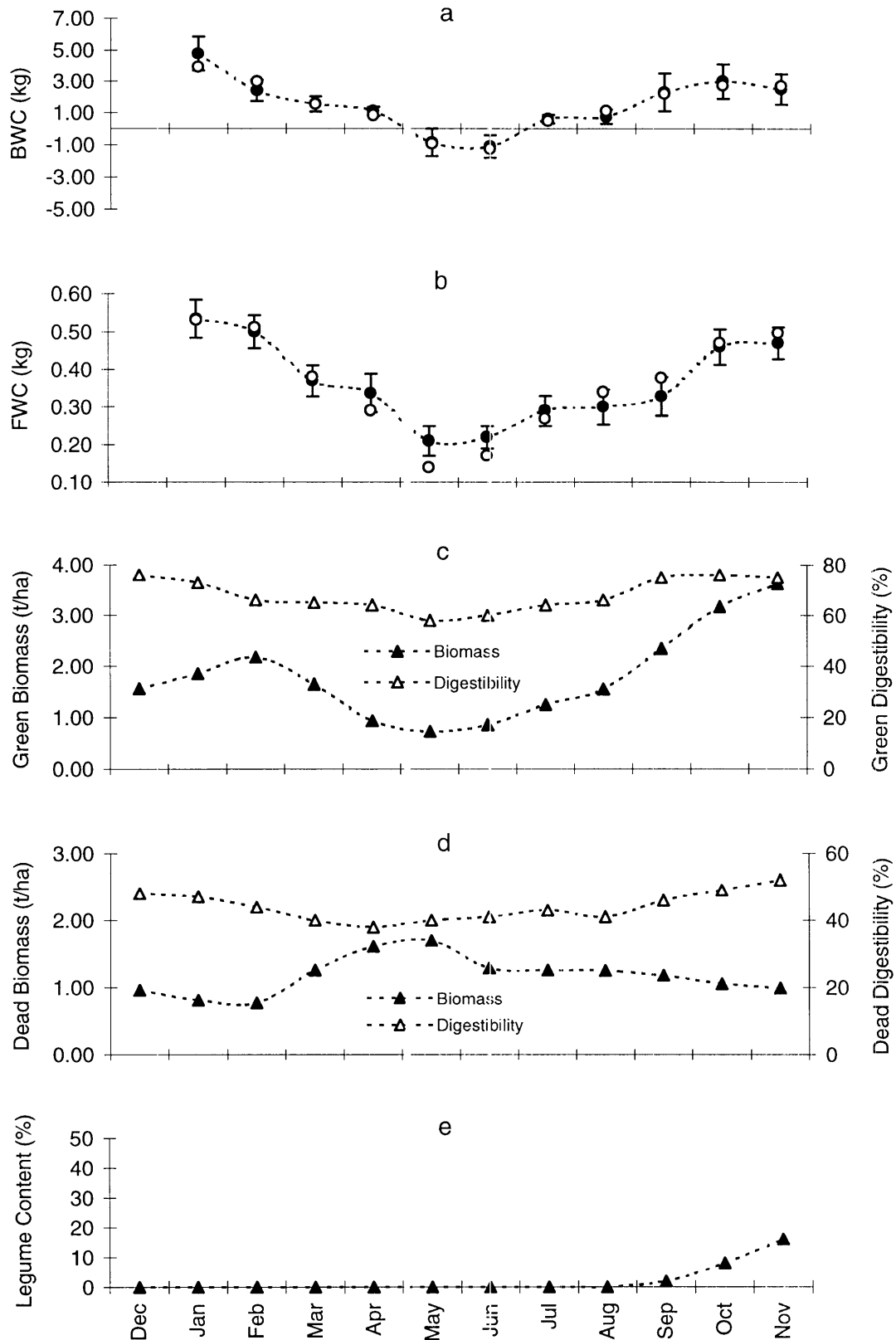


Figure 3.3.2 Seasonal variations in sheep production (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at the degraded pasture (Plot 1). The model's animal predictions (o) are compared with the field data (- - ● - -), with the error bars denoting the standard deviation of the observed treatment means.

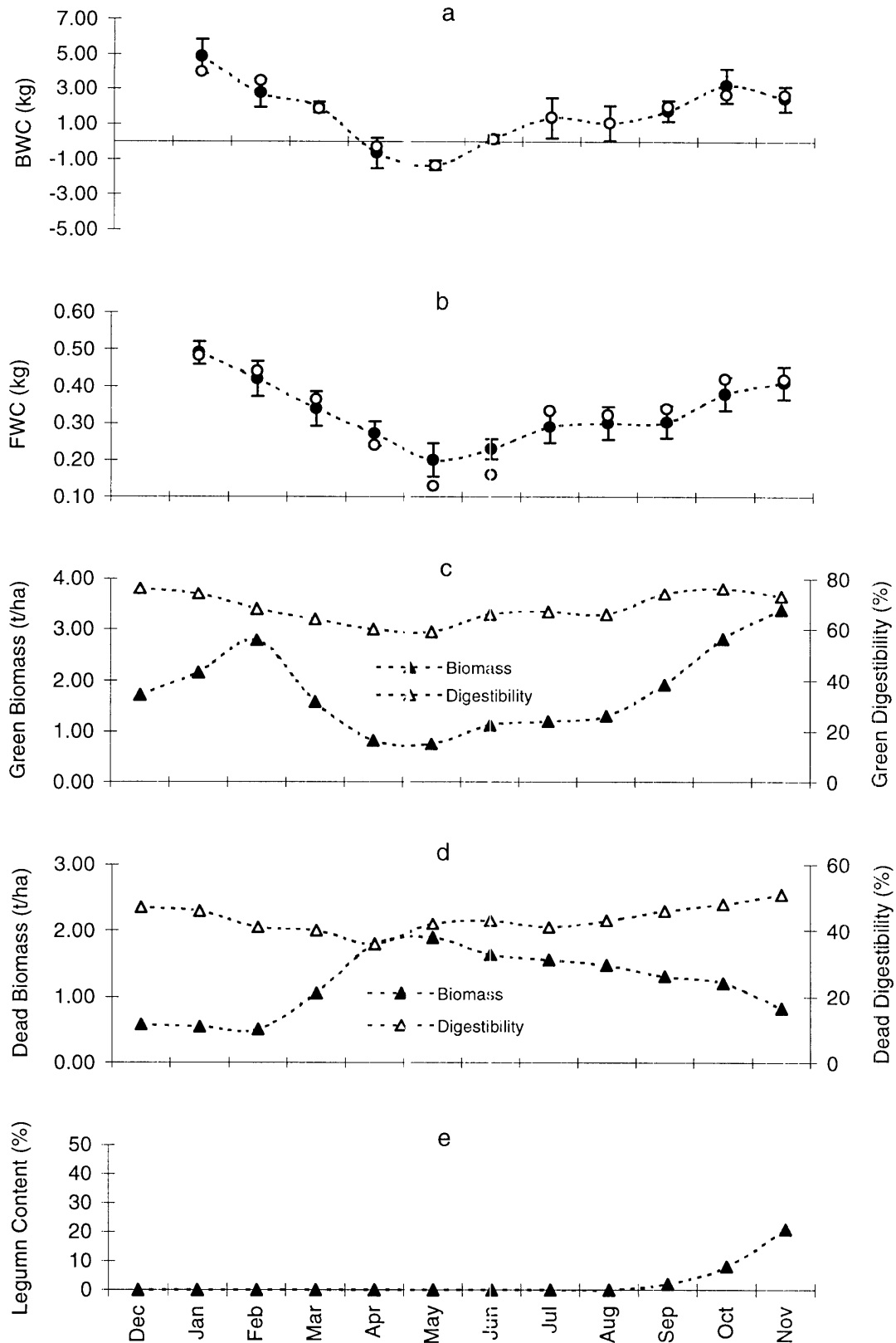


Figure 3.3.3 Seasonal variations in sheep performance (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at the degraded pasture (Plot 2). The model's animal predictions (o) are compared with the field data (- - ● - -), with the error bars denoting the standard deviation of the observed treatment means.

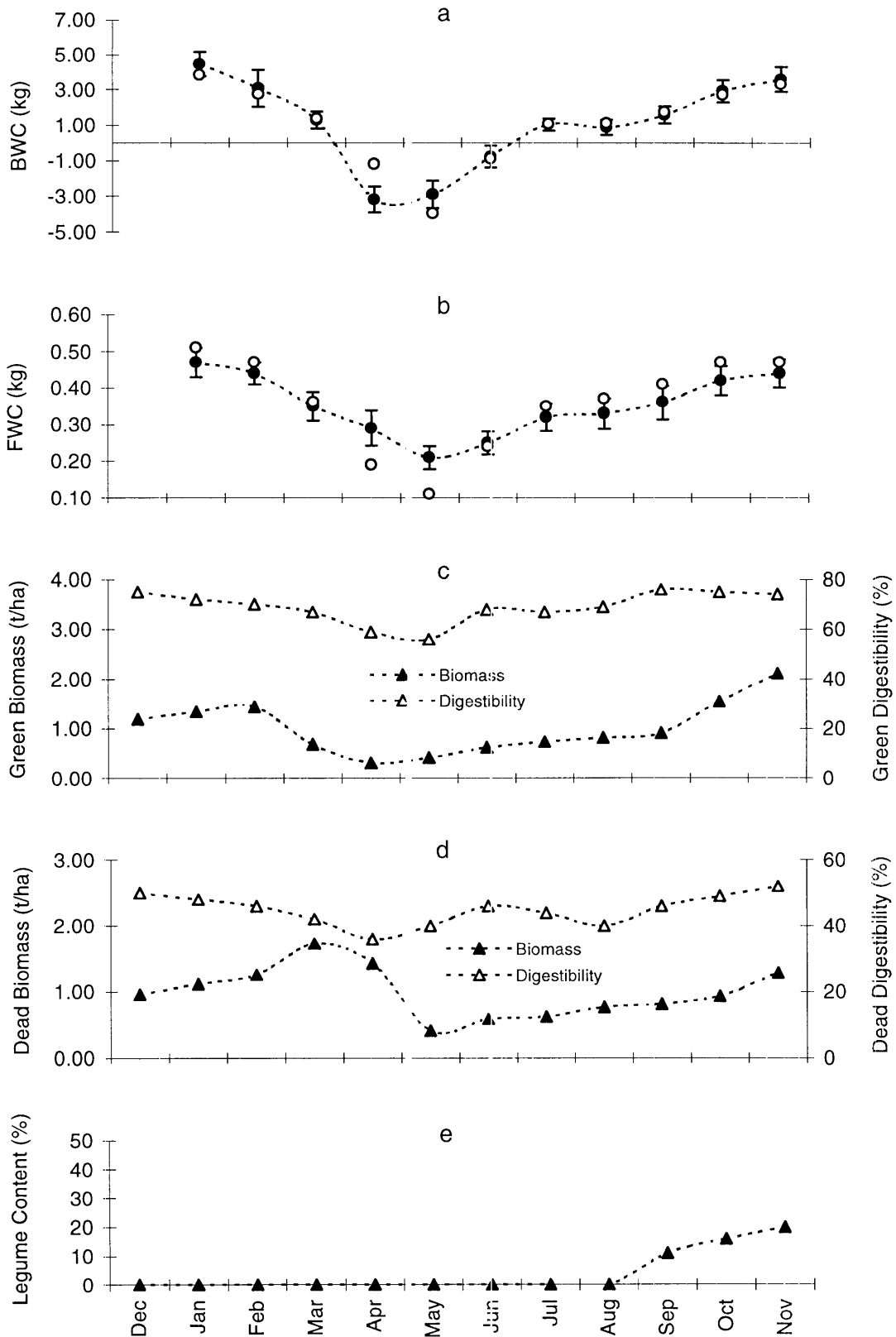


Figure 3.3.4 Seasonal variations in sheep performance (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at the phalaris dominant pasture (Plot 3). The model's animal predictions (○) are compared with the field data (- - ● - -), with the error bars denoting the standard deviation of the observed treatment means.

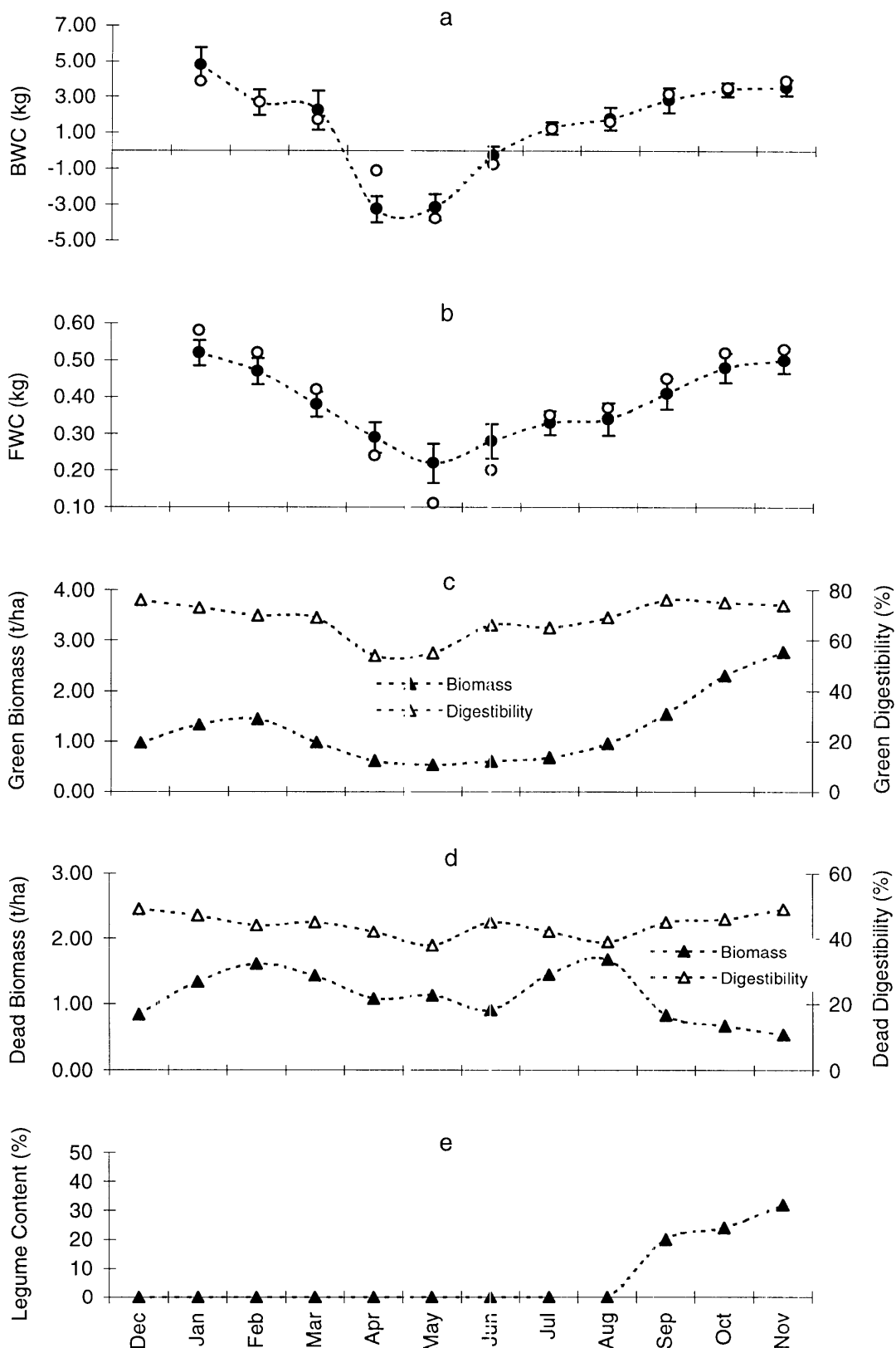


Figure 3.3.5 Seasonal variations in sheep performance (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at the phalaris dominant pasture (Plot 6). The model's animal predictions (o) are compared with the field data (- - ● - -), with the error bars denoting the standard deviation of the observed treatment means.

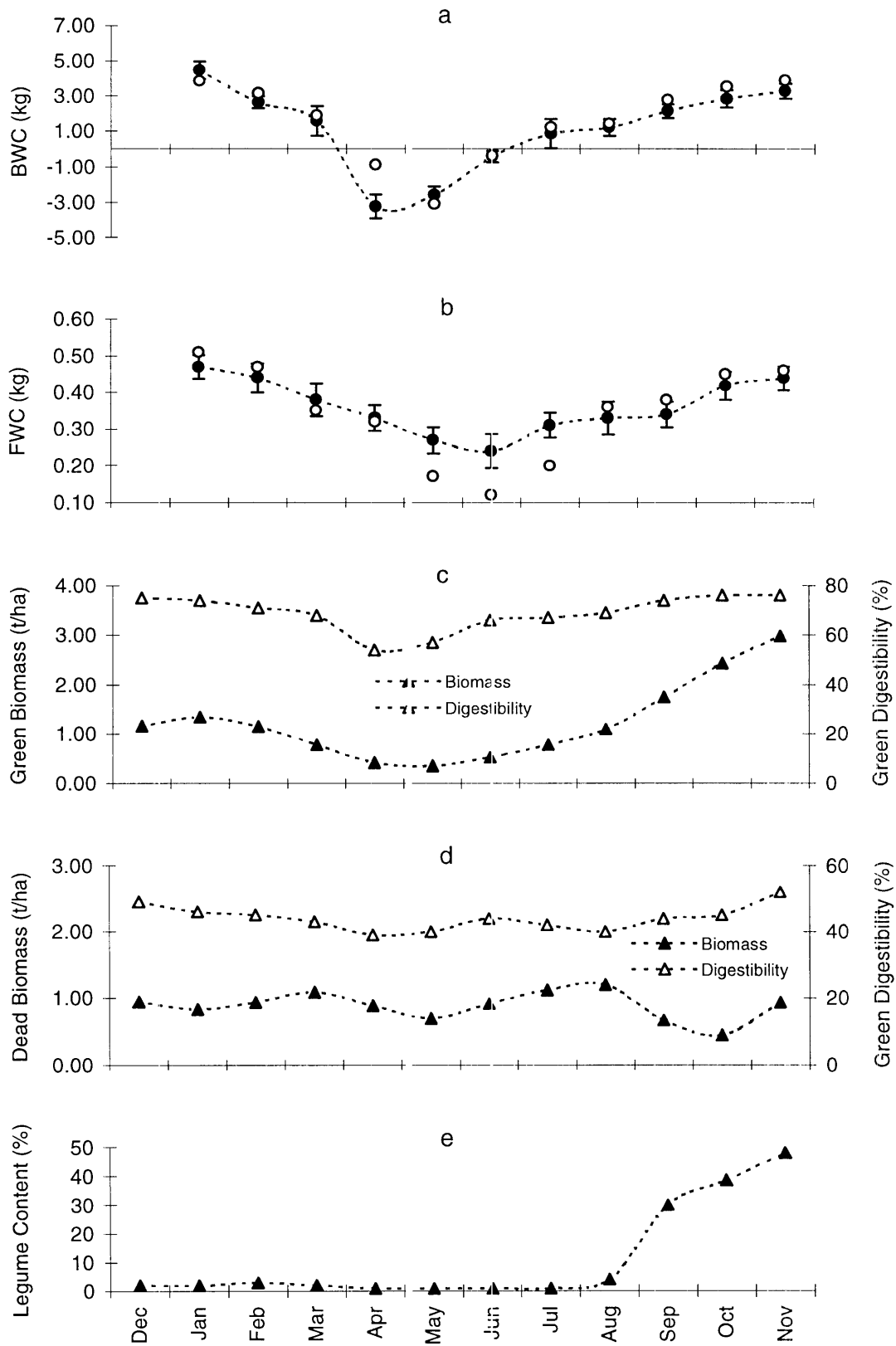


Figure 3.3.6 Seasonal variations in sheep performance (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at the phalaris/white clover pasture (Plot 4). The model's animal predictions (o) are compared with the field data (- - ● - -), with the error bars denoting the standard deviation of the observed treatment means.

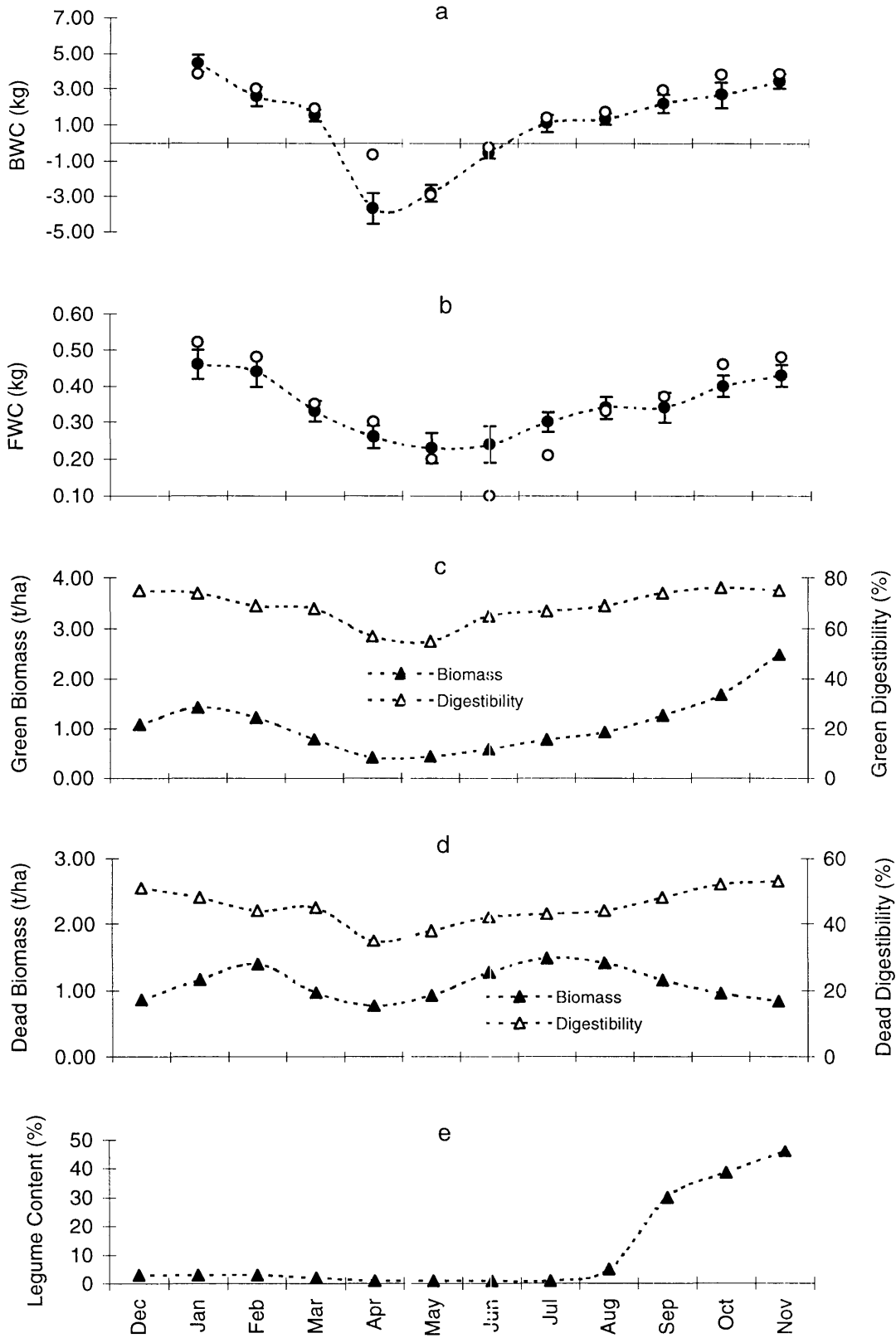


Figure 3.3.7 Seasonal variations in sheep performance (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at the phalaris/white clover pasture (Plot 5). The model's animal predictions (○) are compared with the field data (—●—), with the error bars denoting the standard deviation of the observed treatment means.

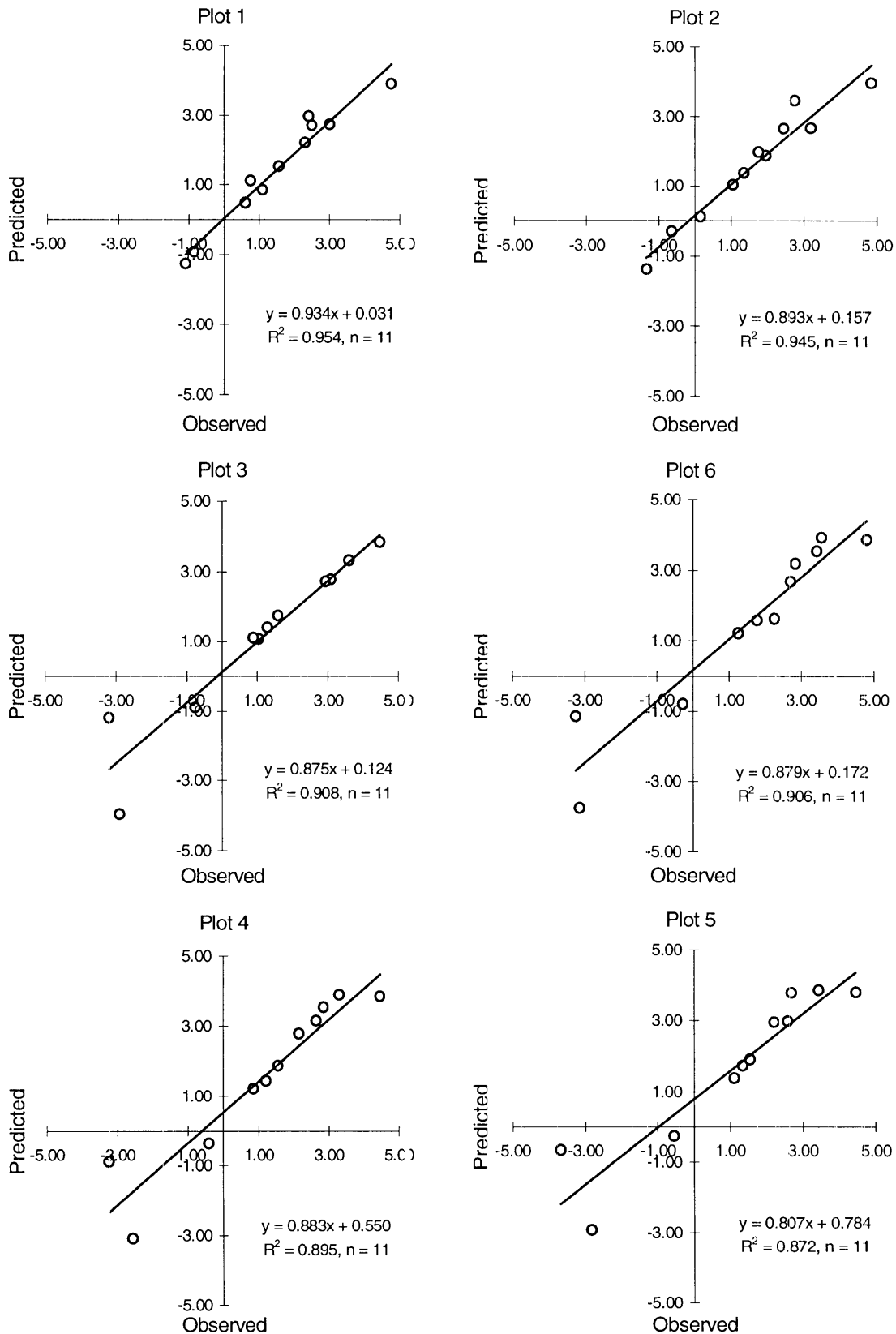


Figure 3.3.8 The agreement between observed and predicted BWC (kg) for the degraded (Plots 1 and 2), Phalaris (Plots 3 and 6) and Phalaris/White Clover pastures (Plots 4 and 5).

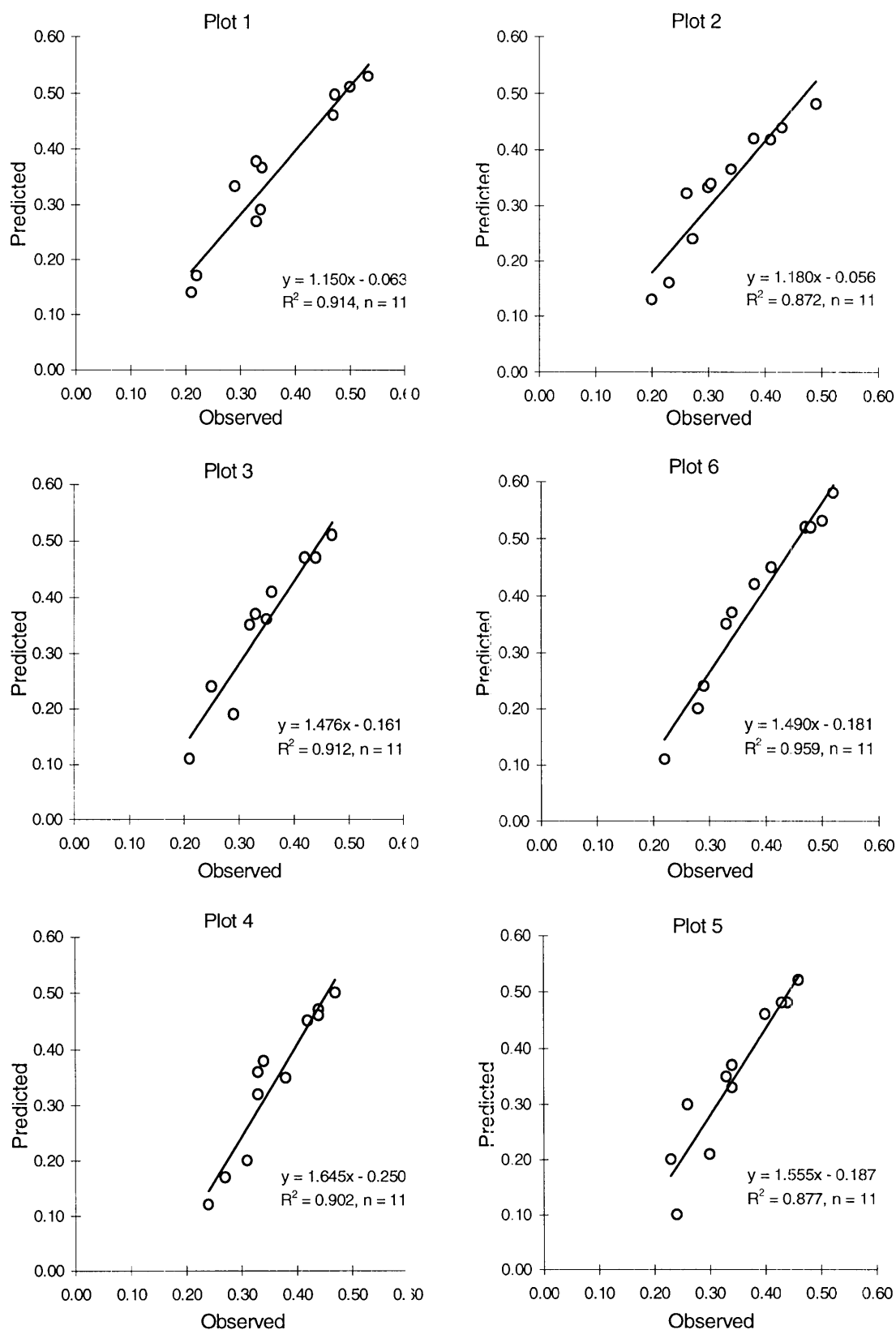


Figure 3.3.9 The agreement between observed and predicted FWC (kg) for the degraded (Plots 1 and 2), Phalaris (Plots 3 and 6) and Phalaris/White Clover pastures (Plots 4 and 5).

Table 3.3.1 An assessment of the accuracy of predictions of BWC and FWC for degraded pastures (Plots 1 and 2).

Statistic ^a	Variable			
	BWC (kg)		FWC (kg)	
	Plot 1	Plot 2	Plot 1	Plot 2
R ²	0.954 ^S	0.945 ^S	0.914 ^S	0.872 ^S
RSD	0.371	0.402	0.042	0.043
Slope ^b	0.934 ^{NS}	0.893 ^{NS}	1.150 ^{NS}	1.180 ^{NS}
Intercept ^d	0.069 ^c	0.072	0.118	0.151
	0.031 ^{NS}	0.157 ^{NS}	-0.063 ^{NS}	-0.056 ^{NS}
	0.154	0.166	0.045	0.051

^a Linear regression of the form Predicted = (Slope × Observed) + Intercept, where R² is the coefficient of determination and RSD is the residual standard deviation.

^b Tested for slope = 1.000.

^c Standard error of the coefficient.

^d Tested for intercept = 0.000.

^S Significant (P < 0.05).

^{NS} Not significant (P > 0.05).

Table 3.2.2 An assessment of the accuracy of predictions of BWC and FWC for Phalaris pastures (Plots 3 and 6).

Statistic ^a	Variable			
	BWC (kg)		FWC (kg)	
	Plot 3	Plot 6	Plot 3	Plot 6
R ²	0.908 ^S	0.906 ^S	0.911 ^S	0.959 ^S
RSD	0.736	0.791	0.041	0.032
Slope ^b	0.875 ^{NS}	0.879 ^{NS}	1.476 ^S	1.490 ^S
Intercept ^d	0.093 ^c	0.095	0.153	0.102
	0.123 ^{NS}	0.172 ^{NS}	-0.162 ^S	-0.182 ^S
	0.244	0.275	0.055	0.040

All the descriptions of the superscripts used in this table are as same as the superscripts used in Table 3.3.1.

Table 3.3.3 An assessment of the accuracy of predictions of BWC and FWC for Phalaris/White Clover pastures (Plots 4 and 5).

Statistic	Variable			
	BWC (kg)		FWC (kg)	
	Plot 4	Plot 5	Plot 4	Plot 5
R^2	0.895 ^S	0.872 ^S	0.902 ^S	0.877 ^S
RSD	0.763	0.824	0.043	0.050
Slope ^b	0.883 ^{NS}	0.807 ^S	1.645 ^S	1.555 ^S
Intercept ^d	0.101 ^c	0.103	0.181	0.194
	0.550 ^S	0.784 ^S	-0.250 ^S	-0.187 ^S
	0.258	0.274	0.066	0.068

All the descriptions of the superscripts used in this table are as same as the superscripts used in Table 3.3.1.

3.4 Discussion

The fluctuating climatic conditions, together with the differences in pasture type and stocking rates employed in the field experiment, caused substantial variation in pasture quantity and quality, as well as animal production. In addition, the stocking rate of each of the six plots often varied within the experimental period. Given the magnitude of the variations and the variety of pathways by which differences emerged between treatments, it was encouraging to see that the model was able to account for the major sources of variation. Although discrepancies between the model predictions and the field observations did occur, at least some of these differences could easily have occurred by chance. With only two experimental sheep per plot on the degraded pasture and four per plot at the other pastures, chance errors could have occurred both with the initial allocation of sheep to the plots and at each sampling time. For most of the BWC data, the model predictions were well within one standard deviation of the field observations.

Discrepancies between the predicted and observed sheep BWCs appeared to occur more frequently during mid (April) and late (May) autumn 1995 on the phalaris dominant pasture and during mid (April) autumn on the phalaris/white clover pasture. On both pastures, discrepancies always appeared immediately after the summer-dormant phalaris re-grew in early autumn (March). The model seriously over-predicted the BWCs in April both at the two pastures and much under-predicted the BWCs in May on the phalaris pasture. There are insufficient data to allow the cause of this discrepancy to be clearly identified, but it may have been due to three possible explanations.

Firstly, there may have been a toxicity problem with the phalaris. The review by Culvenor (1987) indicated that new growth of phalaris is sometimes toxic to grazing animals, consequently, the observed animal bodyweight losses were much higher than those predicted by the model. Secondly, there may have been some errors in the estimation of the *in vitro* digestibility of the pastures in March, April or May. When using near infrared reflectance spectroscopy (NIR) to estimate *in vitro* digestibility the error of prediction has a tendency to increase at the low end of the digestibility scale (F. Pickering, *pers. comm.* 1995). In the region where the experiment was conducted, phalaris usually has the lowest *in vitro* digestibility in early and mid autumn. Therefore, the discrepancy may appear to be associated with an error in the estimation of pasture digestibility for a period in early autumn or mid autumn 1995. The other reason may have been due to the model's poor performance in simulating the pasture with low levels of availability and digestibility. In contrast to the model's poor performance during the period for the phalaris and phalaris/white dominant pastures, the model's performance in the degraded pasture was very good. Thus, the differential performance of the model may be caused by the significant differences in pasture quantity and quality between the degraded pasture and the other two pastures during the period.

The prediction of BWC during early and mid spring 1995 on the phalaris/white clover pasture was another area where discrepancies were evident. Good rainfall in spring 1995 resulted in the percentage of white clover in the pasture increasing from 4% in August to 48% in October. This dramatic change in pasture composition would require an adjustment period in which the rumen microorganisms must adjust for the dietary change from a single grass to a combination of grass and legume. For the experimental sheep, which experienced the severe drought in 1993 and 1994, the adjustment period could have been longer. This may partially explain the model's overpredictions of the BWC during early and mid spring 1995 on the phalaris/white clover pasture. Other reasons relevant to errors in the pasture assessment or deficiencies in the model may also have caused the discrepancies. However, they are difficult to identify clearly.

With the exception of the model's performance in predicting the FWCs on the degraded pasture, the model was unable to accurately predict the FWCs on the other two pastures. However, it is premature to conclude deficiencies in the model itself. For fleece growth, GrazFeed predictions suffer from the limitation that the model can predict only a point estimate in relation to current nutrition. In the real situation, this point estimate is dampened by the lagging of fleece growth in relation to earlier nutrition (M. Freer, *pers. comm.* 1995). In addition, the discrepancies may have been associated with an error in the fleece weight data interpolated by Matlab. For example, during the periods of autumn 1995 on the degraded and phalaris dominant pastures, and early/mid winter 1995 on the phalaris/white clover pasture when the largest discrepancies occurred, the observed greasy fleece growth was more than 0.25 kg/month, approximately equivalent to 8 g/day, on each of the experimental plots. However, in consideration of the poor pasture quantity and quality during this time, the fleece growth of 8

g/day appears to be high. Other causes of discrepancies in predictions of BWC may also have caused the discrepancies in predictions of FWC.