Chapter 4

Comparison of Animal Performance on a Native Pasture Using Experimental Data and GrazFeed

4.1 Introduction

Grazing, dominated by sheep and cattle has been the primary agricultural industry in the Northern Slopes and Tablelands since 1832. Statistics by ABS (1985) shows that the region supports about 12 million sheep, 1.4 million cattle and 42 000 goats. Approximately 70% of the 5.3 million ha of rural land in this region are native or natural pasture (ABS 1985). For animal production, the native pastures of the region have a major limitation of a low availability of green forage in late autumn and winter (Willoughby 1959; Lodge and Roberts 1979; Charles 1988).

Rapid increases in the costs associated with the establishment and maintenance of sown pastures (fuel, fertiliser, herbicide *etc.*) and the lack of persistence of some species in recent droughts have rekindled a growing interest by graziers in the management and increased productivity of native pastures in this region (Lodge and Whalley 1989). Native grasses which have evolved under harsh conditions of periodic drought and inherited low soil fertility could have lower re-establishment and maintenance costs than pastures based on more traditional introduced grass species. In the recent droughts, the adaptability of the native perennial grasses to harsh conditions has proved valuable to graziers (Lodge and Whalley 1989). Thus, native pastures are likely to remain an important resource to supply feed for grazing animals in the region in the foreseeable future.

In comparison to sown pastures, little is known of the management of native pastures for animal production, particularly on the Northern Tablelands (Semple and Waterhouse 1992). Thus, research into the management for sustained and efficient animal production on the native pastures must be undertaken. A decision support system which allows the consideration of more aspects of a decision and more alternative plans has the potential to aid graziers achieving sustainable and efficient animal production. As discussed in Chapter 1, many existing models have not been evaluated sufficiently in real grazing systems. Consequently, the aim of the experiment reported here was to evaluate the GrazFeed model's performance by comparing the model's prediction with the results obtained on a grazed native pasture near Tamworth.

4.2 Materials and Methods

4.2.1 Description of field site and data collection

The data used in this study was collected by Bell *et al.* (*pers. comm.* 1995) from a three-year sheep grazing study conducted on native pastures at Winton as part of the Pasture and Animal Assessment Project. Winton is situated 13.5 km west of Tamworth, Australia at 31°S 151°E, at an altitude of 480 m and s slope of 3°. There were two experimental sites at Winton, Winton 38 and Winton 39. Characteristics of the experimental sites are summarised in Table 4.2.1.

Table 4.2.1 Characteristics of the experimental sites

Characteristics	Winton 38	Winton 39
Area (ha)	3.35	3.35
Land use	Native pasture	Native pasture
Stocking rate (sheep ha^{-1})	Originally stocked at 11.3 reduced to 8.7 on the 14/08/1990	6.3
Soil type	Sandy clay loam	Sandy clay loam

In this experiment, medium 18 month old Merino wethers were set-stocked. Animal liveweight data was recorded approximately every six weeks from September 1989 to September 1991. The dye-banding technique was employed to measure fleece growth weight between measurement dates. The sheep were shorn in August each year and the greasy fleece weight recorded.

Pasture data was collected at the same time as the sheep measurements. The detailed methods used to assess pasture quantity and quality are documented in the *GrazFeed User's Manual* (1994). Pasture data included green and dead biomass, green and dead digestibility and legume content.

Rainfall data was collected on the Winton farm. Temperature data was available from Tamworth Centre for Crop Improvement (TCCI). The relationship between TCCI temperature and Winton was: Winton = 0.728 × TCCI + 4.08 ($R^2 = 0.951$).

4.2.2 Evaluation processes

The methods described in Chapter 3 to calculate the observed and predicted greasy fleece weight changes and sheep bodyweight changes between measurement dates was used in this experiment. The parameters in the animal component of the model which control feed intake, daily weight gain and wool 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 45.0 kg, and her potential greasy fleece weight in a good year was 5.0 kg (Bell, A. *pers. comm.* 1995).

After testing the sensitivity of the model's animal predictions to variation in climatic data using the climate record at Winton from September 1989 to September 1991, it was apparent that the climatic factors had no influence on the model's animal predictions. Hence, the climatic data were not considered in the process of evaluation.

The statistical and graphical procedures detailed in Chapter 3 were used to evaluate the performance of the model employed in this experiment.

4.3 Results

The climatic data recorded throughout the experiment are shown in Figure 4.3.1. The changes in pasture availability and quality at each of the experimental sites over the whole experimental period are presented in c, d and e of Figures 4.3.2 and 4.3.3, respectively. Figure 4.3.2 presents the results for high stocking rate (Winton 38). Figure 4.3.3 presents the results for low stocking rate (Winton 39).

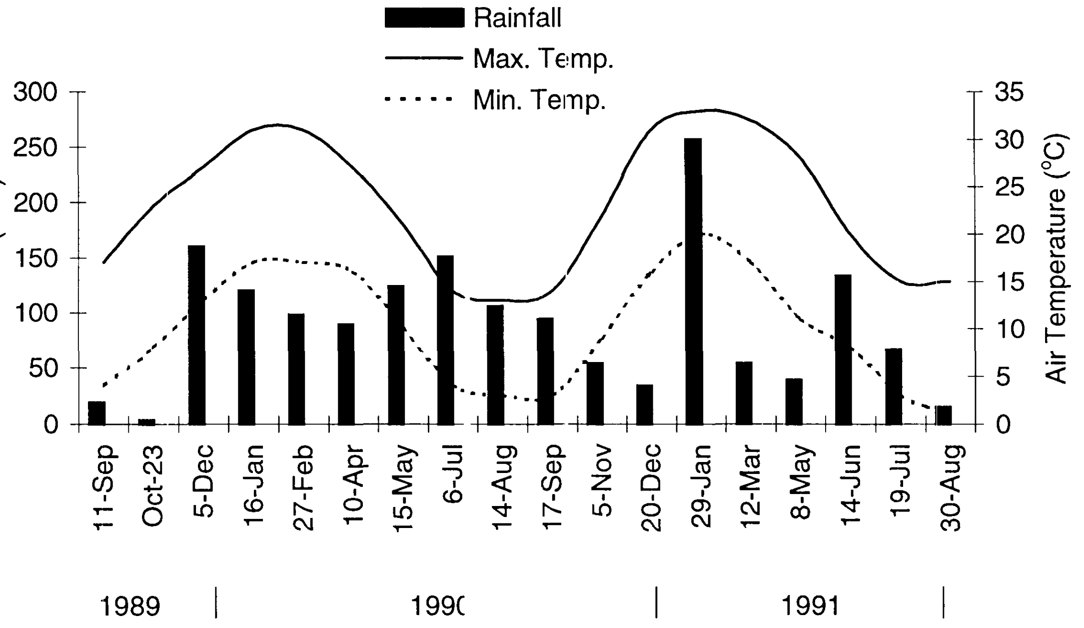

Figure 4.3.1 The total rainfall and average maximum and minimum daily air temperatures between sampling dates at Winton. Total rainfall and average daily temperature for 11/09/1989 was previous six weeks' rainfall and temperature and for the remaining dates the total rainfall and average daily temperature was since the previous date.

Substantial variation in pasture availability and quality was observed, both over time and between stocking rates. The impact of stocking rate on the quantity and quality of pasture available was clearly observed, especially during the drought of 1990. By the end of winter 1990, up to two-fold differences in pasture availability between stocking rates were observed. Due to the deteriorating condition of the pasture (heavy stocking rate and drought), the stocking rate at Winton 38 was reduced from the original 11.3 to 8.7 sheep ha^{-1} on the August 14, 1990.

4.3.1 Bodyweight change

Both the observed and predicted patterns of BWC (Figures 4.3.2a and 4.3.3a) reflect both the seasonal conditions and rates of stocking at the two experimental sites. BWC was observed to fluctuate by as much as 20 kg within a year at the high stocked site. Generally the magnitude of fluctuations at the high stocked site were greater than that of the low stocked site over the entire experimental period. The effect of stocking rate on BWC was clearly evident. The sheep at the high stocked site lost weight for eight experimental periods whereas the low stocked sheep lost weight for only three experimental periods.

A visual inspection of the model predictions compared with the field observations reveals a generally poor agreement at both sites. However, the model did provide some good predictions both at the high stocked and low stocked site, for example, in the springs of 1989 and 1990 and summer 1991 at the high stocked site; in spring 1989 and winters 1990 and 1991 at low stocked site. The largest discrepancies at both sites appear to be from mid-summer 1989 to late autumn 1990 and autumn 1991. With the exception of four predictions slightly higher than the corresponding observations (three at the high stocked site and one at the low stocked site), the model always under-predicted the BWC at two experimental sites.

Pasture availability significantly influenced the model's performance in predicting BWC. Most observations of green and dead herbage biomass at the low stocked site were much higher than those at the high stocked site, however, errors in prediction at the low stocked site were much smaller than those at the high stocked site For example, during summer 1989 and autumn 1991 green and dead herbage biomass at the low stocked site was near twice than those at the high stocked site, but, the differences between observed and predicted BWC at the low stocked site was near half than those at high stocked site. Within the experimental site, the seasonal pasture conditions greatly influenced the model's performance in predicting BWC. With the exception of one period from late spring to early summer 1990 at both experimental sites, errors in prediction tended to increase with a decrease in pasture availability and quality.

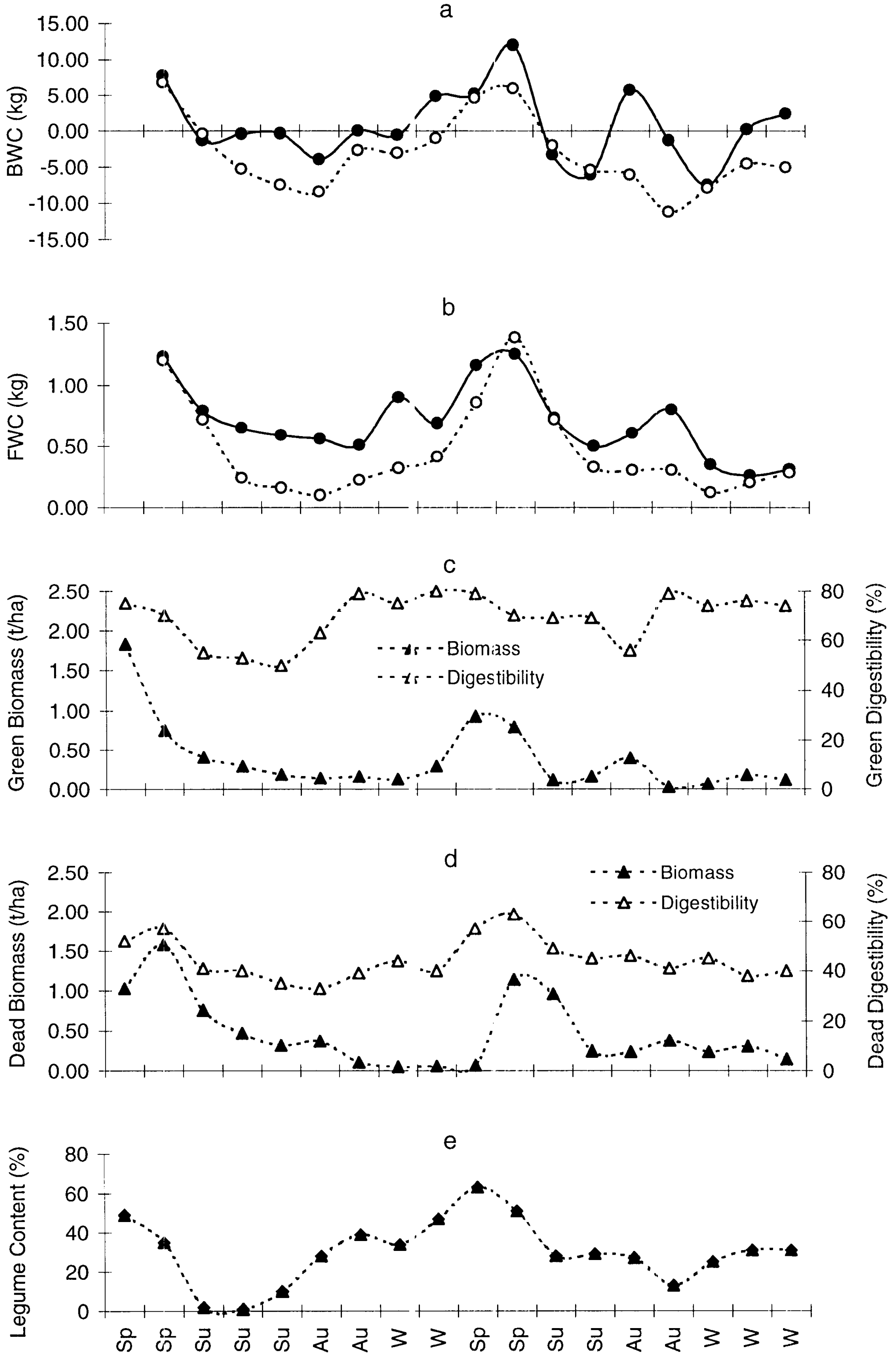

Figure 4.3.2 Seasonal variations in sheep production (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at Winton 38. The model's animal predictions (o) are compared with the field data (- - ● -). Sp = Spring, Sept.-Nov.; Su = Summer, Dec.-Feb.; Au = Autumn, Mar.-May; W = Winter, Jun.-Aug.

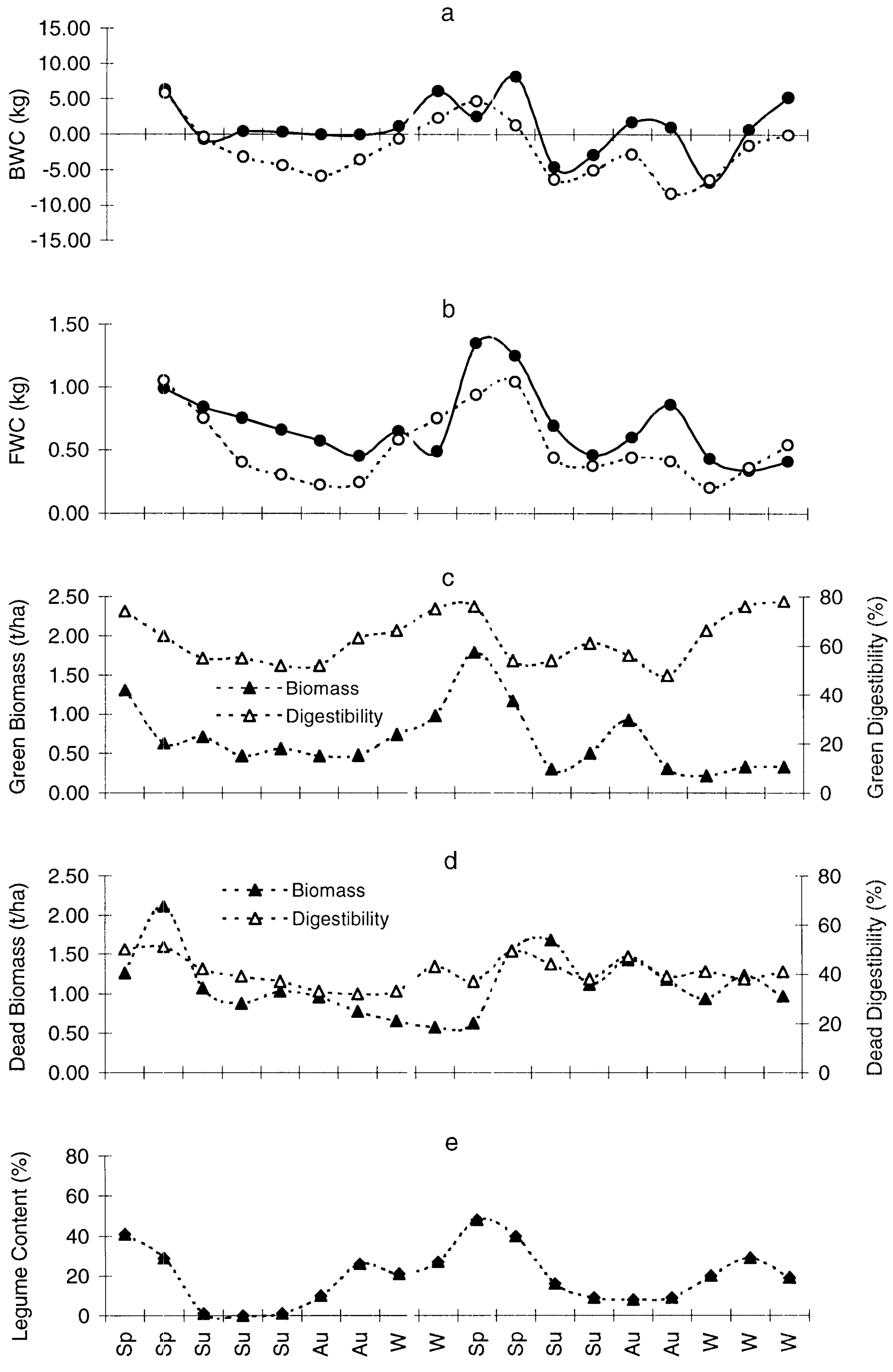

Figure 4.3.3 Seasonal variations in sheep production (a and b), pasture availability and *in vitro* digestibility (c and d), and legume content (e) at Winton 39. The model's animal predictions (o) are compared with the field data (- - ● -). Sp = Spring, Sept.-Nov.; Su = Summer, Dec.-Feb.; Au = Autumn, Mar.-May; W = Winter, Jun.-Aug.

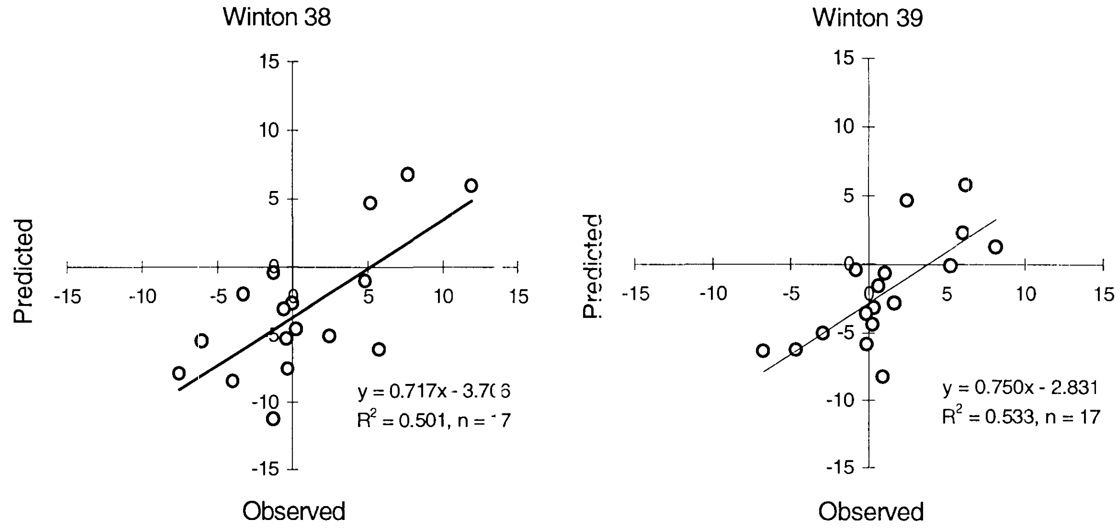

Figure 4.3.4 Agreement between observed BWC (kg) and BWC (kg) predicted by GrazFeed at Winton 38 and Winton 39.

Table 4.3.1 An assessment of the accuracy of predictions of BWC and FWC at Winton pastures

Statistic [a]	*Variable*			
	BWC (kg)		*FWC (kg)*	
	Winton 38	*Winton 39*	*Winton 38*	*Winton 39*
R^2	0.501^{S}	0.533^{S}	0.718^{S}	0.569^{S}
RSD	3.715	2.804	0.211	0.189
Slope^{b}	0.717^{S}	0.750^{S}	1.097^{NS}	0.726^{S}
	0.185^{c}	0.181^{c}	0.178^{c}	0.163^{c}
Intercept^{d}	-3.706^{S}	-2.831^{S}	-0.301^{S}	0.027^{NS}
	0.913^{c}	0.706^{c}	0.134^{c}	0.122^{c}

[a] Linear regression of the form Predicted = (Slope × Observed) + Intercept, where R^2 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 ($P > 0.05$).

The conclusions drawn from the visual assessment are supported by the results of the statistical analysis. When the observed BWCs were regressed against the predictions, the model was found to account for only 50% and 53% of the observed variations at Winton 38 and Winton 39, respectively (Figures 4.3.4). The tests showed that the slopes of the regression lines at

Winton 38 and Winton 39 were significantly different from one and that the intercepts were different from zero (Table 4.3.1). This supports the results of the visual assessment and suggests that major biases in the predictions of the model were evident.

4.3.2 Greasy fleece weight change

Seasonal pasture availability and quality caused substantial variation both in observed and predicted fleece weight change (FWC) at the two experimental sites (Figures 4.3.2b and 4.3.3b). At both sites the wide variation in FWC recorded over the experimental period corresponded well to the patterns of BWC that were recorded.

The effect of stocking rate on the patterns of observed FWC is confusing. For the period from mid-autumn 1990 to late winter 1990, it is surprising to find that the observed fleece growth rate of sheep at the high stocking rate was more than 25% higher than that of sheep at low stocking rate when the availability of green biomass at Winton 38 was much lower than that at Winton 39. Further investigation showed that this may be explained by the observed higher green digestibility and higher legume content at Winton 38 during that period. Unlike the observed patterns of FWC, the predicted patterns of FWC reflect the effect of stocking rate during the drought 1990.

There was no evidence that the model's performance of predicting BWC was significantly influenced by the difference in pasture availability between the two experimental sites. However, seasonal variation in pasture availability and quality within the same experimental site had a great influence on the magnitude of errors in prediction of FWC. With the exception of one period from late spring to early summer 1990 at both experimental sites, errors in prediction tended to increase with the decrease in pasture availability and quality.

The model always under-predicted FWC, with the exception of three predictions (two occurred in springs 1989 and 1990 at Winton 38, one occurred in spring 1989 at Winton 39). Some of the largest discrepancies between observed and predicted FWC appear to be from mid-summer 1989 to late autumn 1990 and autumn 1991.

The conclusions drawn from the visual assessment are supported by statistical tests. Almost 72% of the observed variation in FWC was accounted for by the model at Winton 38 (Figure 4.3.5). Tests of the slope and intercept of the regression line were significant, suggesting that there were major biases in the prediction of FWC at Winton 38. The model was found to account for 57% of the observed variation at Winton 39. There was again a strong evidence in the tests of the slope of a significant bias in the model's prediction (Table 4.3.1). This supports the results of the visual assessment and suggests that major biases in the predictions of the model were evident at Winton 39.

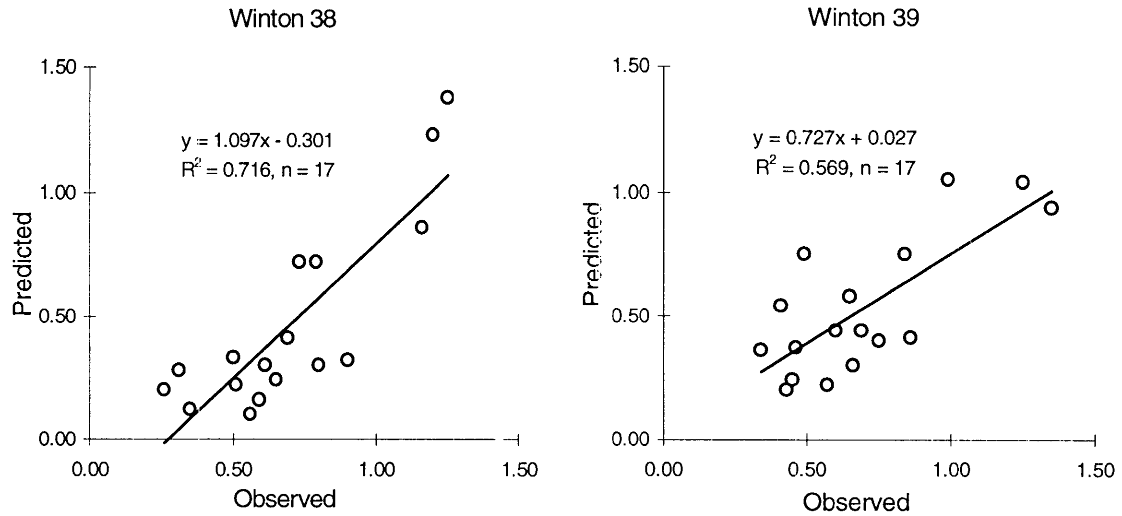

Figure 4.3.5 Agreement between observed FWC (kg) and FWC (kg) predicted by GrazFeed at Winton 38 and Winton 39.

4.4 Discussion

The fluctuating climatic conditions, together with different stocking rates employed in the field experiment, induced substantial variation in pasture production and animal performance. Overall, it was apparent that the model was unable to adequately predict animal performance. With the exception of a few predictions, the model always under-predicted animal performance both in BWC and FWC.

It was found that the accuracy of model prediction of BWC was strongly associated with pasture condition, especially biomass and digestibility of green herbage. When the green herbage biomass was above 800 kg ha^{-1} and its digestibility was above 70%, the model had a tendency to provide adequate prediction of animal BWCs at both experimental sites. Examples of these good predictions are detailed in section 4.3.1. However, when green herbage biomass was below 800 kg ha^{-1} and its digestibility was below 70%, the discrepancies between field observations and model predictions were found to occur more frequently. In addition, the effect of the pasture condition on the model's performance is more clearly evident between experimental sites. The biomass of green herbage at Winton 39 was significantly higher than that at Winton 38 over the experimental time, however, the magnitudes of errors in prediction at Winton 39 were significantly smaller than those at Winton 38.

For FWC, the GrazFeed model generally showed biased prediction. Like the BWC, the model's predictive ability of FWC was greatly influenced by the pasture condition, particularly the biomass and digestibility of green herbage. The model provided some good predictions when the biomass of green herbage and its digestibility were above 800 kg ha^{-1} and 70%, respectively (see 4.3.2). However, when the green herbage biomass and its digestibility were below 800 kg ha^{-1} and 70%, respectively, a large discrepancy between observed and predicted FWC tended to occur more frequently. Although the differences in magnitude of errors in prediction due to differences in green herbage biomass between experimental sites were evident, the effect of green herbage biomass on the accuracy of model prediction between experimental sites were relatively small.

There are insufficient data to allow the cause of the large discrepancies between observed and predicted in BWC and FWC to be clearly identified. However, two reasons are suggested as most likely: deficiencies in the model and errors in the estimation of the biomass and *in vitro* digestibility of the pasture.

Whether there are some deficiencies in the intake module or the animal nutrition module of GrazFeed is also difficult to identify. The most probable deficiencies seem to occur in the intake module. Both between and within experimental sites, the model appeared to be a good predictor under conditions of high green herbage biomass but a poor predictor under conditions of low green herbage biomass. The most likely explanation of this inconsistency is that the model could not accurately predict animal intake when the biomass of green herbage was low.

Some of the discrepancies between observed and predicted animal performance may be also partially related to the difficulty in obtaining reliable biomass values under poor pasture conditions. For example, during autumn 1991, there was a flush of green growth which increased the weight gain of the sheep, but not the predicted gains. At Winton 38, the flush took herbage up to only 500 kg ha^{-1} and digestibility actually dropped to 55%. It was surprising to find that there was a substantial weight gain, and this weight gain was greater than at Winton 39 where the herbage went up to approximate 1000 kg ha^{-1}.

In addition, GrazFeed predictions for FWC 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 damped by the lagging of wool growth in relation to nutrition.

Chapter 5

Comparison of Animal Performance on Xinjiang's Pastures Using Experimental Data and GrazFeed

5.1 Introduction

Grazing livestock populations in the Xinjiang Uygur Autonomous Region of north-west China have risen steeply in recent years from 20 million sheep equivalents of total livestock in 1949 to 55 million in 1990 (Longworth and Williamson 1993). The forage resources needed to sustain this increase have come from increased utilisation of natural pastures, increased production of dryland and irrigated forages, and increased availability of grain, residues and byproducts from expanded irrigated crop production.

Although the expansion of irrigated lands has resulted in some settled livestock production, the majority of grazing livestock, and particularly sheep, are still managed using a traditional annual migration between natural seasonal pastures.

Increased livestock numbers, exacerbated by the conversion of some of the traditional pastures to crop production, have put considerable pressure on these pastures. Many pastures have been seriously overgrazed and degraded. Some observers believe that since mid 1970's pasture productivity may have declined by as much as 50% (Longworth and Williamson 1993). Thus, it appears that scope for increasing animal numbers in the region will be restricted until some widespread pasture improvement has been undertaken. Returns from pasture improvement are expected to be low in this region because of the poor quality of the land. Consequently, policies aimed at increasing animal numbers through increasing pasture area and pasture productivity in the region are not likely to be successful for some years. Hence, developing and implementing efficient and sustainable animal production must be viewed as more important considerations which the Regional Government has prioritised in its animal production policies.

Efficient and sustainable animal production requires that a range of strategies be investigated. With the rapid expansion of computer modelling and some successful applications of computer models to real grazing systems, Chinese authorities have become aware that there is a huge potential for computer models to benefit the grazing industry with regard to assisting the investigation of the best strategies. For instance, computer models can assist the choice of the best supplementary feeding strategies to increase sheep production on autumn and winter pastures. Unfortunately, none of the existing models performance has been documented in such a grazing production system as in Xinjiang.

This chapter presents a quantitative evaluation of the GrazFeed model performance in a typical grazing production system such as that at Nanshan Stud Farm, in central Xinjiang Urgur Autonomous Region. The experimental data used in this study was derived from a nutrition research program conducted at Nanshan Stud Farm during 1992-1994.

5.2 Materials and Methods

5.2.1 Characteristics of the production system

5.2.1.1 Environment and management

Nanshan Stud Farm exhibits a typical conditions of pastoral production in the region, and has a long history as a State Farm for sheep breeding and research. The Farm is located in the foothills of the Tianshan Mountains approximately 75 km south-west of Urumqi at 43°31'N 87°00'E. It covers a total of approximately 12,800 ha at altitudes ranging from 1,200 to 3,400m. Annual precipitation varies from 300 to 600 mm, made up mainly of summer rainfall but including a component of winter snow. Mean monthly maximum and minimum temperatures are about 25°C in summer and -15°C in winter, and maximum temperatures remain below zero from about mid December until mid March. Pastures are green from May to October and dry for the remainder of the year, but they are usually covered with snow for three and a half months during winter.

Sheep production from finewool breed ewes is the main farm enterprise. Sheep are moved between seasonal grazing areas in flocks of 300-350 ewes tended by herdsmen. The animals are grazed on unimproved and unfenced pasture during the day, and held in yards at night. In winter, ewes are fed supplements. Mating takes place during late October and November by artificial insemination for a March-April lambing. Shearing is in late June.

5.2.1.2 Forage resources

Forage resources are dominated by extensive native pastures that occupy 12,600 ha or 98% of the total area. A characteristic of the farm, and typical of the region, is the differentiation of separate seasonal pastures which are defined by differences in patterns of production. Access between seasonal pastures each year is affected by prevailing weather conditions and between-year variation in forage growth, but the general pattern and pasture characteristic are as follows.

a) Summer grazing lands

The summer pastures are located at the higher altitudes (1,900 to 3,400m) and consist of montane meadows, cold moorland meadows, sub-alpine meadows and cold alpine meadows. The vegetation is dominated by *Kobresia* sp., *Carex* sp., *Polygonium* sp., *Stipa* sp., *Festuca* sp., and *Poa* sp. Cooler temperatures associated with the high altitude restrict the growing season to a period from late May to late August. Thus, annual animal access to these lands is restricted to a period of approximately 75 days from the end of June to mid September.

b) Winter grazing lands

The winter grazing lands are located at the middle altitude range (1,600 to 2,500m) and consist of montane grassland and montane meadow vegetation classes. The vegetation in these areas is dominated by *Stipa* sp., *Festuca* sp., *Carex* sp., and *Artemisia* sp., and the growing season is from late April to early September. Because these lands have no permanent stock water, they can only be grazed from the beginning of snow fall (late October) to the end of spring (early May). The present annual grazing period is approximately 150 days from late November to early May.

c) Spring/autumn grazing land

The spring/autumn grazing land is located at the lower altitudes (1,200 to 1,900m) and consists of montane grassland also dominated by *Stipa* sp., *Festuca* sp., *Carex* sp. and *Artemisia* sp. with a growing season from late April to early October. This area has permanent water and unrestricted access, and can be used when the other seasonal pastures are not grazed. Generally it is grazed for a total period of approximately 135 days, extending from early May to the end of June in spring and from mid September to late November in autumn.

Winter forage is supplemented with hay and silage grown within the farm and maize grain purchased from outside. Hay is made from native grasses, lucernes (*Medicago sativa and falcata*) and sainfoin (*Onobrychius viciafolia*), and silage is made from maize (*Zea mays*). The intensively produced hay and silage utilises the limited areas of better soils on the lower slopes and flats irrigated from a river on the spring/autumn land.

5.2.2 The nutrition research program

The nutrition research program included three experiments which were conducted on the different grazing lands. A brief description of the experimental measurements are as follows.

Experiment 1: sheep performance on summer pasture

This experiment was conducted on summer pasture during the summers of 1992, 1993 and 1994. Sixty Xinjiang finewool ewes (30 month old) were selected for monitoring at the beginning of experiment. These animals were also used for Experiments 2 and 3 described below.

Pasture was measured for available dry matter by visual scoring and quality by cutting quadrats with *in vitro* digestibility determined (by acid digestion) on cut samples. Pasture measurements were made three times at the beginning, at the mid-point and at the end of grazing.

Animal measurements were made on the same days as pasture measurements. The measurements included liveweights and greasy fleece growth (using the dyebanding technique) between the measurement periods.

Experiment 2: the effect of supplementation on sheep productivity on autumn pasture

This experiment was conducted on autumn pasture during the autumns of 1992, 1993 and 1994. The ewes monitored on summer pasture (Experiment 1) were used in this experiment, and randomly subdivided into 4 groups of 15 ewes. At the beginning of the experiment and every day thereafter, each of these groups was given one of 4 levels of sunflower meal. The feed offered was equivalent to 0, 40, 80 and 120 g sheep^{-1}day^{-1}.

All pasture and wool measurements were as detailed in Experiment 1. Samples of the supplement were taken and analysed for dry matter content, *in vitro* digestibility and crude protein content. Pasture measurements were made two times at the beginning and at the end of the grazing period.

Animal measurements were made on the same days as pasture measurements and carried out as detailed in Experiment 1.

Experiment 3: sheep productivity on winter pasture

This experiment was conducted on winter pasture during the winters of 1992/1993, 1993/1994 and 1994/1995. The sheep utilised in Experiments 1 and 2 were also employed in this experiment. Following the autumn feeding period, the sheep were randomly chosen to make two new treatment groups with 30 sheep in each group. One treatment group was normally managed (partial grazing and supplementation). The other treatment group was fully housed from when supplementation commenced. All experimental sheep were offered the same amount of supplement over the whole time. The supplementation for the sheep was: 300 g $\text{sheep}^{-1}\text{day}^{-1}$ maize grain, 300 g sheep^{-1} day^{-1} pasture hay and 1000 g sheep^{-1} day^{-1} of silage.

Pasture measurements were as detailed in Experiments 1 and 2. Pasture measurements were taken 4 times, at the beginning of the experiment and end, and at equal intervals between. Samples of each of the supplements were taken and analysed separately (maize grain, pasture hay and silage) as in Experiment 2.

All sheep measurements were as detailed for Experiments 1 and 2 and taken on the same days as the pasture measurements.

5.2.3 Evaluation processes

An evaluation of model performance was made on the three separate experiments described on section 5.2.2. The methods utilised to calculate greasy fleece weights between measurement periods in Chapters 3 and 4 were also used in these experiments. Since no distinction was made between green and dead in the available herbage, the following assumptions were made: (i) herbage on the summer pasture was green; (ii) herbage on the autumn pasture at the beginning of the feeding experiment was green, and at the end was dead; and (iii) herbage on the winter pasture was dead (Liu and Ren *pers. comm.* 1995). The weight of a mature ewe in average condition was 45.0 kg, and her potential greasy fleece yield in a good year was 5.0 kg (Liu, *pers. comm.* 1995).

Both of the statistical and graphic of procedures detailed in the Chapters 3 and 4 were employed to assess the performance of the model.

5.3 Results

5.3.1 Pasture availability and quality

The monthly climatic data recorded throughout the experiment are shown in Figure 5.3.1. Pasture availability and *in vitro* digestibility on each of the seasonal grazing lands over the experimental period are presented in Figure 5.3 2. The nutrient contents of supplements used in the experiments are summarised in Table 5.3.1. No substantial variations in pasture production and quality existed between years on same seasonal grazing land. This is consistent with there being no substantial climatic variation recorded between the experimental years on the same seasonal grazing land.

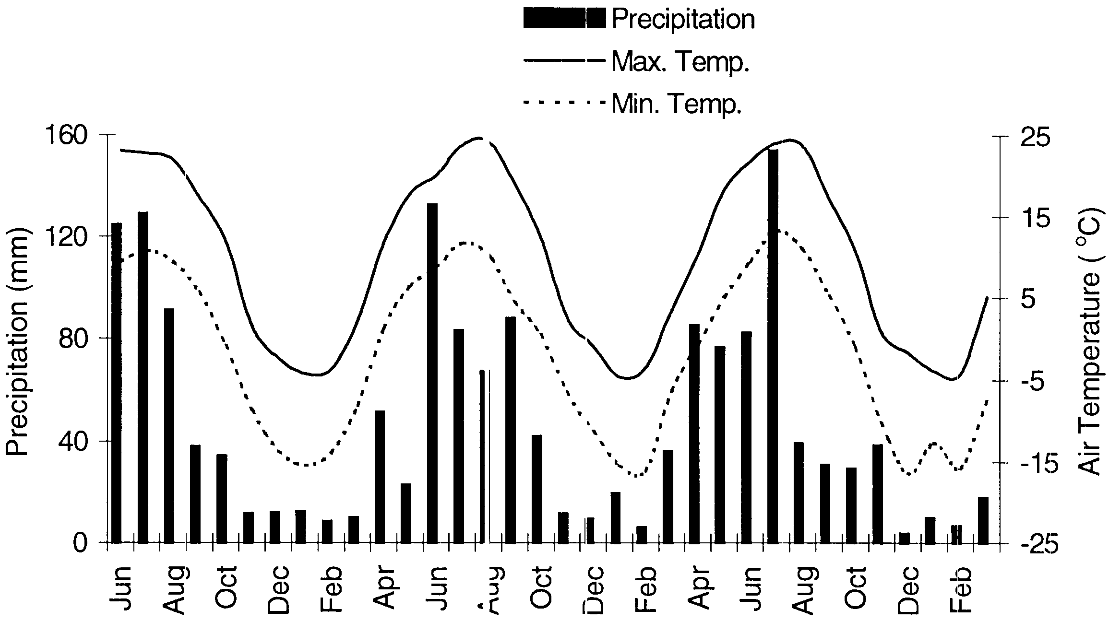

Figure 5.3.1 The total monthly rainfall and maximum and minimum monthly air temperatures for the experimental period (June 1992 to March 1995) at Nanshan.

Table 5.3.1 The nutrient content of supplements used in the experiments

Supplements	%DM	*In vitro* digestibility (%)	% CP
Hay	85	60	11
Maize grain	87	91	10
Maize silage	23	60	6
Sunflower meal	90	73	27

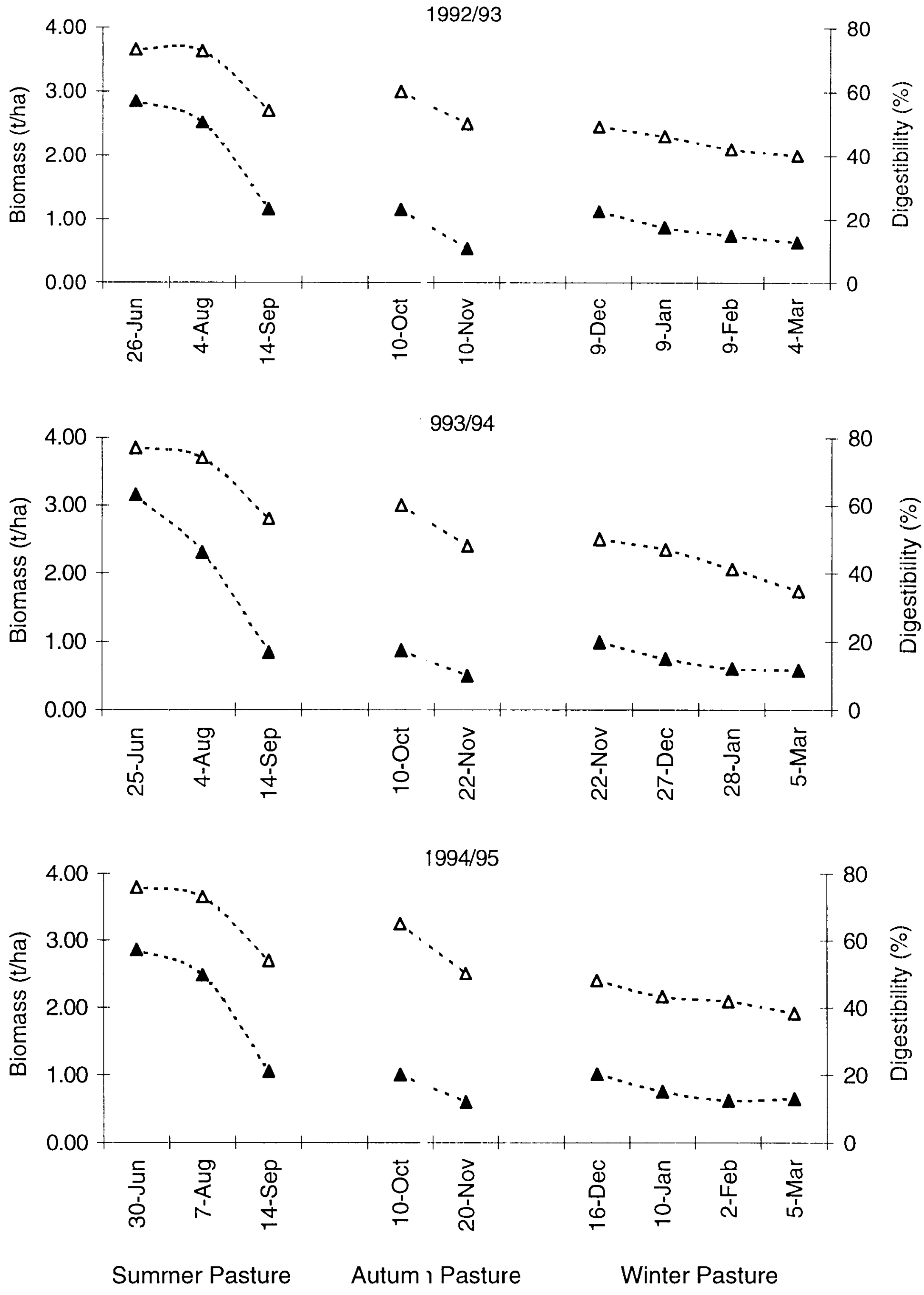

Figure 5.3.2 Pasture biomass (- - ▲ - -), and *in vitro* digestibility (- - △ - -) measured over different seasons within the three year experimental period.

5.3.2 Evaluation the model's performance on the summer pasture

5.3.2.1 Bodyweight change

The observed patterns of BWC (Figure 5.3.3a) reflects the changes in pasture availability and quality. Shorn bodyweights were observed to fluctuate from late June to early August, and then rapidly decline before entering the autumn pasture in all experimental years.

A visual inspection of the model predictions of BWC compared with the field observations reveals a poor agreement over the experimental periods. All the model predictions were greater than one standard deviation from the observed BWCs.

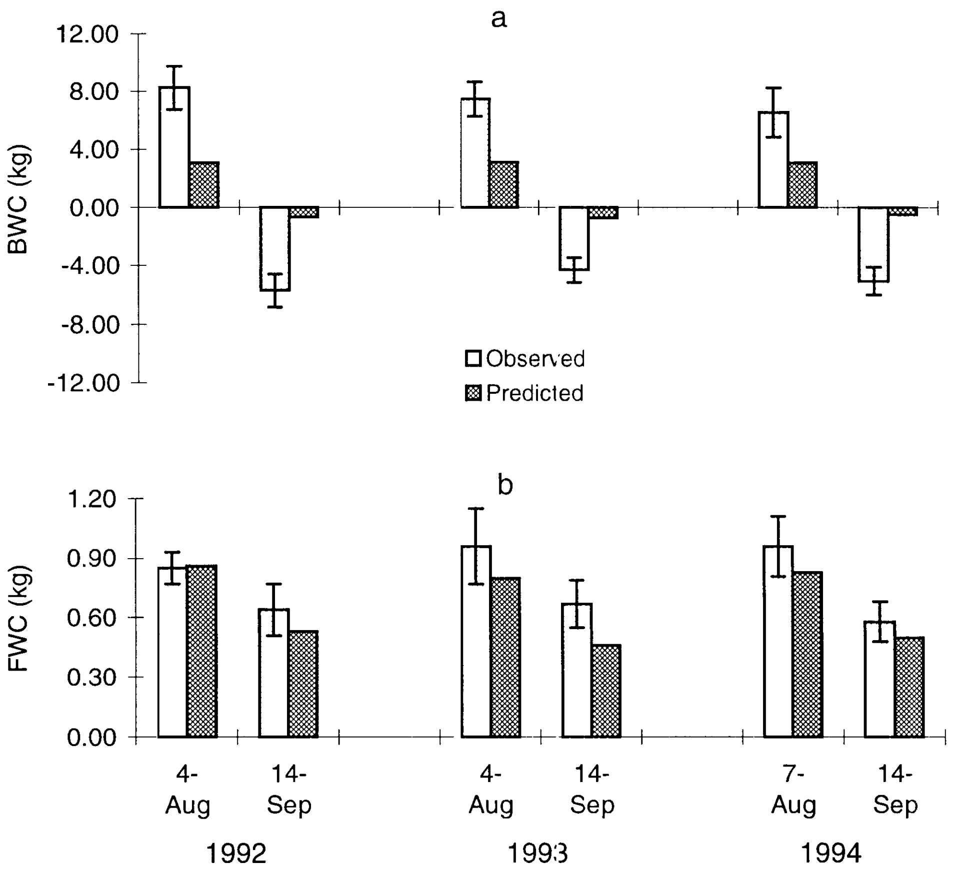

Figure 5.3.3 The model's prediction of sheep (a) BWC and (b) FWC compared with the field data on the summer pasture, with the error bars denoting the standard deviation of the observed means.

The conclusion drawn from the visual assessment are supported by the results of the statistical analysis (Table 5.3.2). The model accounted for 90% of the variation in the observations, however, the slope and intercept of the linear regression of the observations against the predictions were significantly different (P>0.05) from 1.0 and 0, respectively, showing that the model provided biased predictions of BWC. The model had a tendency to under-predict the BWC for the period from late June to early August and overpredict the BWC for the remaining period on summer pasture in all experimental years.

Table 5.3.2 An assessment of the accuracy of predictions of BWC and FWC on the summer pasture

Statistic [a]	*Variable*	
	BWC (kg)	*FWC (kg)*
R^2	0.991[S]	0.843[S]
RSD	0.257	0.081
Slope[b]	0.297[S]	0.998[NS]
	0.017[c]	0.216
Intercept[d]	0.904[S]	-0.110[NS]
	0.107	0.171

[a] Linear regression of the form Predicted = (Slope × Observed) + Intercept, where R^2 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 ($P > 0.05$).

5.3.2.2 Fleece weight change

As can be seen from Figure 5.3.3b, the model provided good predictions of FWC over the experimental period. With the exception of one observation, the model predictions always fell within one standard deviation of the observed FWCs.

The conclusions drawn from the visual assessment are supported by statistical tests (Table 5.3.2). Almost 90% of the observed variation in fleece weight was accounted for by the model. The model provided unbiased predictions of FWC, with the slope and intercept not significantly different from 1.0 and 0, respectively. Despite the fact that the statistical tests did not show any significant bias in the model's predictions of FWC, there appeared to be a tendency to under-predict the FWC in all experimental periods, with the exception of one prediction which was slightly greater than the observed data.

5.3.3 Evaluation the model's performance on the autumn pasture

5.3.3.1 Bodyweight change

In the experiment there was no significant increase in BWC as a result of supplementation in any year (Figure 5.3.4a). Sunflower meal at 27% CP was fed at a rate of up to 120 g sheep^{-1} day^{-1} but pasture availability was extremely low perhaps resulting in an energy deficit for the animals. This may explain the observed results although it is possible that the protein source can also act as a source of ME. The predicted patterns of BWC reflected the differences in supplementation rate. A visual inspection of the model predictions clearly reveals the differences in the predicted BWC between treatments.

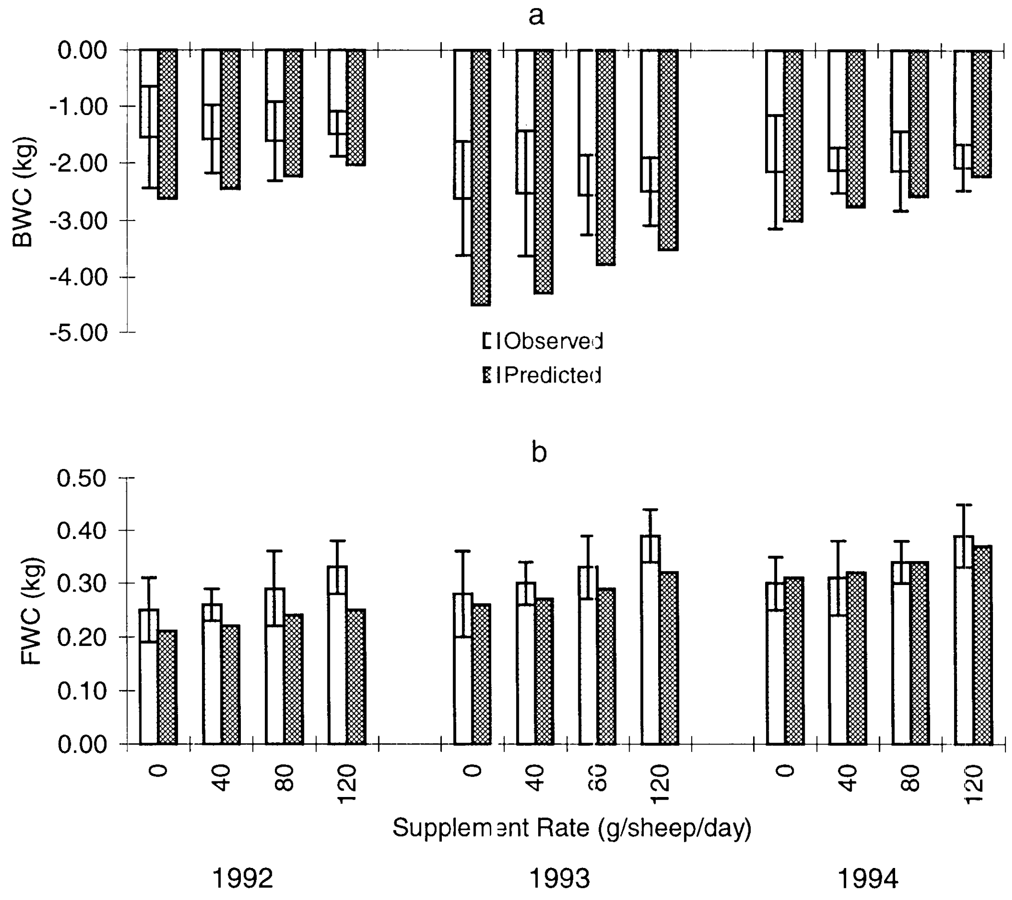

Figure 5.3.4 The model's prediction of sheep BWC (a) and FWC (b) are compared with the field data on the autumn pasture, with the error bars denoting the standard deviation of the observed means.

As can be seen from Figure 5.3.4a, the model provided poor predictions of BWC in the experimental periods. All the model predictions were greater than one standard deviation of the observed BWCs. The visual assessment is consistent with the results of the statistical analysis (Table 5.3.3). Despite the model accounting for 90% of the variation in the observations, the slope and intercept of the linear regression of the observations against the predictions were significantly different (P>0.05) from 1.0 and 0, respectively, showing the model provided biased estimates of BWC. The model had a tendency to markedly under-predict BWC, especially in 1993, when sheep had high liveweights.

Table 5.3.3 An assessment of the accuracy of predictions of BWC and FWC on the autumn pasture

Statistic^{a}	*Variable*	
	BWC (kg)	*FWC (kg)*
R^2	0.849^{S}	0.672^{S}
RSD	0.339	0.030
Slope^{b}	1.578^{S}	0.915^{NS}
	0.210	0.202
Intercept^{d}	0.056^{NS}	-0.004^{NS}
	0.420	0.064

All the descriptions of the superscripts used in this table are as same as the superscripts used in Table 5.3.2.

5.3.3.2 Fleece weight change

Both the observed and predicted FWC presented a good response to supplementary feeding (Figure 5.3.4b). The model generally provided good predictions of FWC over the experiment. Most of the model predictions fell within one standard deviation of the observed treatment means, with some of the best recorded in 1994.

Errors in prediction tended to increase at the high levels of supplementation with the model tending to under-predict the FWC. When the observed FWC were regressed against the predictions, the slope and intercept of the regression line were not significantly different from 1.0 and 0, respectively (Table 5.3.3), suggesting that there were no major biases in the prediction of FWC. However, although the correlation coefficient was significant it was not strong indicating that the accuracy of model predictions may be somewhat limited.

5.3.4 Evaluation of the model's performance on the winter pasture where sheep were partially grazed and fed supplement

5.3.4.1 Bodyweight change

A visual inspection of the model predictions of BWC compared with the field observations (Figure 5.3.5a) reveals a poor agreement over the experimental periods. Most of the model predictions were outside of one standard deviation of the observed BWCs.

The conclusion drawn from the visual assessment are supported by the results of the statistical analysis (Table 5.3.4). The slope and intercept of the linear regression of the observations against the predictions were significantly different from 1.0 and 0, respectively, showing the model provided biased predictions of BWC. The model had a tendency to seriously under-predict BWC in 1993/94 when the sheep had high liveweights.

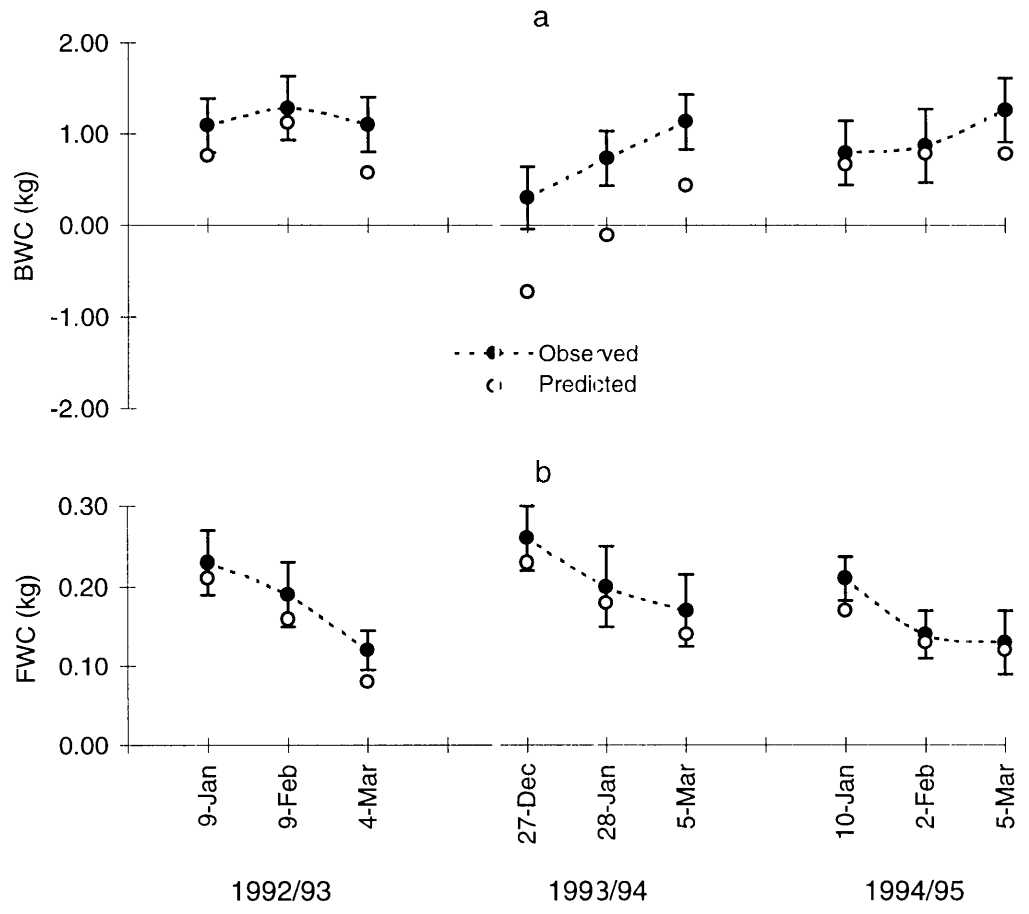

Figure 5.3.5 The model's prediction of sheep BWC (a) and FWC (b) are compared with the field data on the winter pasture where sheep were partial grazed and fed supplement, with the error bars denoting the standard deviation of the observed means.

5.3.4.2 Fleece weight change

The model generally provided good predictions of FWC over the experimental period. Most of the model predictions fell within one standard deviation of the observed treatment means (Figure 5.3.5b) and were found to account for 94% of the variation (Table 5.3.4). Despite no bias being detected by the statistical tests, there appeared to be a tendency to under-predict during all experimental periods.

Table 5.3.4 An assessment of the accuracy of predictions of BWC and FWC when sheep were partial grazed and fed supplement on the autumn pasture

Statistic ^{a}	*Variable*	
	BWC (kg)	*FWC (kg)*
R^2	0.713^{S}	0.943^{S}
RSD	0.321	0.012
Slope^{b}	1.345^{S}	0.948^{NS}
	0.322	0.088
Intercept^{d}	-0.809^{S}	-0.016^{NS}
	0.325	0.017

All the descriptions of the superscripts used in this table are as same as the superscripts used in Table 5.3.2.

5.3.5 Evaluation the model's performance on the winter pasture where sheep were fully housed and fed supplement

5.3.5.1 Bodyweight change

As can be seen from Figure 5.3.6a, the model generally provided good predictions of BWC over the experimental periods. With the exception of one observation, the model predictions always fell within one standard deviation of the observed mean.

When the observed BWC were regressed against predicted values, the model was found to account for 97% of the variation in the observations (Table 5.3.5). Tests of the slope and intercept of the regression line were not significant, suggesting that no major biases in the predictions of BWC was evident.

Some discrepancies between the observed and predicted BWC always appeared approximately one month after the supplementary feeding commenced. In contrast to the observed BWC, the predicted values were always higher. The reason for the discrepancies may due to an adjustment period in which the rumen microorganisms may adjust to the dietary change from pasture to supplement.

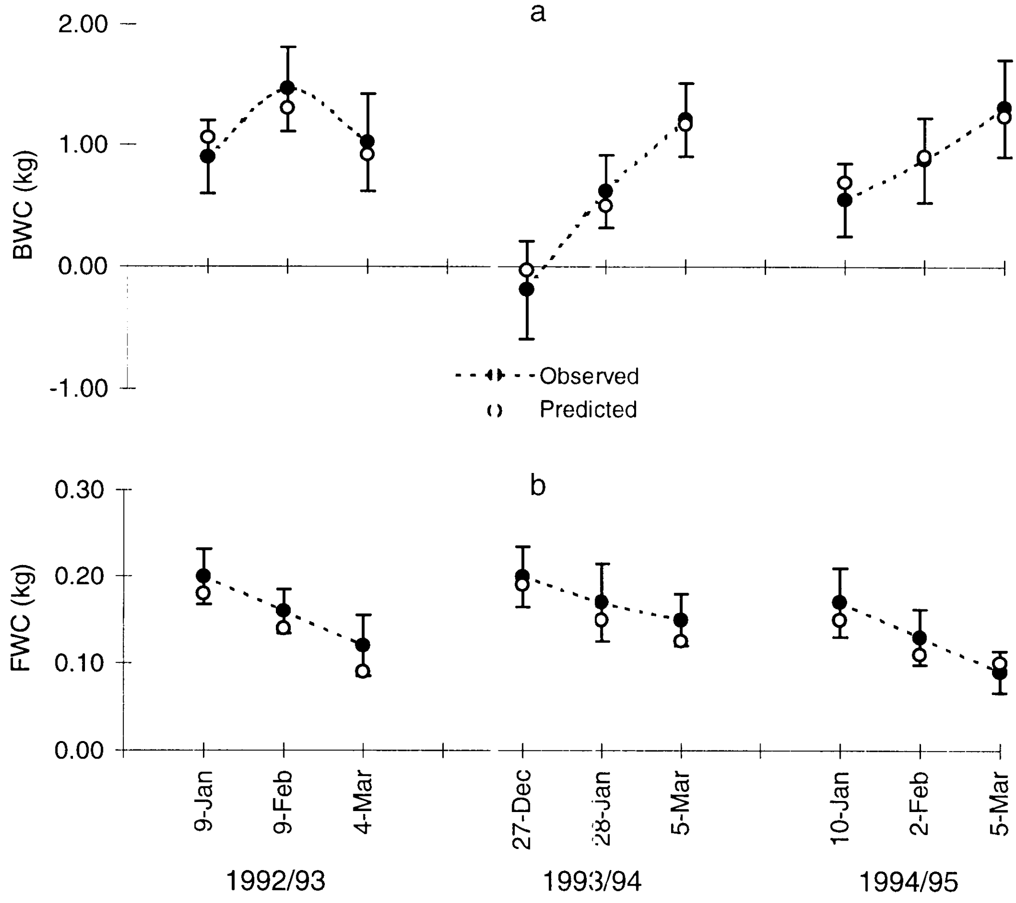

Figure 5.3.6 The model's prediction of sheep BWC (a) and FWC (b) are compared with the field data on the winter pasture where sheep were fully housed and fed supplement, with the error bars denoting the standard deviation of the observed means.

Table 5.3.5 An assessment of the accuracy of predictions of BWC and FWC when sheep were fully housed and fed supplement on the winter pasture

Statistic ^{a}	*Variable*	
	BWC (kg)	*FWC (kg)*
R^2	0.973^{S}	0.865^{S}
RSD	0.077	0.014
Slope^{b}	0.900^{NS}	0.930^{NS}
	0.056	0.139
Intercept^{d}	0.085^{NS}	-0.008^{NS}
	0.055	0.022

All the descriptions of the superscripts used in this table are as same as the superscripts used in Table 5.3.2.

5.3.5.2 Fleece weight change

A visual inspection of the model predictions compared with the field observations reveals a good agreement during the experimental periods. All the model predictions fell within one standard deviation of the observed mean (Figure 5.3.6b). The statistical analysis (Table 5.3.5) show that 87% of the observed variation in FWC was accounted for by the model, and there was no evidence in the tests of the slope or intercept of any significant bias in the model's predictions. Despite no bias being detected by the statistical tests, there did appear to be a tendency to under-predict the FWC during all experimental periods.

5.4 Discussion

With the exception of the model's performance on the winter pasture where sheep were fully housed and fed supplement, the model failed to accurately predict the BWCs. The model appeared to under-predict BWCs on each seasonal pasture over the three-year experimental time. There are insufficient data to allow the cause of this discrepancy to be clearly identified, but it may have been due to errors in the assumption of green and dead herbage biomass, and consequently the errors in the assumption of *in vitro* digestibility of the green and dead herbage. On the winter pasture, where the experiment was conducted, there is usually a small amount of green herbage which exists under the cover of snow but there was not any quantitative data available (Liu, *pers. comm.* 1995).

In addition, a genetic evaluation experiment conducted at Nanshan in cooperation with the Chinese Ministry of Agriculture, Animal Husbandry and Fisheries and the Australian Centre for International Agricultural Research indicates that purebred Xinjiang Fine Wool sheep are genetically superior to Australian Merinos in bodyweight growth by 11% (Chen *et al.* 1988). This finding may partially explain the model's under-prediction of BWC.

Given the importance of supplementation of grazing animals in Xinjiang's grazing systems, the assessment of the predictions of BWC conducted on the winter pasture are of special interest. For the animals which were fully housed and fed supplement, it was encouraging to see that the model was able to account for the major sources of variation. Although small discrepancies between the model predictions and the field observations did occur, the statistical tests suggested that no bias was detected in the predictions. In addition, for all the BWCs, the model predictions were well within one standard deviation of the field observations.

The substantial climatic variation between the seasonal pastures, together with different pasture species present in the seasonal pastures, resulted in substantial variation in pasture and animal production between the seasonal pastures. In addition, supplementary feeding varied between autumn and winter pastures. Give the magnitude of the variations and the variety of pathways by which differences emerged between pastures, it was encouraging to see that the model accurately predicted much of the observed variation in FWCs. Although some discrepancies between the model predictions and the field observations did occur, the statistical tests suggested that no major biases in the predictions of FWC of the model were evident. For most of the FWCs, the model predictions were well within one standard deviation of the field observations.

In summary, it can be concluded from the results that the assessment of the model performance of predicting greasy fleece growth was favourable. The model successfully predicted the effects of seasonal pasture conditions and different supplementary feeding, as well as the interactions between them on the greasy fleece growth. However, using the assumed green and dead herbage biomass data (which, of course, is subject to error) the model did not accurately predict the sheep bodyweight change under grazing conditions. However, it was encouraging to see that the model was able to accurately predict BWC when sheep were fully housed and fed supplement. GrazFeed showed potential as a management tool to determine supplement requirements.

Chapter 6
Concluding Discussion

A world-wide demand for sustainable and efficient use of grazing lands has increased the need for graziers to improve their management. Referring to literature reviews in Chapter 2, management within the context of a grazing system is complex, as the management must balance the nutritional requirements of different classes of stock with a food supply which continually changes in amount and quality in response to pasture growth, maturation and decay, and the effects of grazing itself (Freer and Christian 1983). Furthermore, climatic and market variability make the management within the context of a grazing system more complicated. It follows that reliable grazing management requires that a range of strategies be investigated, taking the variability of climate and market into account. Unfortunately, the complexities of management in grazing systems have outstripped our ability to investigate the best strategy using traditional techniques because of the difficulties we face in bringing the wide range of relevant factors together in an objective way.

With the advent of computer technology and the dramatic increase in information about grazing management, interest in the use of computerised decision support systems (DSSs) has increased. These systems assist graziers in dealing with complex planning problems by allowing exploration of alternatives and selection of appropriate strategies (Stuth *et al.* 1993). Computerised DSSs, therefore, have become popular tools in the field of graziers' management support (Korver and Van Arendonk 1988).

Before a DSS can be used to make management decisions it must be shown to be valid for the ecosystem in which it is being applied (Stout *et al.* 1990). Predictions from DSS need to be compared with experimental observations to determine the usefulness and limitations of each approach. GrazFeed DSS has been routinely used in temperate southern Australia to provide graziers with expert advice on ruminant nutrition (Moore *et al.* 1991; Moore 1992). The model implements the Australian Feeding Standard for Ruminants and contains selective grazing logic, therefore, it appears to be soundly based. However, the literature contains few evaluations where the model is compared with field data. Much of the work reported in this thesis has attempted to evaluate the performance of GrazFeed on a range of pasture types and different sheep breeds by comparing the model's prediction with the data obtained from field experiments. Such evaluations may reinforce the confidence of applying the model in real systems, or may permit the identification of weaknesses in the model and specific input parameters which might cause any consistent pattern in the difference between the model prediction and field data to be identified.

Chapter 3 compared the model's prediction of sheep BWC and FWC with field data collected from three improved pastures in a high rainfall area of Australia. Results showed that the model accurately predicted the observed variation in BWC on the degraded pasture. Although large discrepancies between the predicted and observed BWC did occur with the phalaris and phalaris/white clover pastures in autumn 1995, no consistent bias was detected over the whole experimental period. For sheep FWC, the model successfully estimated much of the observed variation on the degraded pasture. However, the model was generally unable to adequately predict FWCs with the phalaris and phalaris/white clover pastures, especially, when pasture conditions were drought affected.

Chapter 4 set out to evaluate the model's performance on two native pastures in a high rainfall region of Australia where native pastures are still the main feed supply for grazing animals. In contrast to the model's performance on the improved pastures, the model's performance with these pastures was less favourable. The model provided biased predictions of sheep BWC and FWC on the two native pastures, and was unable to account for the major sources of observed variation (most of the r^2 were less than 0.57). Similar to the finding on the improved pastures, the prediction of BWC and FWC under poor pasture conditions was one area where large discrepancies appeared to occur more frequently.

The reasons for the large discrepancies between the model predictions and the field observations on the improved and native pastures were discussed in detail in Chapters 3 and 4, respectively. Besides errors in estimation of the pasture *in vitro* digestibility and availability as well as other factors (see details in Sections 3.4 and 4.4), deficiencies in the model, itself, might also have been partly responsible for the discrepancies. Although there are insufficient data to allow deficiencies, whether occurring in the intake module or the animal nutrition module, in the model to be clearly identified the most probable deficiencies seem to occur in the intake module. The evidence to support this presumption were detailed in Chapters 3.4 and 4.4.

Accurately predicting the intake of grazing animals is one of the most difficult aspects of modelling grazing systems (Freer and Christian 1981, 1983; Loewer 1987) because of the difficulty for the model to take account of all of the factors that influence intake (see details in Chapter 2.4). In GrazFeed, intake of pasture is predicted from functions of available herbage and its digestibility (Moore *et al.* 1991). It is assumed that voluntary intake increases linearly with increasing digestibility (Freer and Christian 1983; SCA 1990). However, there are two complications to this simple assumption First, the relation between digestibility and intake need not be the same for different plant varieties or species; secondly, there is some controversy concerning the range of digestibility over which such a relationship applies (Elsen *et al.* 1988). As discussed in Section 2.4.3.1, some studies have suggested that at high levels of digestibility, energy requirements supplant gut distension as the factor limiting intake, and as a result, intake decreases with increasing digestibility. However, other studies have shown that intake increases with digestibility, even up to digestibilities which are near the maximum encountered for herbage. At the lower limit of digestibility, if intake consists mainly of straw or senescent herbage, then intake may be severely depressed as a result of impaired microbiological activity in the rumen (Elsen *et al.* 1988).

Reviewing the literature, animal preference, and the extent to which this preference can be expressed in a particular situation, have been extensively discussed when predicting animal intake on a heterogeneous pasture. It is generally accepted that the diet of grazing sheep may be of quite different composition from that of the grazed pasture (see for instance: Freer 1981; Forbes and Hodgon 1985). It is not clear in general, however, which plant characteristics are most closely related to preference. The intake module of GrazFeed assumes that *in vitro* digestibility is the sole factor that determines preference (Moore *et al.* 1991). Obviously, this assumption simplifies the complexity of the factors affecting intake and selectivity; for example, it is known that animals may initially avoid some feed simply because they are unfamiliar with it (Nolan, pers. comm.).

A number of studies support the view that the factors affecting intake are complex. For example, studies of Arnold and Dudzinski (1967) found that pasture availability and digestibility affect intake differently in different types of pasture. Forbes and Hodgson (1985), on *Lolium perenne* pastures, found large differences in intake occur over a fairly short time interval, during which the pasture characteristics varied relatively little.

There are thus fundamental differences between scientists as to how animal intake is affected by pasture availability and digestibility as well as heterogeneity. However, experimental evidence does not seem sufficient to choose unequivocally between the possibilities presented. It follows that further evaluation of the intake module of GrazFeed using experimental data may be desirable. The experimental findings by Arnold and Dudzinski (1967) and Forbes and Hodgson (1985) may partially explain the reason why GrazFeed showed differing predictive abilities on the improved and native pastures.

The biggest disappointments of many foreign assistance programs in agriculture have been related to the inability to take highly successful agricultural technology and successfully apply it in developing countries (Smith 1983). The development of computerised DSS in technologically advanced countries provides good opportunities of successful transfer of technology to improve decision-making to all other relevant, less technological countries, because the component knowledge upon which this technology is founded is integrated into a single package that can be adjusted to local conditions (Smith 1983). Comparing the model performance with local data is the first step to allowing the model be applied in that environment. This was the motivation for evaluation of the GrazFeed model's performance at Nanshan in Xinjiang province, China presented in Chapter 5 of this thesis.

Generally the model was able to adequately predict sheep FWCs on each of the seasonal pastures at Nanshan. Although the model consistently under-predicted the sheep BWCs in most cases, it was encouraging to see that the model was able to account for the major sources of the observed variation on each of the seasonal pastures. The consistent lower predictions of BWC and the strong relationships (with the exception of one r^2 was 0.71, all others were greater than 0.84) between the predicted and observed BWCs imply that the model has the potential to be modified and then applied in a grazing system such as at Nanshan. Alternatively, improvements in information on botanical composition may improve the model's predictions. Given the importance of supplementary feeding in this grazing system, the evaluation of the model's performance in predicting the BWCs of sheep fully housed and fed supplementation was favourable. The model accurately predicted their BWCs over the experimental period. GrazFeed shows potential as a management tool to assist graziers to make better supplementary feeding decisions in Xinjiang's environment. Furthermore, the model's accurate predictions obtained from the sheep which were fully housed and feed supplementation indirectly supports the findings in Chapters 3 and 4 that either there may be some deficiencies in the intake module of the model under grazing situations, or that better information on the botanical composition of the grazed pastures is required.

In summary, the work reported has evaluated the performance of GrazFeed concerning its predictive ability for sheep production on a range of pasture types, and increased our confidence in the application of the model on improved pastures in the high rainfall regions of Australia. Although the model's performance on the native pastures was less favourable, investigation showed that at least some of the discrepancy between the model prediction and the field observations was related to the difficulty in obtaining reliable pasture values under field conditions. Given the huge differences in environment and grazing management between north-west China and Australia in which the model was developed, it was encouraging to see that the model showed potential as a management tool to determine supplementation requirements in the environment of north-west China. The research has also raised a number of areas where further study is needed to enhance the performance of the model.

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Appendices

Appendix 1 An example of the output from a complete run of the GrazFeed model

```
                                                          10 Apr 1996 10:00

                  RECORD OF INPUT VALUES FOR THIS RUN

Pasture                             Weight          Mean
                                    (t DM/ha)       digestibility (%)
           Green herbage            0.40            70
           Dead herbage             0.80            45

           The main grasses are of improved types
           Legume percentage                        30
           The paddock is                           Gently sloping

Supplement
           Maize grain       80%          Lupins          20%

           DM digestibility (%)                     90
           Protein content (%)                      14.4
           Protein degradability (%                 79

Weather
           Maximum temperature (°C)                 20
           Minimum temperature (°C)                 10
           Mean wind speed (km/h)                   5
           Daily rainfall (mm)                      0

Animals    Mature wethers of Med. Merino, Polwarth breed type
           Bodyweight (kg)                          50.0
           Age (months)                             36

ANIMAL CLASS: MATURE WETHERS

WEIGHT OF SUPPLEMENT: 0.30 kg
```

```
Table 1. DIET COMPOSITION

                          Intake   ___Herbage___       Supplt  Total   Milk    Total
                          limit    on offer   eaten    eaten   solid           diet

Weight of DM (kg)         1.77                1.02     0.26    1.28
Digestibility (%)                  53         67       90      71
Crude protein (%)                  11         18       14      18
Percentage degradable              75         78       76
ME intake (MJ)                                                 13.14   0.00    13.14
ME/DM (MJ/kg)                                                  10.26
Maint. efficiency                                                              0.71
Gain efficiency                                                                0.38

Table 2. ENERGY AND PROTEIN PARTITION AND PROTEIN REQUIREMENTS

                        Intake    Maint     Wool      Wt gain   Total     Surplus
                                                                used

ME partition (MJ)       13.14     9.69
NE stored (MJ)                              0.35      1.08
Protein (g)             225.4     30.2      10.1      3.1       43.4
Rum degr prot (g)       175.0                                   108.2     66.8
Undegr prot (g)         50.4                                    0.0       50.4

Table 3. ANIMAL MEASUREMENTS:

                           Shorn       Clean       Greasy      Supplement
                           body        wool        wool        cost (c/head)

New weight (kg)            50.04
Daily gain (g)             45          10.1        14.4        4.8
Table 4. EFFECT OF CHILLING ON METABOLISM (MJ)
Coat         Condition    LCT          Extra heat   ___NE retention___
length       score        °C           production   Uncorrected  Corrected


3.0          1.9          -7.1         0.0          1.1          1.1

COMMENTS ON THE PRECEDING PAGE OF OUTPUT:

Production is limited by factors other than protein
```

The production of these animals is not being limited by the concentration of protein in their diet. This is indicated in Table 2 by the surplus of 67g/d in the intake of rumen degradable protein (right-hand column of row 4), and the surplus of 50g/d in the intake of undegraded protein (right-hand column of row 5).

These animals are eating only 72 per cent of their potential intake (Table 1, row 1).

Pasture intake comprises 58 per cent of their potential intake, with the remainder (15%) coming from supplement. It may be that pasture intake is limited by the availability of high quality pasture, as indicated in the first table of input values on the first page of this output.

However, remember that one effect of the supplement that you are feeding, may be to depress the intake of pasture (see Chapter 13 of the manual). If you wish to increase animal production, you could either move the animals to a better pasture or test the effect of feeding more of the supplement.

Estimate of possible stocking rate

The program has predicted that these animals will eat 1.0 kg/day of pasture dry matter. To get an estimate of the maximum stocking rate that you can maintain on this pasture, divide your estimate of current pasture growth rate by 1.5 times the intake of herbage (to allow for trampling and other wastage). For example, if intake by sheep is 1 kg per head per day and the pasture is growing at 20 kg/ha/day, then the pasture should be able to carry 20/1.5 or 13 sheep/ha without reducing the level of herbage. For ewes with lambs, do not forget to add in the herbage intakes by the young before doing the sum.

The value you calculate should give you a guide to management for, perhaps, the next two weeks but, as soon as you can see a change in pasture conditions, you should use GrazFeed to make fresh estimates.

Pasture growth rates in southern Australia range from 5-20 kg DM/ha/day in the winter to 40-120 kg/ha/day in the spring, depending on temperature, rainfall and pasture type.

This method of estimating stocking rate cannot be used in situations where the animals are grazing a large mass of accumulated herbage, with little or no new growth.

Production is not being reduced by chilling

The energy that these animals need to maintain themselves is not being increased by the weather conditions that you specified. This is indicated by the zero value for "extra heat production" in column 4 of Table 4. For these animals, the air temperature would have to fall below the lower critical temperature (LCT) of -7°C, as shown in column 3, before the maintenance requirement would be increased.

Appendix 2 The detail of input data used for generating Figure 2.4.1

Pasture	Not considered	
Supplement	Roughage	
	Dry matter (%)	86
	DM digestibility (%)	80
	ME/DE	11.8
	Protein content (%)	12
	Protein degradability (%)	75
Weather	Not considered	
Animals	Wethers of large Merino	
	For this breed type,	
	- the weight of a mature ewe in average condition (kg)	60.0
	- her potential greasy fleece weight in a good year (kg)	6.0
	Wethers of small Merino	
	For this breed type,	
	- the weight of a mature ewe in average condition (kg)	40.0
	- her potential greasy fleece weight in a good year (kg)	4.0

Appendix 3 The detail of input data used for generating Figure 2.4.3

Table 1. Constant input values for these runs

Pasture	Not considered	
Supplement	Roughage	
	DM digestibility (%)	30
	ME/DE	10.2
	Protein content (%)	See Table 2
	Protein degradability (%)	65
Weather	Not considered	
Animals	Mature wethers of Med. Merino, Polwarth breed type	
	Bodyweight (kg)	50.0
	Age (months)	24
	For this breed type,	
	- the weight of a mature ewe in average condition (kg)	50.0
	- her potential greasy fleece weight in a good year (kg)	5.0

Table 2. Input protein content (%) values and output intake values (g/day)

Protein content (convert to nitrogen content %)		Organic matter intake (convert to g/kg MW*/day)	
6	(0.96)	450	(23.93)
10	(1.60)	740	(39.36)
13	(2.08)	970	(51.59)
16	(2.56)	1190	(63.29)
19	(3.04)	1390	(73.92)
22	(3.52)	1440	(76.58)
25	(4.00)	1440	(76.58)
28	(4.48)	1440	(76.58)

*MW = Metabolic weight, which is expressed as (Liveweight)$^{0.75}$.

Appendix 4 The detail of input data used for generating Figure 2.4.5

Pasture I		Weight (t DM/ha)	Mean digestibility (%)
	Green herbage		70
	The main grasses are of	improved types	
	The paddock is		Gently sloping
Pasture II		Weight (t DM/ha)	Mean digestibility (%)
	Dead herbage		50
	The main grasses are of	improved types	
	The paddock is		Gently sloping
Weather	Not considered		
Supplement I	Maize grain		
	Dry matter (%)	87	
	DM digestibility (%)		90
	ME/DE		14.0
	Protein content (%)		10
	Protein degradability (%)		80
Supplement II	Maize grain		
	Dry matter (%)	87	
	DM digestibility (%)		70
	ME/DE		10.4
	Protein content (%)		10
	Protein degradability (%)		80
Animals	Mature wethers of Medium Merino, Polwarth breed type		
	Bodyweight (kg)		50.0
	Age (months)		24
	For this breed type,		
	- the weight of a mature ewe in average condition (kg)		50.0
	- her potential greasy fleece weight in a good year (kg)		5.0