Chapter 3

A Comparison of Measured Feed On Offer in Three Pastures Varying in Perennial Grass Content with Predicted Values from the GrassGro Model

3.1 Introduction

Managers of pastoral grazing systems have always had to cope with the effects of environmental and biological variation can have on the achievement of their gaols. This variation has shaped farming practices as managers develop strategies to cope with this inherent variation. For example, a common method of coping with variability in the growth of animals for slaughter is to have a flexible slaughtering date. Other strategies may involve changing of stocking rates, feeding supplements, matching animal breeding to pasture production or altering the mix of livestock classes on a farm.

Traditional methods of managing variability in pasture production systems may not be sufficient to enable graziers to meet new competitive market requirements. The market increasingly demands that products be produced to specification with constraints on the time of supply. These contrast with commodity production systems where animals are supplied according to the vagaries of the season and seasonal differences. Developing farm grazing systems to meet the demands of quality production requires a description of feed budgeting, and assurance of quality, over time. Feed planning and time-controlled grazing have been shown by Lile and George (1993) in California, USA to enhance profitability of livestock operations, through the efficient utilisation of available forage resources. Milligan *et al.* (1987) showed how feed budgeting was essential to meet the production targets by matching the forage demand of livestock to pasture supply. Feed budgeting requires an estimation of the daily growth rate (DGR) of the specific pasture.

In California, USA (Lile and George, 1993), monthly estimates of DGRs for several locations are made available from the Agronomy and Range Science Dept., University of California. For the temperate pastures of the Northern Tablelands of NSW, this has been reported by various organisations, such as the University of New England (UNE) (Lazenby and Swain, 1973) and NSW Agriculture (McDonald, 1995). These average DGRs are a good starting point for forage budgeting, but are likely to require modification for a particular farm to account for local variations in climate, soil fertility, and time to time monitoring in variation due to year-to-year climatic variability. Apart from weather, daily growth rate will also vary between years due to variations in herbage mass (HM). Likewise, Radcliffe and Baars (1987) reported a strong relationship between soil temperature and the growth of a perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pasture (r^2 = 0.75 in spring and r^2 = 0.70 in autumn). Brougham (1959) reported seasonal changes in growth rate were correlated with seasonal differences in solar irradiance (r^2 = 0.98), maximum air temperatures (r^2 = 0.73), and minimum air temperature (r^2 = 0.61). Brougham (1956) showed an increasing growth rate as the height, leaf area, and therefore light interception of the sward increased. Lamaire and Salette (1982), however found variations of spring growth of tall fescue were related only to temperature and not to solar irradiance. When HM is extremely low (<1120 kg DM ha^{-1}) or high (>2800 kg DM ha^{-1}) DGR is usually depressed (Korte *et al.* 1987).

The collective views of different workers about the factors affecting DGR compiled by McDonald (1995) for the temperate pastures of the Northern Tablelands are climate, soil type, grazing management and soil fertility/fertiliser use. DGR predicted from the "Growest" model (Nix, 1981), (a simple growth model using soil moisture, temperature and light) and from long-term observations by experienced workers showed a wide range of variations across the seasons and pasture types (McDonald, 1995). However, during the winter months, only fescue, white and sub-clover, and phalaris, white and sub-clover based pastures were found to be productive.

The objectives of this study were to (i) measure the available herbage mass (HM) at day_0 and day_t from grazed and ungrazed rainfed pastures, (ii) determine the daily change in feed on offer (Δ FOO) from the three pasture types over time and, finally, (iii) compare them with the GrassGro model predictions.

3.2 Materials and Methods

3.2.1 Site Description

The experimental site was located at "Chiswick", the CSIRO Pastoral Research Laboratory near Armidale on the Northern Tablelands of New South Wales, (lat. 30°31'S; long. 151°33'S; altitude 1046m). The Armidale region has a cool temperate climate and the mean annual rainfall is 795 mm with a 60% summer and 40% winter incidence (Lovett, 1973). The soil type where the experiment was located was a gleyed podzolic (Saumarez series) formed from Paleozoic and laterized Tertiary sediments with some basaltic colluvia, and has been described by Schafer (1980). The soil is a duplex with a fine sandy loam surface texture and a pH of 6.0 (0-110 mm). A detailed description of the soil type is given in Appendix 2.

The area had been sown with a mixture of *Phalaris aquatica* and *Trifolium repens* in 1958 and lightly grazed for five years with an annual autumn application of 250 Kg ha^{-1} of superphosphate. In addition to the superphosphate, an annual application of 125 kg of potassium chloride was applied from 1963. Sixteen rectangular sites of 0.405 ha were established in 1963 and stocked from 1963 to 1980 with 0, 10, 20, and 30 sheep per hectare (i.e. four replicates for each treatment). From 1980 until 1992, the higher stocking rates were reduced from 20 and 30 dse ha^{-1} to 15 and 20 dse ha^{-1} repectively due to animal welfare considerations.

The botanical composition of the pasture has dynamically changed over the past 28 years as a function of grazing intensity (Hutchinson and King, 1993). The zero stocking rate (0 dse ha^{-1}) is almost entirely dominated by Phalaris. At the low stocking rate (10 dse ha^{-1}), the phalaris remained relatively stable with a ratio of perennial to annual of about 3:1 and satisfactory recovery (resilience) after severe drought in 1965. The medium stocking rate (15 dse ha^{-1}) has a ratio of perennial to annual grass of about 1:1, and high stocking rate (20 dse ha^{-1}) phalaris has been entirely replaced by annual grass species. Hutchinson and King (1993) reached the conclusion that the combined impact of drought and high stocking rates had resulted in selective and year-long grazing of the phalaris, which reduced the number of buds and resulted in a failure of the plant to regenerate. The presence of white clover is cyclical, being influenced strongly by drought, dry summers, overstocking, and reduced seed banks (Hutchinson and King, 1994). The annual grass species include *Vulpia*, *Bromus*, *Eragrostis*, *Elusine*, *Chloris*, *Danthonia*, and *Poa* (Hutchinson and King, 1993). In 1995, a new experiment was established on the site. In this, stocking rate is variable to maintain the feed on offer (FOO) between 1200 and 2500 kg DM ha^{-1}. The layout of the experiment is presented in Figure 3.1.

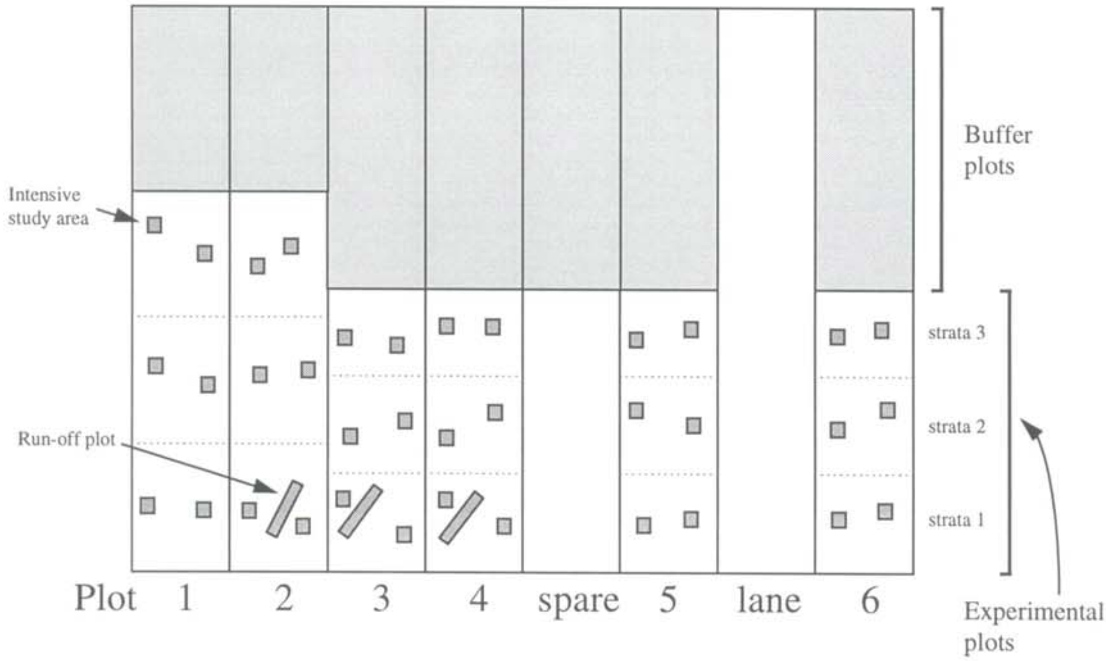

Figure 3.1 Layout of the experimental paddocks. Buffer plots are used to change the stocking rates as per the availability of pasture. Plot 1 & 2 for degraded (0.53 ha each), 3 & 6 for phalaris, and 4 & 5 for phalaris/white clover (0.4 ha each).

3.2.2 Measurement of Feed On Offer (FOO) and Daily Δ FOO

The method used in measuring FOO was non-destructive and relied on the relationship between yield and settled height of a weighted disk. Change in feed on offer (Δ FOO) were estimated as follows; a rising plate meter was used to measure FOO along one side of a 10m fixed transect in each strata. The average FOO was calculated as the mean of the ten readings. The rising plate meter was then used to locate true areas within 2m of either side of the transect where FOO was equal to the average of ten readings. This location was marked with a flexible pin and a 1.5×0.5m wire cage placed over the area.

After t days the cage was removed, the pin located and the settled height of the plate recorded at that point. The FOO in the next period was determined by repeating the above procedure on a new area selected by the above procedure. For each period of t days, the Δ FOO of pasture (NB some workers would designate the Δ FOO as net pasture growth, or growth - decay) was taken as:

$$\Delta FOO = \frac{HMC_t - HMC_o}{t} \qquad (3.1)$$

Where, $HMCo$ = *Herbage Mass* in the cage on day_0 and,

$HMCt$ = *Herbage Mass* in the cage on day_t

t = *time* in days

Measurements commenced in February/March 1995 and continued until November/December 1995. At each measurement time (i.e. day_0 and day_t), a separate calibration of the rising plate was made and both linear and curvilinear regression equations were developed. The most significant of these relationships were used. The equations used at each sampling are presented in Appendix 3. When the botanical composition was not significantly different in the Phalaris and Phalaris/white clover pastures (during the drought period), only one calibration was made for both the pasture types.

Estimates of pasture growth are most accurate from cages when the differences in yield, height, LAI etc. between the pasture in and outside the cages are minimal (Cayley and Bird, 1991). It is therefore best to move the cages more, rather than less often. Bearing these facts in mind it was attempted to match the frequency of measurement and shifting the cages with the rate of accumulation of HM. Sampling frequency increased with increasing Δ FOO. When Δ FOO was low, sampling frequency was decreased because it took longer to accumulate a measurable increase in HM. HM was estimated weekly in the spring and monthly in the winter. However, because of delays in reaching the experimental site, measurement was delayed in some of the sampling periods.

It was also planned to use the Pasture Probe™ (capacitance meter) along with the rising plate. The probe has been successfully used on irrigated pasture by several workers (Neal and Neal, 1973; Stockdale and Kelly 1984; Gabriels and Van Den Berg, 1993; Lile and George, 1993), however, its use on rainfed pasture has not been reported. The ability of the probe to measure FOO was investigated at the Big Ridge-2 experiment but when there was a high proportion of dry pasture in summer (during the drought in 1994/95) the probe was inaccurate, so it was not used.

For each time of measurement a separate sample cutting was made for the ungrazed pasture from the exclosure at the same time and location as the measurement of FOO was taken with the rising plate, whereas the sample was cut from the grazed pasture 7 to 9 days pre-or post-the measurement made on the grazed pasture. This was because of the unavailability of transportation to the site.

Separate simulation runs were made for the grazed and ungrazed pastures for each time the measurements were taken in the field. To simulate the effect of grazing animals on the pasture prior to the short term simulation run, the model simulation was run from January 1, 1994 through to the February 21, 1995, the commencement date of the experiment and then simulated again as ungrazed pasture for a short duration. The procedure was repeated for the eight consecutive measurements because in the version of the GrassGro program used the same file cannot be converted back into a grazed situation. If this is attempted it locks up the program function. The information from the model was read at the end of each simulation run separately for the grazed and ungrazed pastures.

In the physical experiment stocking rate (SR) was frequently changed in each of the pasture types, (e.g. degraded, phalaris and phalaris/white clover) because of the availability of pasture. The magnitude of change in stocking rate used in the field is not compatible with the model, particularly when it was changed intermittently and for short periods.

Therefore, for the ease of simulation a weighted average SR was used for the entire simulation.

3.2.3 Statistical Analysis

Minitab (release-9, 1993) was used to analyse the relationships between observed and predicted FOO. NEVA (third edition, 1980) was used for ANOVA for measured change in feed on offer (Δ FOO), beginning herbage mass (BHM), relative growth rate (RGR), regression analysis of total feed on offer (T.FOO) and green feed on offer (G.FOO). Excel (version 5) was used for t-test analysis of measured vs predicted FOO. A pasture meter software developed by Cayley (1994) based on LOTUS-2 was also used to find out the appropriate regression model for measuring HM; the reading obtained by the rising plate meter.

3.3 Results

3.3.1 Rainfall, Temperature and Radiation

The site received below average rain in 7 out of the 12 months, particularly in the part early of 1995 (Figure 3.2 a). Total rainfall in 1995 was not below average however more than 80% of rain was received during late 1995. Due to the severe drought, the total rainfall received in 1994 was only 575 mm, which is below the 34 average years from 1960 to 1995. Temperature and solar radiation almost follow the average except the temperature was below average in February and April.

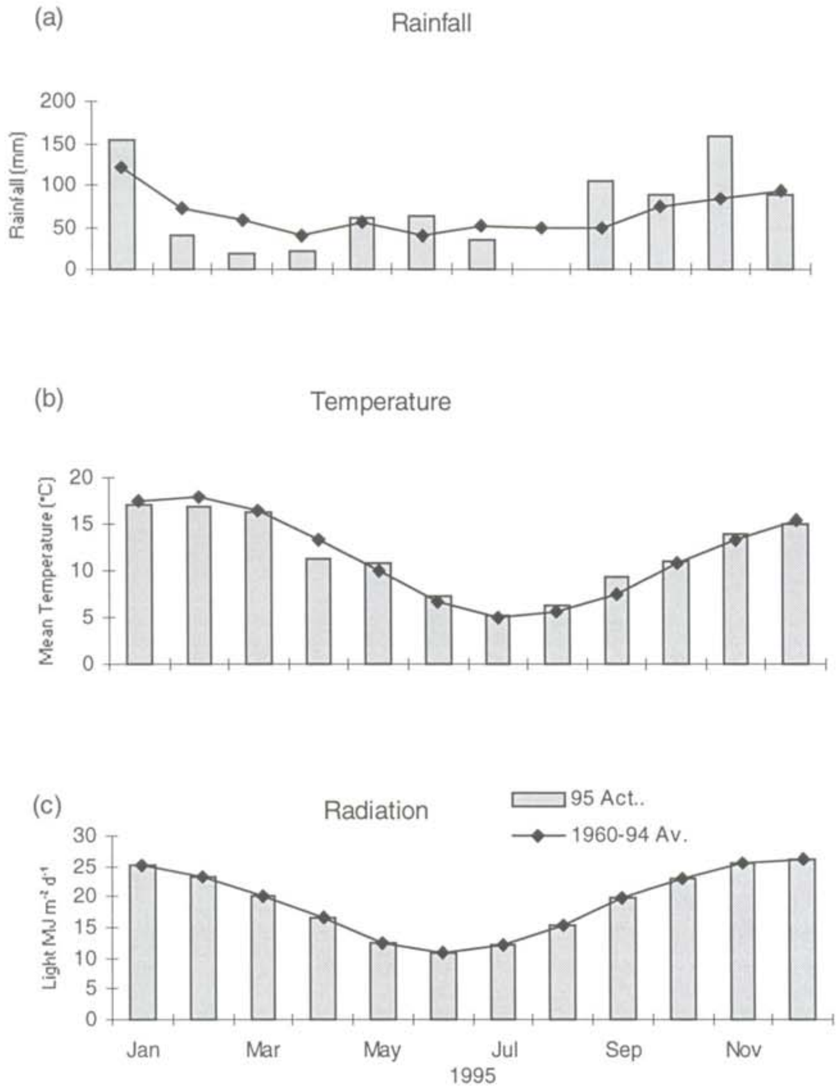

Figure 3.2..Actual monthly rain, average mean temperature, and solar radiation at Big Ridge 2 compared with 34 year average.

3.3.2 Change in Daily Feed On Offer (Δ FOO)

The average daily change in feed on offer (Δ FOO) of the three pasture types generally followed the same pattern except in the winter. Δ FOO varied considerably between seasons, being highest in spring and late autumn and lowest in winter (Figure 3.3).

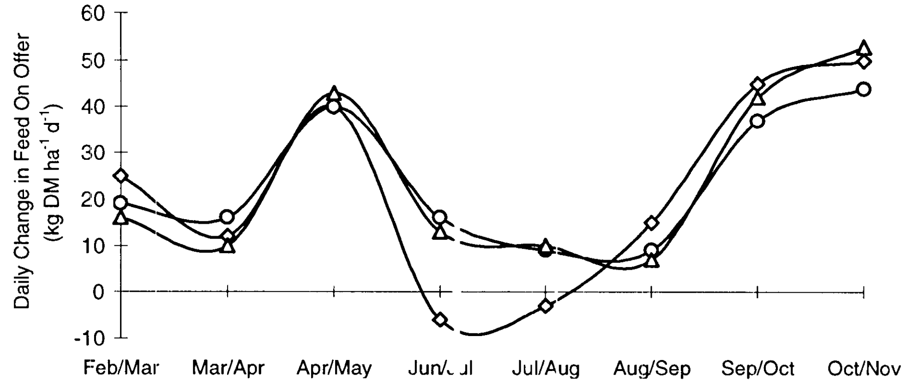

Figure 3.3. Daily change in feed on offer (Δ FOO) *of the three pasture types* (—o— degraded; —o— phalaris; —Δ— phalaris/w.clover) *measured in 1995. Values are means from 12 cages (2 per strata x 3 strata per plot x 2 replicates).*

Daily Δ FOO of the degraded pasture was significantly ($P<0.05$) lower than the other two pasture types in the winter, the pastures phalaris and phalaris/white clover maintained their growth rate around 12-15 kg DM ha^{-1} d^{-1} during the same period (Figure 3.3). A negative Δ FOO of the degraded pasture was recorded during the winter months because the dominant species in the degraded pasture were mostly frost susceptible, summer annuals, biennial, and perennial grasses. These species do not grow in the winter but the process of decomposition of their accumulated dead herbage continues resulting in a decline in FOO.

3.3.3 Simulated Growth Curve for Phalaris, White clover and Eleusine using the GrassGro model

Growth curves for the two grass species, *Eleusine* (C_4, tropical summer perennial) and *Phalaris* (C_3, temperate perennial) and a legume, white clover (C_3, temperate perennial) were simulated using 1995 "Chiswick" weather data. Paddock inputs listed in Table 3.1 were used in the simulation run. The parameters for soil fertility, soil types and stocking rate used in the simulation, as described in Chapter 2.4, were those which were most appropriate for each experimental unit in the field trial. The general growth pattern of the three pasture species was found consistent except some discrepancies occurred with *Eleusine* and white clover.

Table 3.1 Major paddock inputs used for the simulation of growth of the three pasture species. Phalaris and white clover were also simulated in mixed sward using stocking rate (SR) at 10 dse ha^{-1} on phalaris soil conditions.

	Fertility scaler *	Stocking rate (dse ha^{-1})	Soil type
Eleusine	0.8	5	sandy clay loam
Phalaris	0.8	10	sandy clay loam
White clover	1.0	5	clay loam

* 1 = no soil nutrient stress, 0 = complete stress

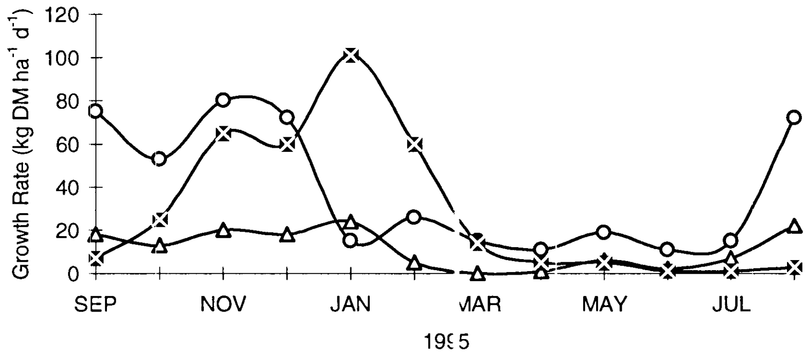

Figure 3.4 Simulated growth curves produced by the GrassGro model using 1995 weather data from the "Chiswick" meteorological station. Values are monthly average DGR for the three species (—— Eleusine; —o— Phalaris; and —Δ— White clover) *grown in pure sward conditions.*

In the simulation phalaris produced the highest DGR 89 kg DM ha^{-1} d^{-1} in November/December and the lowest 1 kg DM ha^{-1} d^{-1} in January and August. White clover alone produced daily growth rate of 35 kg ha^{-1} in January and 0 kg ha^{-1} in March/April. When they were grown in mixed swards, the highest production rate reached

120 kg ha^{-1} d^{-1} in January and 1 kg ha^{-1} d^{-1} in March/April. However, the average DGR production rate was maintained at 10-13 kg ha^{-1} d^{-1} in the winter months. Likewise, *Eleusine* exhibited the highest DGR in January and lowest, 0, in June/July with a tendency to increase after August.

3.3.4 Growth Limiting Factors

The growth limiting factors related to the three pasture species indicated by the model under the "Chiswick" Big Ridge 2 conditions in 1995 are shown in Figure 3.5. Temperature was the most limiting factor for *Eleusine*, particularly in April through to September followed by soil moisture during March-April (Figure 3.5 a).

For phalaris (Figure 3.5 b), soil moisture was frequently a limiting factor particularly in November, March and April. Leaf area tended to limit growth in general, but was most severe in January. However for the clover pasture, both light (GAI = green area index) and most frequently soil moisture were the major limiting factors. Temperature tended to be a limiting factor in winter (Figure 3 5 c).

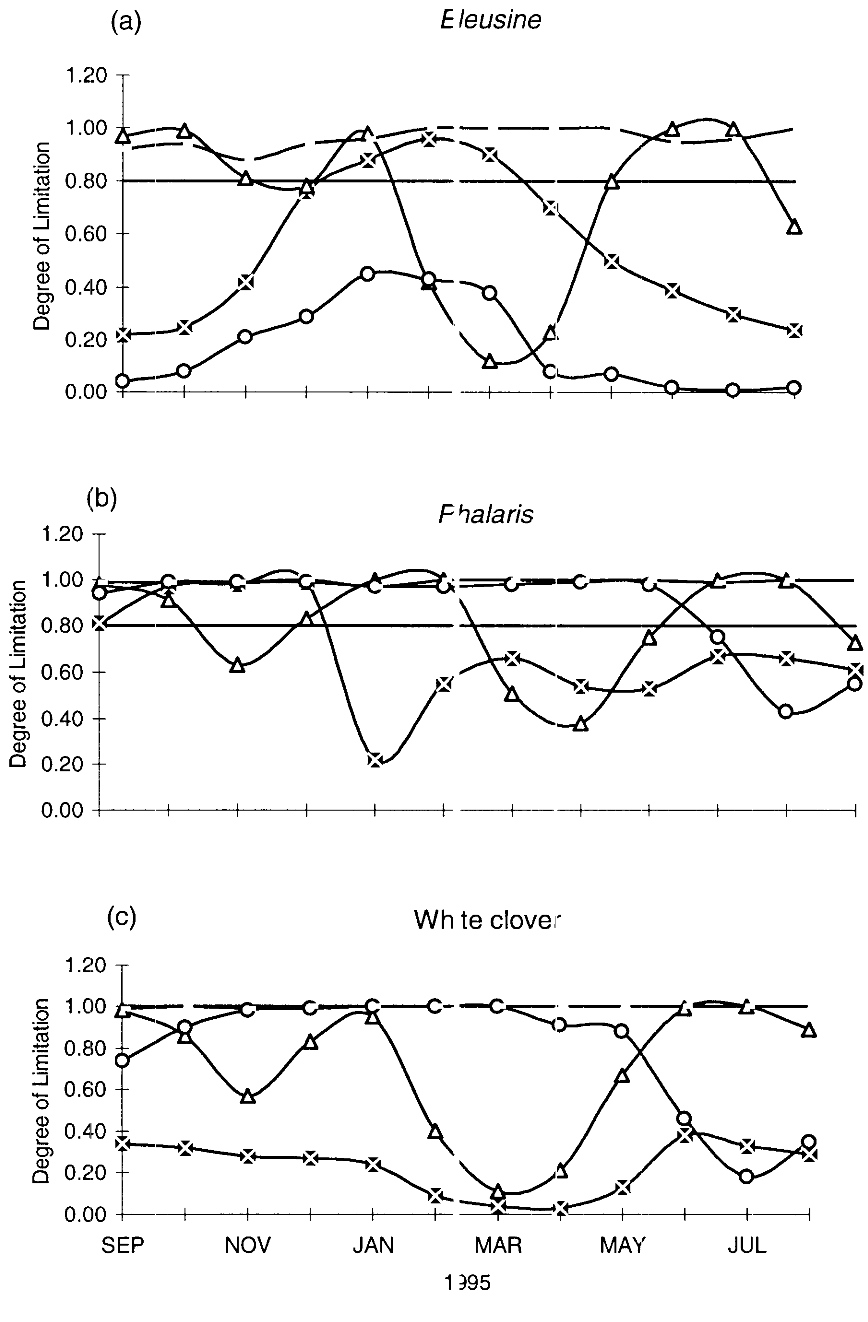

Figure 3.5 Growth limiting factors associated with the three pasture species under "Chiswick" environmental conditions, 1995. Values range from 0-1. Lowest value indicates the most limiting conditions whilst the highest value represents non-limiting factors for plant growth (—— GAI or light; —Δ— soil moisture; —O— temperature; ⊗⊗ ⊗⊗ waterlogging; and —— fertility status of soil).

3.3.5 Comparison of Predicted and Measured Feed On-Offer (FOO) of the Three Pasture Types

Measurements of feed on offer (FOO) were made on the three pasture types under grazed (sheep on) and ungrazed (sheep off) using the exclosure technique. This measurement was made by the pasture plate meter (or rising plate or falling plate) as outlined in section 3.2.2.

3.3.6 Phalaris (Phalaris aquatica) Pasture

Relationships were explored from 8 concomitant measurements (288 individual observations) of meter readings with the same combination of the model predictions. Several relationships between measured and predicted FOO were tried to verify the model predictions. In all situations, the linear model resulted in the best fit among the available data sets. The relationship between measured change in feed on offer (FOO) and predicted for the different observation periods are presented in Figure 3.6 (a), (b), (c) & (d). These data sets adequately represent the seasonal effects on both Δgreen FOO and Δtotal FOO. The results from ungrazed phalaris (Figure 3.6 a, b) for green and total FOO show that at each harvest and for the pooled data (predicted), there were significant relationships ($P<0.05$) between the change in green FOO and total FOO predicted from the model. The R^2 value for the pooled data, was 0.80 for green FOO DM (Figure 3.6 a) and 0.60 for total FOO DM (Figure 3.6 b) for the ungrazed phalaris pasture, and the S.E. of the Y estimates were ±756 and 1340 kg ha^{-1} dry matter respectively. The paired t-test of sample means showed no difference between the observed and predicted data.

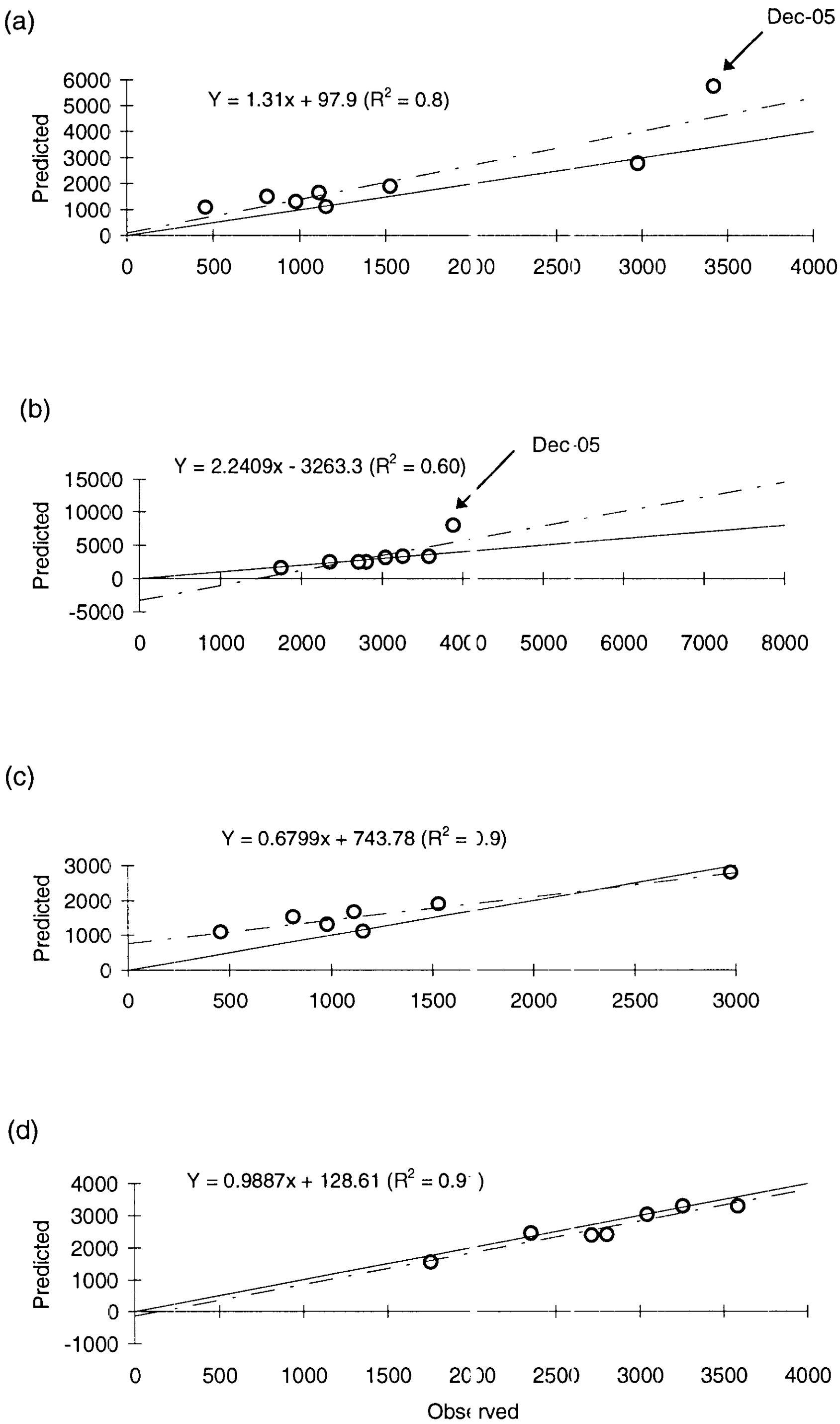

Figure 3.6 Phalaris: A comparison of regression analysis, observed and predicted change in FOO of green and total herbage (DM kg ha^{-1}), 1995. (a) change in green FOO, ungrazed (b) change in total FOO, ungrazed (c) change in green FOO when the extreme point in Dec-05 was excluded from the regression (d) change in total FOO when the extreme point in Dec-05 was

excluded. The solid line (——) in the regression shows the 1:1 relationship whereas the broken line (– — –) is the line of best fit to the model.

The model's prediction is considerably higher in the December harvest (3418 vs 5752, 3884 vs 7939) for both Δgreen and Δtotal FOO under ungrazed conditions. However, when these extreme points were excluded from the regression, the R^2 values were improved from 0.8 to 0.9 (Figure 3.6 c) and from 0.60 to 0.91 (Figure 3.6 d) respectively. The phalaris pasture (grazed) did not show any significant relationship either in green or in total FOO even after excluding the December data sets (Table 3.2).

3.3.7 Degraded Pasture

The degraded pasture at Big Ridge 2 experimental site "Chiswick" consisted of a mixture of C_3 and C_4 species, for example *Eleusine*, *Chloris*, *Danthonia*, *Eragrostis*, annual clover, *Vulpia*, broad-leaf weeds etc. which are predominantly summer active and have slightly different growth rhythms and life cycles. As explained earlier in Chapter 2 that due to the developmental stage of the model (version 1.2.5.a) which has a number of programming and technical difficulties, it was not possible to model mixed pastures. It was not possible to simulate a new species and because of this the turnip model was over-written to produce one for *Eleusine*, which was the major contributing species in the degraded pasture.

In the comparison, *Eleusine* did not show any significant relationships with the observed data sets with either grazed or ungrazed pastures (Table 3.2). However in

Table 3.2 Comparison of the regression analysis of the three pasture types.

	Y	a	b	x	R^2	Status	t-test	Remarks
Phalaris:	P G	283.2	1.472	O G	0.24	NS	Sig	Grazed
	P T	43.89	1.28	O T	0.12	NS	Sig	Grazed
	P T	308.5	0.942	O T	0.32	NS	Sig	Grazed, E.P.
Degraded:	P G	-561.4	0.832	O G	0.41	NS	Sig	Grazed
	P G	58.58	0.003	O G	----	----	----	Ungrazed
	P T	-556.1	2.445	O T	0.40	NS	Sig	Grazed
	P T	837.0	0.341	O T	0.03	NS	Sig	Ungrazed
Phal/Wc:	P T	-3284	3.933	O T	0.45	NS	NS	Grazed

Legends:

P (G/T) = predicted (green/total) feed on-offer (DM kg ha^{-1})

O (G/T) = observed (green/total) feed on-offer (DM kg ha^{-1})

E. P. = excluded point, here refers the regression relationship after excluding the December data set from the regression.

Phal/Wc = phalaris and white clover

the period when *Eleusine tristachya* was the major species, and made up 38 to 56% of the total pasture on-offer, the percentage of variation explained by the regression were surprisingly high both under grazed (93%) and ungrazed (84%) conditions (Figure 3.7 a, b).

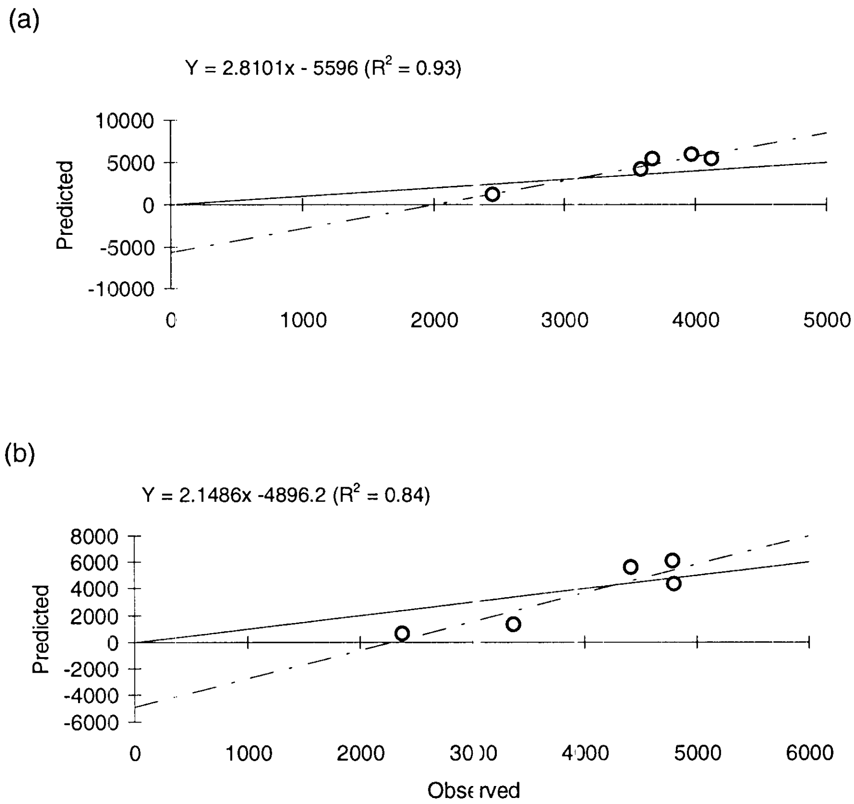

Figure 3.7 A comparison of Δ total FOO (DM kg ha^{-1}) of the degraded pasture with Eleusine tristachya, the simulated species after the exclusion of spring data points when Eleusine was not growing from the regression. (a) grazed (b) ungrazed, Solid line (——) shows the 1:1 relationship whereas the broken line (– · — –) is the line of best fit in the model.

3.3.8 Phalaris/White clover Pasture

Relationships between measured and simulated data sets from the model for the phalaris and white clover pastures were explored. There were significant relationships ($P<0.05$) under grazed and ungrazed conditions for Δgreen FOO and Δtotal FOO. However, Δtotal FOO (grazed) did not show a significant relationship ($R^2 = 0.45$) (Table 3.2). The percentage of variation explained by the regression (R^2) were 71%, 94% and 60%; and the S.E. of estimates were ±1173, 611 and 1937 DM kg ha^{-1} for the change in green FOO (grazed), change in green FOO (ungrazed) and the change in total FOO (ungrazed) respectively.

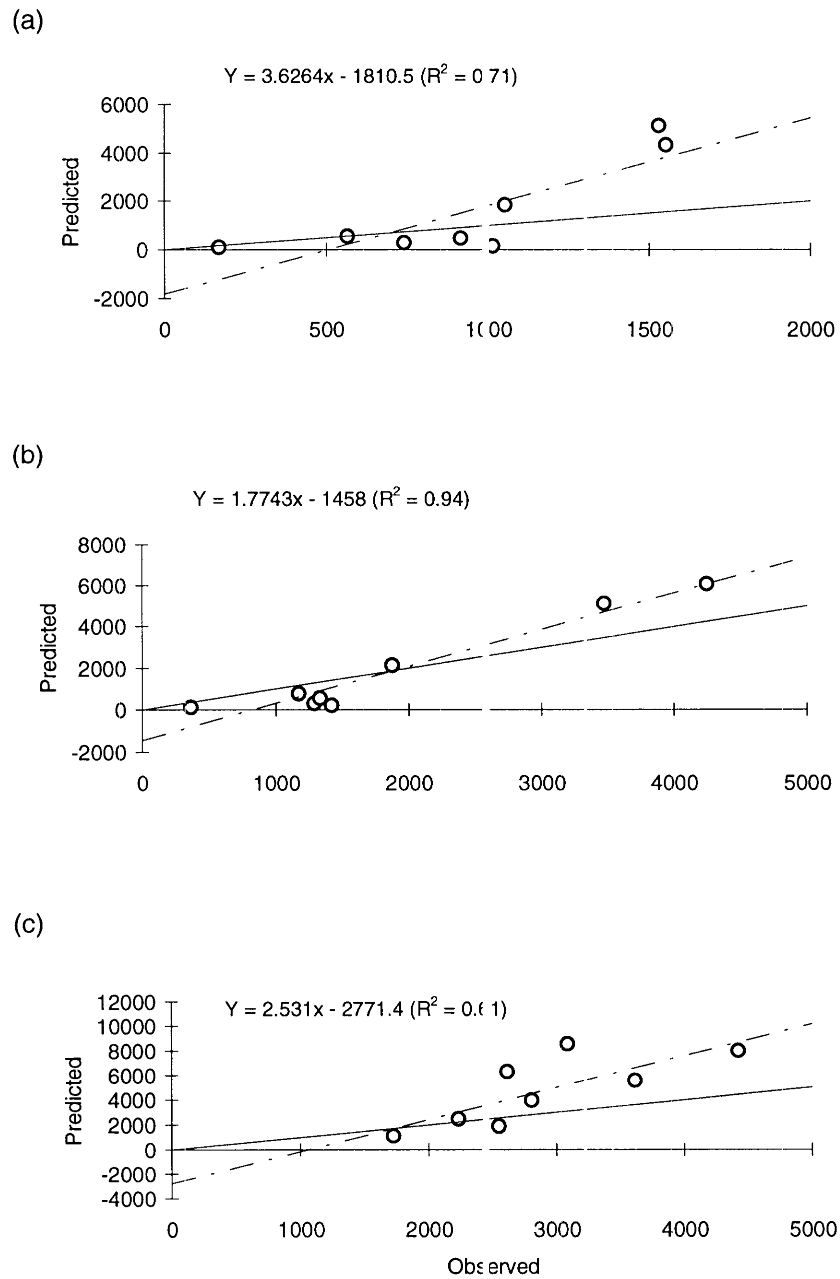

Figure 3.8 Phalaris/white clover: The relationship of Δgreen FOO and Δtotal FOO (DM kg ha^{-1}) between measured and simulated, 1995; (a) Δgreen FOO (grazed), (b) Δgreen FOO (ungrazed) and (c) Δtotal FOO (ungrazed). The solid line (——) in the regression represents the 1:1 relationship whereas the broken line (– · — –) is the line of best fit in the model.

The t-test of the paired sample means for the significant equations further confirmed no difference between the measured and predicted lines. Despite the significant test of the regression and non-significant analysis of the t-test, the model, like in the phalaris pasture, generally tended to predict noticeably higher in the December harvest under both grazed and ungrazed conditions. Moreover, the predictions were considerably higher, almost 2x, for the total FOO (ungrazed) in other harvests as well.

3.4 Discussion

3.4.1 Average Change in Feed On Offer (Δ FOO) of the Three Pasture Types

Variability in plant growth and pasture production on the Northern Tablelands and slopes districts can be very large and for this reason, it is wise to consider all important variables that may affect growth and production in the paddock. The most important factors (McDonald, 1995) to consider are climate, soil, grazing management, and soil fertility and fertiliser use; of these the climate is considered as one of the most influential and erratic factor.

The mean of Δ FOO of the three pasture types are presented in Figure 3.3. Each pasture types exhibited the highest growth rate in the summer, followed by spring, autumn and winter. Summer growth rate was mostly accompanied by a higher percentage of dead material than the spring growth. Therefore, the maximum green growth rate took place in the spring in the phalaris and phalaris/white clover pastures. The degraded pasture, consisting a mixture of year-long green species (*Danthonia linkii* Kunth) and summer-growing frost susceptible species (*Eleusine, Eragrostis, Chloris* etc.) did not have a higher growth rate in summer than the other two introduced pastures. In the experiment of Robinson and Archer (1988), using frequent cutting and low levels of irrigation, these species including *Themeda australis* Stapf, *Sporobolus elongatus* R. Br. and *Bothriochloa macra* S.T. Blake, outyielded the introduced species (*Phalaris aquatica* L. cv. Sirosa, *Festuca arundinacea* Schreb. cv. Demeter, *Trifolium repens* L. cv. Haifa).

Some of the effects associated with lower growth rate of the degraded pasture are low carrying capacity, unpalatability of the species on-offer and the lower digestibility which result in an accumulation of uneaten herbage (the beginning herbage mass, BHM) (Archer and Robinson, 1988; Lodge *et al.* 1990; The Northern Site Team, 1995 unpublished) and consequently reduced the relative growth rate (RGR) potential of the pasture (Bircham and Korte, 1984; Hodgson, 1990; Lile and George, 1993; Cacho, 1993). The winter and spring growth rate of the three pasture types match well with the curve produced by the SPUR (Simulation of Production and Utilisation of Rangelands) (McDonald, 1995) model and the published data for phalaris and white clover (Lazenby and Swain, 1973) for the Northern Tablelands of NSW. The negative net growth rate of the degraded pasture in the winter is exceptional.

The decline in FOO during winter in the degraded pasture can be explained by the variation in photosynthetic gain and senescence and decomposition rate of the herbage. Negative net growth rates were also encountered with the other two pastures (phalaris and phalaris/white clover) in the individual readings but these were compensated for in the mean data. For most of the period the photosynthetic rate of phalaris and phalaris/white clover, or the absolute growth rate (not measured in this experiment), i.e. an expansion and elongation of lemina and stem (Hurd, 1977; Parsons *et al.* 1983; Johnson and Parsons, 1985; Parsons *et al.* 1988) was higher than the respiratory loss and decomposition whilst in case of the degraded pasture the situation was reversed due to high senescence rate of the herbage and the overall high decomposition rate, and other losses such as losses by wind. High decomposition rate can be associated with high quality pasture, such as in phalaris and phalaris/white clover (King, 1991), however, the quantitative loss (breakdown) from the dead pool was higher with the degraded pasture. This has also been observed by The Northern Site Team (1995 unpublished data).

3.4.2 Comparison of DGR

The measurement of growth for the three pasture types was undertaken according to the experimental protocols of the Temperate Pasture Sustainability Key Program, September 1993, which were based on those developed by Cayley and Bird (1991). This provides a measurement of the so called net pasture growth (NPG), which is the difference between true growth and decay. This has been considered as Δ FOO in this study. The details of the measurement are explained in section 3.2.2.

The method of calculation of growth rate in the model is not clear. Because of this the following assumptions were made prior to making the comparison between predicted and observed data. Phalaris pasture was simulated on a 'loamy clay' soil with stocking rate (SR) of 12 dse ha^{-1}. The reference weight (RW) of the grazing animal was 43 kg each (conceptus free). Nutrient status of the paddock was not a limiting factor for plant growth which means the fertility scaler in the model was set at 1.00. The result was plotted for the total herbage on-offer and growth rate simultaneously on a daily basis. For example:

	Herbage on-offer (kg DM ha^{-1})	Growth rate (kg DM ha^{-1} d^{-1})
10 March 1995	8983	7
11 March 1995	8964	5
	.	.
	.	.
	.	.

The difference in herbage on offer between March 10 th and 11th, 1995 is 19 kg DM ha^{-1} which represents animal intake (AI) plus decay (D), whilst the predicted growth is 7 kg DM ha^{-1} d^{-1}. Therefore, the apparent growth rate (AGR) = true growth rate - decay = 7 - 19 = -12 kg DM ha^{-1} d^{-1}.

$$AI = RW * (Intake\ of\ DM\ by\ 2\%\ of\ the\ BW) * SR \qquad (3.2)$$

$$= 43 * 2/100 * 12 = 10.32\ kg\ DM\ ha^{-1}\ d^{-1}$$

$$\therefore Decay\ (D) = 19 - 10 = 9\ kg\ ha^{-1}\ d^{-1}$$

These assumptions are based on the flow chart of the pasture production process produced by Bircham and Korte (1984), P.J. Vickery pers. comm. and K. Hutchinson (unpublished data).

With this understanding, a comparison of growth of the three pasture types was made between measured and predicted data and there were no significant relationships found between these two data sets. Several transformations of the measured data set were tried but none of them showed any reasonable relationship. However, the measurement of the pasture at day_0 (grazed) and day_t (ungrazed) have shown reasonable and significant relationships between observed and predicted data which are presented in the discussion section 3.4.4.

3.4.2.1 Some possible reasons for the discrepancies of measured and predicted growth rates

Measurement of plant growth has been found to be one of the most variable areas of pasture research. Different researchers have shown different ways and implications of growth measurement. Most objectively, it has been found to be guided by the need and the field of application, i.e. research and production. For instance, Lile and George (1993) measured the DGR for feed budgeting on a Californian irrigated pasture using a pasture probe with rotational grazing between the beginning and end of the rest period. Robinson and Archer (1988) estimated the DGR, so called the average relative growth rate (RGR) in a cutting sward (ungrazed) on a fortnightly basis using the following equation:

$$(\log Y_{t2} - \log Y_{t1})/(t_2 - t_1) \qquad (3.3)$$

where, Y = herbage mass (HM) and t = time in days.

According to Thornley and Johnson (1990), this relationship only applies to exponential growth.

The sample was separated into green leaf (lamina only), green stem (+ leaf sheath), and dead matter on each occasion.

Grant *et al.* (1983) measured the rate of growth and senescence of leaf lamina per tiller and of changes in tiller population densities in a continuously stock sward using the exclosure technique. For the measurement of tissue turnover the tillers were marked at their bases using a twist plastic covered wire and the lengths of the individual laminae (green leaf only) were recorded. In the case of immature laminae the length noted was the visible length (i.e. from the tip of the leaf to the point of emergence). The transects were protected from grazing by cages for 6 days after which the tillers were re-measured to establish the length (mm) of new leaf which had emerged and of green leaf which had senesced per tiller. This procedure was repeated for each measurement. The linear measurement of both immature i.e. expanding laminae (to calibrate growth) and of mature green laminae (to calibrate loss to senescence) were converted to weight at weekly intervals.

In a study of physiology of grass production under grazing, Parsons *et al.* (1983) estimated canopy photosynthesis using the modified technique explained by Grant *et al.* (1983). In the procedure, samples were divided into growing leaves, youngest fully expanded leaves, older leaves, sheath (pseudostem) and dead tissue. The number of tillers in the sub-sample was counted. The areas of laminae in each leaf category, and projected area of sheath, were measured using an electric planimeter. Samples were ground and analysed for carbon content to correct errors in the calculation of total dry weight of each category in the sward.

Many research workers (Jagusch *et al.* 1978; Grant *et al.* 1981; Bircham and Hodgson, 1983; Frame, 1993) have measured the growth, either with rotational grazing, i.e. the measurement of difference between the beginning and the end of rest period, or with a continuous grazing system using the exclosure technique. For an accurate determination of growth, the movement of exclosure cages should be made frequently. The measurement of herbage production. or net production in these circumstances, is the amount of live and dead herbage that accumulates between the two points in time, i.e. it is the resultant of the process of new growth and disappearance. Many other different techniques have been used to measure growth and production but all measure the balance between new herbage growth and its disappearance which is determined by utilisation i.e. efficiency of harvesting. "New herbage growth has been measured by only a few research workers throughout the world because the measurements are both difficult and time consuming" (Bircham and Korte, 1984), as some of these procedures are explained above.

Taking these different techniques of growth measurement into account (from the simple to the most sophisticated) it can be inferred from this short review that different researchers have their own way of measuring pasture growth and it can also be assumed that these methods would have a wide range of variation between them. In most pasture measurement experiments, the interval between the successive measurements was generally kept to less than 7 days whilst in the experiment at Big Ridge 2, measurements were made monthly or sometimes even longer. This could be the factor which contributed to the large variation in the comparison with the model's prediction, which calculates DGR on a daily basis. If the model calculates the absolute growth rate (AbGR) that should always be higher than the apparent growth rate (AGR) as indicated in the above assumptions, provided the assumptions made for the model are correct. J. Donnelly, A. Moore, and M. Freer (1994 unpublished) reported in the discussion document at a Tamworth workshop that the growth rate predicted by the model would generally be higher than the AGR as measured by the usual exclosure techniques. This trend was not observed in this study. It is still to be confirmed which kind of exclosure techniques they used. Because of these fundamental differences between the observed and predicted growth measurements, no further comparisons were made.

3.4.3 Simulated growth curves for Phalaris, White clover and Eleusine

The major fundamental differences between these three species in terms of biomass production, light interception, temperature and available soil water (ASW) responses are briefly presented in Table 3.3 (for detail, see Appendix 1).

(a) Eleusine

Growth curves of the three pasture species (*Eleusine*, *Phalaris*, White clover) using 1995 weather data are represented in Figure 3.4. *Eleusine* being a tropical C_4 pasture plant exceeded the growth rate produced by the other species. Considering the weather data of 1994/95 (Figure 3.2), this is the effect of temperature and solar irradiance. The influence of temperature on net photosynthesis is well known and the response of a number of species has been well documented by Hesketh (1968). This author reported that species with higher rates of photosynthesis tend to be those with a tropical origin and a higher optimum temperature for photosynthesis. Black (1971) reported that this difference in photosynthetic rate between species is the reason for the higher dry matter production of tropical species. In contrast, when C_4 plants of tropical origin are grown in temperate regions, their potential growth rate is first restricted by the lower cool night temperatures, a characteristic feature of temperate environments (Vickery, 1981). The reason for the prediction of higher growth rates of *Eleusine* is due to the higher value of the maximum temperature response in the parameter set (e.g. 40°C) compared to 30°C and 27°C of phalaris and white clover respectively (see Appendix 1). Another reason for the high prediction is the notional maximum net primary production (NPP) which was set out 3 to 4 times greater than these two species. This set of parameters for temperature and production responses were in line with those of Cook *et al.* (1978) and Mitchell (1956) (see parametrisation section, Chapter 2). With these parameters the predicted growth rate of *Eleusine* seems to be higher than observed in the field. Because of this, the production response of the species should be decreased from 400 to 300 kg DM ha^{-1} d^{-1} and the maximum temperature for growth from 40 to 35°C. These changes are in line with Hatch (1971) and Vickery (1981).

Table 3.3 A summary of some of the major differences in parameters setting for the three species. Parameters for Eleusine are newly created whereas phalaris and white clover are the original set from the model. Some of these parameters require fine adjustments as explained in the discussion.

	Phalaris	*White clover*	*Eleusine*
Notional maximum NPP	160	180	400
Biomass for LAI = 1	950	700	870
Light extinction coefficient	0.60-0.90	0.70-0.90	0.65-0.70
Temperature Response (°C):			
Low (5%)	2.0	3.0	10.0
Low (95%)	9.0	12.0	25.0
High (95%)	18.0	22.0	35.0
High (5%)	30.0	27.0	40.0
Soil moisture response	0.25	0.35	0.20

The lower temperature response would be expected to work reasonably well as *Eleusine* does not grow in the winter or when overall temperature drops below 10°C (Figure 3.2 b and Figure 3.4). This effect is well represented in the factors of plant growth Figure 3.5 (a). The overall growth of *Eleusine* in the temperate environment is most adversely affected by the temperature, particularly in the winter.

(b) Phalaris

Phalaris had a high growth rate (about 80 kg ha^{-1} d^{-1}) in the Armidale field conditions when the soil moisture is non-limiting factor for plant growth. When the soil moisture becomes a limiting factor and temperatures increases in January daily growth rate declined drastically to about 10 kg ha^{-1} d^{-1} (Figure 3.4). This is the time when *Eleusine* has its highest growth rate due to the temperature effect and it can also tolerate more water stress than phalaris. These responses to temperature and soil moisture between these two types of species has been found by various workers (Hatch, 1971; Black, 1971; Gifford, 1974). Like the tropical species, when the temperate C_3 species are grown in the tropics they are above their optimum temperature for photosynthesis, and they waste much of the energy they have fixed by continuing to respire. However, as soon as this condition develops, phalaris goes to a dormant stage to escape from both the low soil moisture and the high temperature stress in the temperate environment (Vickery, 1981). This is the main agronomic and ecological attribute of this species which enables it to persist in the long-term and survive under harsh conditions.

(c) White clover

As soil moisture is one of the most determining factors for white clover, it showed measurable growth during 1995. Lazenby and Swain (1973) demonstrated the effect of water stress on the production of the three exotic species, i.e. phalaris (*Phalaris aquatica*), perennial ryegrass (*Lolium perenne*), and white clover (*Trifolium repens*). Under irrigated conditions, the production was recorded at 3200, 4000, and 5000 kg dry matter per hectare respectively. When they were grown under non-irrigated conditions, the production of white clover declined remarkably to 500 kg ha^{-1} and of ryegrass to 2500 kg ha^{-1}. Phalaris was the lowest yielder among the tested species under irrigated conditions but the relative decline, compared to others, was much less under rainfed (non-irrigated) conditions (3200 to 2400 kg ha^{-1}). White clover production throughout the winter was almost zero due to high moisture stress. Because of its complete disappearance, white clover was re-sown in 1995 at the Big Ridge Site 2 to maintain the white clover in the phalaris sward. Winter in 1995 was exceptionally dry.

Analysis of the factors affecting growth show that the growth of white clover during 1995 was severely affected by light (Figure 3.5 c). Solar radiation has rarely been found to be a limiting factor in Australian pasture under normal growth and sward canopy (Figure 3.2 c). It is well known that after reaching a ceiling yield, plants suffer from the light competition. Because of this, there will be no further light interception by the lower layers of leaves in the sward beyond this point, leading to negative balance of the assimilates. This has been well documented by various authors (Donald, 1961; Stern, 1962; Brown and Blaser, 1968; Bircham and Korte, 1984; Korte *et al*. 1987; Gay, 1993). Therefore, light should not be the limiting factor for white clover because it never attained its yield potential in 1995 because of moisture stress. In the parameter set the value of light extinction coefficient for white clover should be changed from 0.7-0.9 to 0.65-0.70. This change is made in line with the suggestion of Stern (1962).

3.4.4 Comparison of Feed On-Offer (FOO) of the Three Pasture Types

As explained in the earlier section the experiment was conducted throughout 1995 which was exceptionally dry at the start of the year. However, the later part of 1995 was exceptionally wet. In general, Australia faces severe drought once in every ten years and moderate drought once in five years (Scott and Virgona, 1994). These droughts have devastating effects on the pastoral community. Perennial and annual grass species and legumes react differently to the periods of drought and immediately after its cessation.

(a) Phalaris

Dry matter production and its components fluctuate from year-to-year and on different soil types (Ayres *et al*, 1995). Robinson and Archer (1988) recorded 3079 (spring), 2324 (summer), 2144 (autumn) and 510 (winter) kg ha^{-1} dry matter yield of phalaris and that of green 2348, 1137, 1734 and 317 kg ha^{-1} DM respectively. The experiment was conducted at Glen Innes (latitude 29° 44' S.; longitude 151° 42' E., altitude 1057m) on a self-mulching black soil of basaltic origin in a paddock with a long history of cultivation. Their measurements of total and green DM yield support the observations made at "Chiswick" Big Ridge 2 under ungrazed conditions. However, minor discrepancies between these two studies are evident on occasions. At the Big Ridge 2 Site, phalaris constituted only up to

88% of pasture on-offer. The remainder were broadleaf weeds and annuals and perennial summer grass species.

A comparison of observed, and the predicted data sets from the model have shown significant correlations between Δtotal FOO and Δgreen FOO under ungrazed conditions over time except at the December harvest. General discrepancies between the observed and predicted are inevitable due to difference in pasture composition. The simulation results are for a pure stand of phalaris whereas the observed was a mixture of up to 20% other annuals and perennials summer growing species which have different growth rhythms and contribute differently to the total and green dry matter.

Despite these minor discrepancies, the model tends to over-predict by more than two fold at the December (summer) harvest (i.e. 3418 vs 5752; 3884 vs 7939) for both green and total dry matter (Figure 3.6 a & b), which when excluded from the regression dramatically improve the relationships, particularly with Δtotal FOO (ungrazed), i.e. the coefficient of variation (R^2) from 0.80 to 0.90 and 0.60 to 0.91 for the Δgreen FOO and Δtotal FOO respectively. The models higher prediction in the December harvest is supported by the findings of Mcwilliam (1973). This author found that during the late spring and early summer phalaris enters into the reproductive phase; causing the physiological transformation of the carbon substrates being more partitioned to the above ground part than the underground root system. Because of this the translocation factor in the model would have to be given more weighting than in a normal vegetative pasture plant.

The another possible reason for the high prediction could be that the model may not sufficiently take into account the subsequent effect of drought on the resilience and recuperation phenomenon of perennial pasture plants (Hutchinson, 1992). In 1995, December was a wet transitional stage just after the cessation of the long drought which would be expected to cause considerably more damage to root systems than to shoots (Wilson, 1988). Caloin (1994) showed the effect of water stress in modelling of root and shoot partitioning of *Dactylis glomerata*. Prior to drought stress, perennial plants, for example *Phalaris aquatica*, perennial ryegrass *Lolium perenne*, *Dactylis glomerata* initially put more assimilates towards the building of root reserves which was spent during the survival of drought and/or severe defoliation and gradually increase the partitioning to the above ground parts (Caloin, 1994; FitzGerald *et al.* 1995). This finding is also supported by Jones (1995) that "high initial production and long-term persistence are inversely correlated". FitzGerald and his colleagues at Glen Innes in a drought study found that among the exotic species (i.e. Fescue, Cocksfoot, Ryegrass and Phalaris) phalaris showed an exceptional contribution to the pasture composition (from 1994 to 1995).

Considering these facts, it can be inferred that the model should not show an abrupt increase in growth and DM yield immediately prior to cessation of drought and the start of rain. In order to determine the post-drought effect on the prediction, the model needs to be tested under several droughts and climatic regimes.

The comparison of Δgreen FOO and Δtotal FOO in respect to the model prediction did not show any significant relationships under grazed pastures, even after the exclusion of the December data set (Table 3.2). This is presumably due to the fact of frequent changes in stocking rate in the experiment which was not compatible in the model particularly for the short simulation runs. Although a weighted average stocking rate was used in the model it was still unrealistic when SR in the field was abruptly changed from 10 to 20 and then to 12.5 dse ha^{-1}. To make a fair comparison, it was attempted to change SR by halting the simulation process but this procedure locks up the model.

The other possible reason for the discrepancy, although minor, would be the separation of green and dead which was not performed at the same time as the measurement for the grazed pasture, as it was in the ungrazed cages. These are the two major sources of error, most importantly SR, causing discrepancies between observed and simulated data sets in the grazed pasture.

(b) Degraded (Eleusine based) Pasture

The *Eleusine* based degraded pasture did not show any significant ($P<0.05$) relationship between observed Δgreen FOO and Δtotal FOO with the model predictions either under grazed or ungrazed conditions (Table 3.2). The discrepancies between Δgreen FOO and Δtotal FOO appeared in the whole simulation. This does not mean that the model was not working properly with the *Eleusine* pasture. The reason for the discrepancies was the fundamental differences between the two pastures (observed vs simulated). The observations made in the experiment constituted a complex mixture of C_3 and C_4 plant species, ranging up to 56% *Eleusine*, 30% broadleaf weeds, up to 64% annual clovers in the later part of 1995, 16% *Danthonia*, 19% *Vulpia*, 13% *Eragrostis*, 12% *Phalaris* and others. Their contribution to the total yield, dead pool and green dry matter were different and therefore the quality differed widely with time and season (Lazenby and Lovett, 1975; Cook *et al.* 1976; Archer and Robinson, 1988; Robinson and Archer, 1988; Jones, 1995; McDonald, 1995; Archer, 1995; Marshall and Nelson, 1995; Dowe *et al.* 1995) whereas the simulated pasture was a pure stand of *Eleusine* which has a short growing period being usually active from the onset of summer, i.e. December through to the late autumn, i.e. April (Burbidge, 1966; Lodge *et al.* 1990). Generally, *Eleusine* pastures are uneaten (The Northern Site Team, 1995 unpublished) and are not relished by livestock due to their tough fibrous leaves, low palatability and digestibility (Lodge *et al.* 1990). The Northern Site Team (1995 unpublished) of Sustainability Key Program at "Chiswick" Big Ridge 2 observed that grazing sheep selectively grazed broadleaf weeds (mainly *Hypochoeris radicata,* which is more succulent and palatable, probably due to high sugar content) when *Eleusine tristachya* alone composed 55% of the total pasture species on offer. Taking this information into account, the relationship was re-established between the degraded pasture (when *Eleusine* had major contribution to the total FOO) with the pure stand of *Eleusine* simulated from the model, the percentage of variation (R^2) measured up to 93% and 84% for grazed and ungrazed pastures respectively (Figure 3.7 a & b). The reason for the comparatively lower R^2 value for ungrazed pasture is likely due to one and half month time difference in the grazed pasture when the contribution of *Eleusine* to the dead pool and/or total herbage declined sharply in both the simulation and observation, whilst other species, such as *Danthonia*, *Vulpia*, broadleaf weeds and other species started contributing substantially to the green and dead pool of the observed data set (641 vs 2375). In conclusion, although it was a partial comparison (by excluding spring data sets from the regression) there is a strong indication that the model predicts *Eleusine* growth reasonably well.

Further evaluation of the *Eleusine* simulation was sought through changes in stocking rate. The model was simulated for 2 and 10 dse ha^{-1}, however there was a little or no difference in Δtotal FOO observed between these two stocking rates due to its low digestibility and palatability (Lodge *et al.* 1990; The Northern Site Team, 1995 unpublished; P.J. Vickery, pers. comm.). Thus SR does not have strong effect on the *Eleusine* pasture. This also further confirms that both stocking rate and the *Eleusine* routine are working reasonably well in the model.

(c) Phalaris/ White clover

Basically, treatment 2 (phalaris, plot 3, 6) and 3 (phalaris and white clover, plot 4, 5) were the same from the botanical composition stand point due to the severe drought in 1994/95. The contribution of white clover declined markedly during the year consequently it was re-sown in the middle of 1995, however it did not grow well until late 1995 due to low available soil moisture (ASM).

The change in green FOO and total FOO biomass simulations for the model calibration using 1995 data for the grazed and ungrazed pastures are shown in Figure 3.8 a, b, and c. Simulated above ground production for Δgreen FOO agreed well the observed Δgreen FOO (R^2 = 0.94) under ungrazed conditions (Figure 3.8 b). However, despite the significant relationships ($P<0.05$) between simulated biomass production for Δgreen FOO (grazed) and Δtotal FOO (ungrazed) with the observed data, the R^2 values are considerably lower (0.71 and 0.61) compared to Δgreen FOO (ungrazed) (Figure 3.8 a, c). In general, the predicted values followed a similar pattern as with the phalaris pasture but the simulated data exceeded the 1995 observations for the phalaris and white clover mixed pasture. This is mainly because of over prediction of the white clover component simulated in the mixed sward.

To obtain the fits to the 1995 observed above-ground biomass for Δgreen FOO and Δtotal FOO under grazed and ungrazed conditions, some radical adjustments need to be made with white clover parameters set. The first is to decrease the notional net primary production (NPP) from 180 to sufficiently lower than phalaris, 160 kg $ha^{-1}d^{-1}$. This decrease is in line with Johns (1973) who compared the three temperate grasses; phalaris, tall fescue and perennial ryegrass; and a temperate legume white clover under rainfed (dryland) Armidale conditions. The second adjustment to be made is with the soil moisture response (SMR) variable. The SMR value should be increased from 0.35 to 0.60. This is again in line with Johns (1973) and Lazenby and Swain (1973).

The third adjustment involves the two parameters of allocation to the target root:shoot ratios (RSR). The value of RSR at the start of reproduction in white clover should be decreased from 5.00 to 1.4 and at 50% flowering from 2.00 to 1.00. These changes are in line with Johnson (1991) based on his statement that "mineral deficiency leads to a relatively greater proportion of plant growth being partitioned to the roots" and general calculations for grasses and legumes.

Discrepancies occurred between observed and simulated data for the Δtotal FOO (R^2 = 0.45) under grazed conditions for the phalaris and white clover pastures (Table 3.2) for the same reasons explained in the phalaris pasture.

3.5 Application of GrassGro

3.5.1 Environmental Comparison

One of the basic uses of the model is to analyse how weather and soil differences affect both pasture and consequently animal production. The model was used to compare Canberra (35° 18'S, 149° 6'E) and Cooma (36° 13'S, 149° 8'E) which are located in the northern and southern parts of the Southern Tablelands and Armidale (31° 31'S, 150° 39'E) which is in the northern part of the Northern Tablelands of New South Wales. The data in Figure 3.9 which was generated from the model shows that Cooma has lower temperatures than Canberra and Armidale (Chiswick) and is also drier, especially in winter and spring. On the other hand, overall total annual average precipitation at Armidale (787 mm) is much higher than Cooma (521 mm) and slightly higher than at Canberra (713 mm). The effects of these climatic differences on the growth and productivity of pasture stocked at 12 wethers per hectare can be seen in Figure 3.10.

Table 3.4 Farm information: These are some of the major but common inputs used for the simulation to all the three sites (Armidale, Canberra, and Cooma).

Enterprise	wether
Animal breed	Med. Merino Polworth
Standard reference weight	45 kg
Adult mortality	2%
Stocking rate	12 wethers (equiv. dse.) ha^{-1}
Live weight	43 kg (conceptus free)
Management	Simple, no rotation
Initial animal age	18 months
Pasture species	Phalaris and white clover
Soil type	Sandy clay loam
Fertility scaler	1.00

The general pattern of plant growth throughout the year is similar at the three sites but the spring growth at Cooma and summer growth at Canberra are much lower than at Armidale. Although Canberra and Armidale have almost the same pasture growth in the spring, annual average net primary productivity is much higher at Armidale than at both Canberra and Cooma. The environmental differences and their effects on growth and productivity are further classified and summarised in Table 3.5.

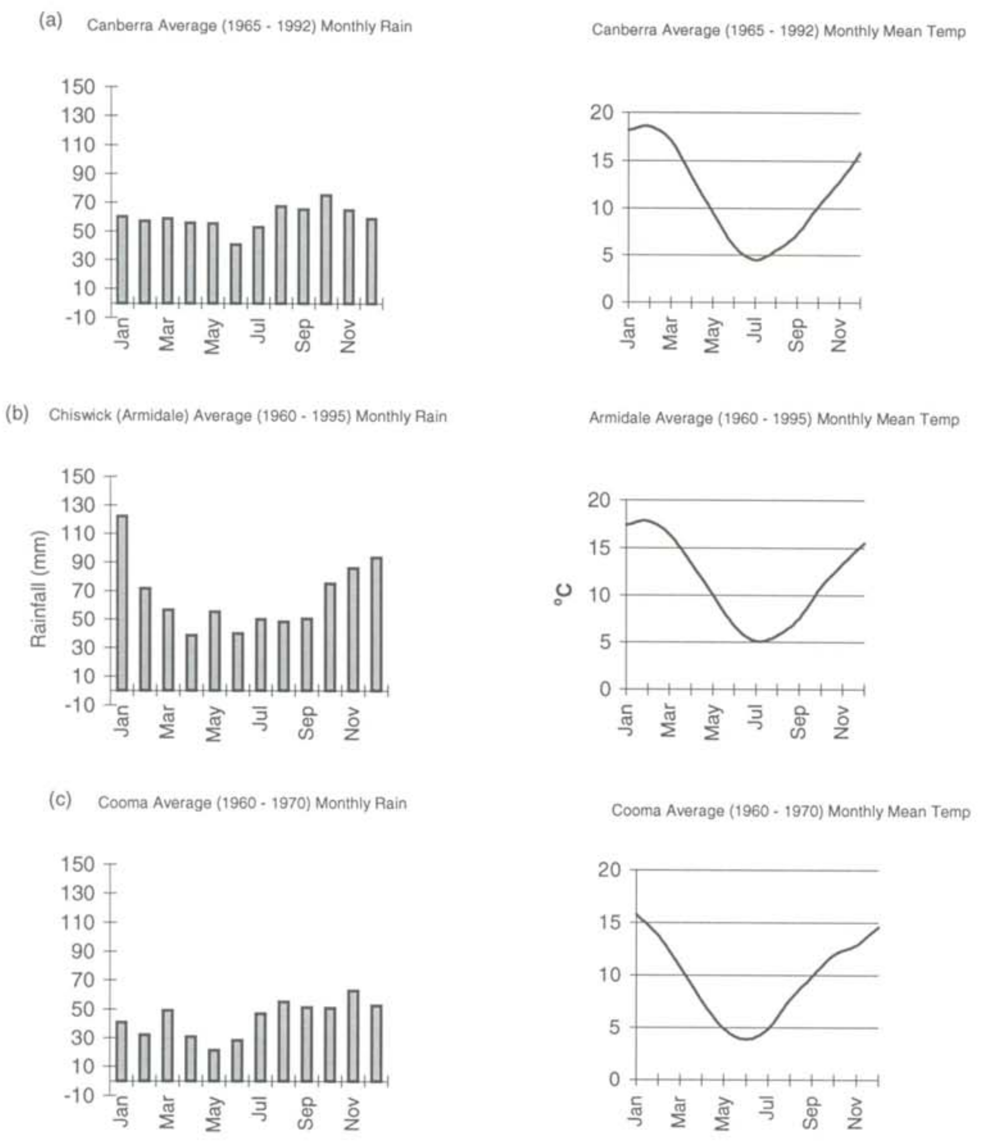

Figure 3.9 Long-term average of the environmental factors (Rainfall and Temperature) of the three sites and their consequent effect on the temperate pasture species.(see *Figure 3.10*)

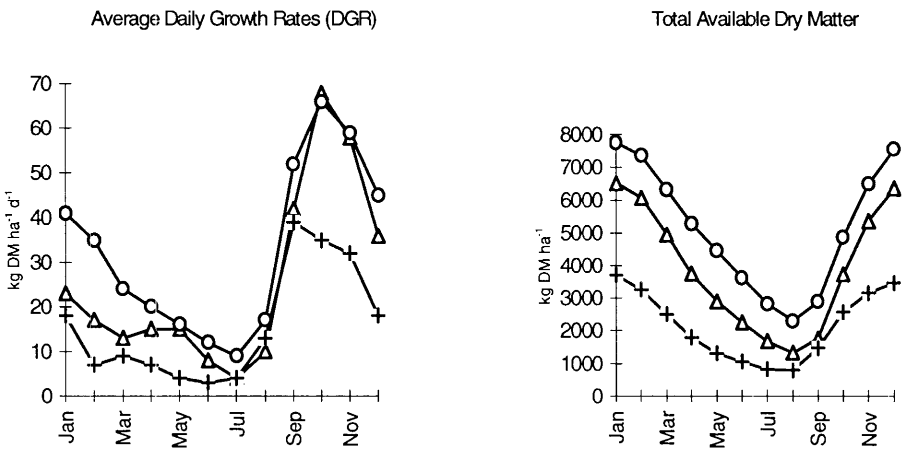

Figure 3.10 Simulated growth and productivity of temperate pasture species at the three sites as a consequent effects of the environmental factors (Figure 3.9) (—o— Armidale; —△— Canberra; — + — Cooma)

Table 3.5 Summary of simulated monthly and annual above ground production (kg DM ha^{-1} d^{-1}), and precipitation at the three sites.

	Canberra	Cooma	Armidale
Monthly av. growth rate (*kg DM ha^{-1} d^{-1}*)	26	16	33
Annual av. growth rate (*kg DM ha^{-1} d^{-1}*)	27	20	38
Annual available DM. (*kgDM ha^{-1}*)	6,527	3,771	7,751
Annual precipitation (mm)	713	521	787

3.5.2 Environmental Comparisons

The aim of this simulation was to see how the model predicts pasture growth and net primary productivity under different climatic conditions. It was intended to test the model with daily weather data of Kathmandu, Nepal. Unfortunately, despite our enormous and sustained efforts we could not obtain the full set of the required daily data, particularly radiation and pan evaporation. As a result, Kathmandu was replaced with Cooma which has some similar climatic conditions. However, the major differences between these two sites are precipitation, both in the amount and its distribution, being very high in

Kathmandu (altitude 1350m, surrounded by steep mountains rising up to 2800m above mean sea level), usually exceeding 1300 mm of which almost 80% falls during the monsoon months of June through to September. Monsoon rains have a tendency to be more frequent at night.

Armidale and Canberra have almost the same temperatures but are warmer than Cooma. Pasture growth and net primary productivity at Armidale and Canberra are largely governed by precipitation, i.e. the amount, seasonal distribution, reliability and its effectiveness. Canberra and Armidale are also similar in the amount of precipitation they receive annually but the seasonal distribution more closely matches to plant water use at Armidale than at Canberra, consequently the growth and net primary productivity are much higher at Armidale than at Canberra (av. annual growth 38 vs 27 kg DM/ha/day; av. annual available DM 7751 vs 6527 kg DM/ha) (Table 3.5). Detail of the seasonal effect of precipitation and the amount of water necessary for plants at different times can be seen in the report of Haurwitz and Austin (1944), Lovett (1973), and Hilder (1964).

In temperate region such as Armidale, a very small amount of precipitation in winter can supply a plant's water needs for longer period of time than the same amount of water in summer when both temperature and evaporation are high. However, deficiencies in precipitation are enhanced in regions where winter growth is severely curtailed by low temperature. This effect can be observed at Cooma.

In contrast, in climates such as in Canberra or Perth where more than 70% of rain falls between May and October winter rainfall cannot be fully utilised by plants whereas in the summer irrigation is required to maintain stands of plants. Because of this inappropriate distribution pattern the productivity of pasture are lower at Canberra than at Armidale, although they are similar in average annual precipitation. This type of information generated by the model will be of use when considering the appropriateness of grazing management for other localities.

3.5.3 Matching Animal Demand to Pasture Supply

A ten year intensive study by George and Pearse, 1978 of an ewe enterprise based on economic analysis showed that the choice of lambing time in breeding ewe flocks in the Northern Tablelands is governed by many factors, but one important element in the decision making process is the pattern of pasture supply. The sequence of pasture growth in relation to the reproductive cycle will affect the nutrition of pregnant and lactating ewes and subsequently the growth and survival of the lambs. It may also alter the likelihood of supplementary feeding and its proximate quantity that will be required to maintain the animal. The model can be used to illustrate how the animals' requirement matches the pasture supply through growth in a variety of pastoral and climatic regimes.

As an example, three Border Leicester x Merino flocks, each consisting 1000 ewes grazing perennial temperate pasture (*Phalaris aquatica* and *Trifolium repens*) at "Chiswick" were simulated with different lambing dates, namely 30 May, 29 July and 29 August; average conception rates for these lambing dates have been taken from George and Pearse (1978) and FitzGerald (1976). Lambs were sold once they reached an age of 187 d (26 weeks) or a live weight of 37 kg. Figure 3.11 shows how the patterns of pasture production and animal intake vary with lambing date. It is apparent that early spring lambing (August 29) results in a better match between demand for pasture by the flock and its availability than does winter or, to a lesser extent, autumn lambing.

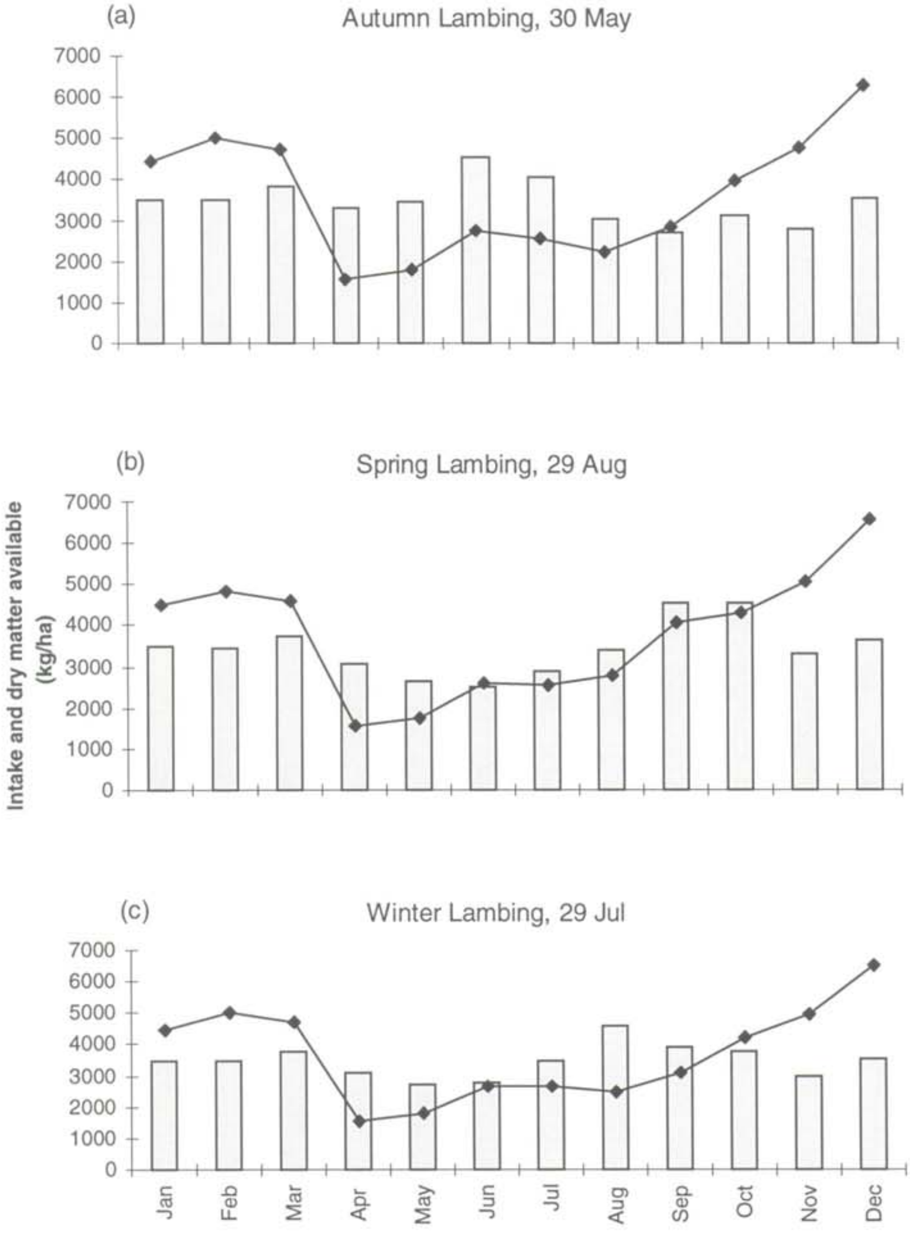

Figure 3.11 Pattern of animal intake and pasture supply simulated over 3 different lambing dates. Vertical bars represent the monthly intake of dry matter of the grazing animals (kg DM/ha) and the lines are the total available green dry matter on offer (FOO) (kg DM/ha).

3.5.4 Matching Supply with Animal Demand

In George and Pearse's (1978) study, three widely separated times of lambing with Merino ewe were tested. They concluded that the seasonal conditions can affect the results but, in general, spring lambing, a traditional system for the Northern Tablelands, gave the greatest number of lambs weaned, followed by about 3% lower in the winter lambing, and summer lambing being substantially lower than spring and winter. Although the difference between spring and winter lambing was not large, they found the cost of production was higher with winter lambing due to a relatively high supplement requirement, consequently it reduced the overall gross margin (GM) of the farm enterprise.

The authors also recommended that the optimum stocking rate (SR) for a phalaris and white clover pasture could be between 12 and 16 ewes ha^{-1}. In the simulation SR was taken from the Big Ridge 2 experiment. Furthermore, the dry matter intake (DMI) in the simulation calculated by the model was verified by the procedures adopted by Black and Bottomley (1980), and this showed no difference. In conclusion, the information generated by the model, used in conjunction with other factors such as month-to-month changes in lamb prices, can be used to guide a decision about the optimal lambing date.

3.6 Comments on GrassGro model

It should be noted that the GrassGro model version used in this thesis (version 1.2.5.a) was a developmental version. Many of the help files had not been written and the documentation to support the program was inadequate. In addition to the lack of help files, there were a number of technical problems in running the model such as the inability to model mixed pastures, nor to readily simulate a new species such as *Eleusine*. This is not a criticism of the model; rather, it is an explanation of some of the difficulties faced by this author and by the supervisor. At times, assumptions had to be made about what the model authors intended.

The setting of parameters for the *Eleusine* pasture was difficult, partly because of the lack of published information on that species but also because of the type of physiological parameters required. It remains to be seen as this model is released and used by a wider range of specialists whether the detail required in the parameters is at a sufficient level of detail or, alternatively, too detailed.

It should be pointed out that this author does not consider the current version of the model appropriate for farmer use; nor was it intended for use by farmers in its current form. Because of the difficulty of defining a sufficient data set for running the model, it is not in an appropriate form for running generic comparisons without careful and detailed setting of a wide range of parameters. Thus, it is considered as a tool for pasture specialists - it is also likely that intensive training will be needed for operators to become competent in the use of the model.

Nevertheless, grazed pasture ecosystems are exceptionally complex and it is only through models such as GrassGro, which attempt to include factors governing most levels interacting within the system, that solutions will be found to reliably predict grazed pasture performance.

3.7 Conclusions

The GrassGro model predictions showed a good fit to the observed data for ΔFOO for the three pasture types under ungrazed conditions and relatively less and/or no fit under grazed conditions. The reason for the poorer fit under grazed conditions was due mainly to the frequent changes in stocking rate to match animal demand to pasture supply in the experiment which was not compatible with the model. However, SR did not show much influence on the Eleusine pasture because of its low digestibility and palatability to stock. Thus the model indicated no significant different between grazed and ungrazed pastures. The comparison of Eleusine with the degraded pasture showed a significant ($P<0.05$) relationship under both the grazed ($R2=0.93$) and ungrazed ($R2=0.84$) conditions, when the spring data points were excluded from the regression.

Phalaris and phalaris-white clover pastures generally exhibited a similar pattern of ΔFOO with the model predictions under both grazed and ungrazed conditions. Phalaris pasture explained 80% of the variation under ungrazed and 60% under grazed conditions. In both conditions, the model predictions were higher in the December harvests than the actual.

When December data points were excluded, the relationships (R^2) improved to 0.9 and 0.91 respectively.

The R^2 for the predicted vs measured phalaris-white clover pasture were 0.71 (Δgreen FOO grazed), 0.94 (Δgreen FOO ungrazed) and 0.60 (Δtotal FOO ungrazed). Despite these significant relationships, the model always predicted higher than the measured. This was mainly due to the higher predicted values of white clover pasture in the model. To obtain the fits to 1995 observed data, some parameters of the white clover model need to be adjusted. The first is to decrease the NPP from 180 to lower than phalaris, 160 kg ha^{-1} d^{-1}. The second, SMR value should be increased from 0.35 to 0.60. The third, RSR value at the start of reproduction is to be decreased from 5.00 to 1.4 and at 50% flowering from 2.00 to 1.00.

Comparison of ΔFOO measured using the exclosure technique in the experiment did not match the predicted, mainly because of the differences in the methods of calculation. This is not clearly documented in the model. Measurement of pasture growth is one of the most diversified areas of a pasture science.

In general, the calibration of the model under different climatic regimes (Cooma, Canberra and Armidale) for the above ground production in the environmental comparison showed no difference from published reports. Likewise, the simulated results matching animal demand to pasture supply, using different lambing dates agreed well with the data reported by various workers under the conditions of the Northern Tablelands of NSW.

4. References

Archer, K. (1995) The New South Wales pasture base. *Grassld. Soc. NSW. Proc. **10th** Conf.* pp 10-13.

Archer, K.A. and Robinson, G.G. (1988) Agronomic potential of native grasses species on the Northern Tablelands of New South Wales. II. Nutritive value. *Aust. J. Agric. Res.* **39**: 425-436.

Askin, D.C., Pownall, D.B. and Lucas, R. J. (1987) cited in Smetham, M.L. (1990) Pasture management. *Pastures-Their Ecology and Management* (ed. R.H.M. Lauger). Oxford University Press, Auckland. pp 197-240.

Ayres, J., Caradus, J., Lane, L. and Murison, B. (1995) White clover breeding for dryland pastures. *Grassld. Soc. NSW Proc. **10^{h}** Conf.* pp 81-82.

Begg, J.E. (1959) Annual pattern of soil moisture stress under sown and native pastures. *Aust. J. Agric. Res.* **10**: 518-529.

Beinhart, G. (1962) The effect of temperature and light intensity on CO_2 uptake, respiration and growth of white clover. *Plant Physiology.* **37**: 709-715.

Bell, C.J. (1981) The testing and validation of models. *Mathematics and Plant Physiology.* (eds. D.A. Rose and D.A. Charles-Edwards). Academic Press. pp 299-309.

Bircham, J.S. and Hodgson, J. (1983) The influence of sward condition on rates of herbage growth and senescence in mixed swards under continuous stocking management. *Grass and Forage Sci.* **38**: 323-331.

Bircham, J.S. and Korte, C.J. (1984) Principles of herbage production. *NZ Agriculture Science.* **18(3):** 123-126.

Black, C.C. (1971) Ecological implications of dividing plants into groups with distinct photosynthetic capacities. *Adv. Ecol. Res.* **7**: 87-114.

Black, J.L. and Bottomley (1980) Effects of shearing and lambing dates on the predicted pasture requirements of sheep in two Tasmanian locations. *Aust. J. Exp. Anim. Husb.* **20**: 654-661.

Blackburn, H.D. and Kothmann, M.M. (1989) A forage dynamics model for use in range or pasture environments. *Grass and Forage Sci.* **44**: 283-294.

Brougham, R.W. (1956) Effect of intensity of defoliation on regrowth of pasture. *Aust. J. Agric. Res.* **7**: 377-387.

Brougham, R.W. (1959) The effects of season and weather on the growth of a ryegrass and clover pasture. *N.Z. J. Agric. Res.* **2**: 283-296.

Brown, R.H. and Blaser, R.E. (1968) Leaf area index in pasture growth. *Herbage Abstracts.* **38**(1): 1-9.

Burbidge (1966) cited in 'Plants of Western New South Wales' (by G.M. Cunningham, W. E. Mulham, P.L. Milthorpe and J.H. Leigh (1981)). *Soil Conserv. Service of NSW.* p92.

Cacho, O.J. (1993) A practical equation for pasture growth under grazing. *Grass and Forage Sci.* **48**: 387-394.

Cacho, O.J., Finlayson, J.D. and Bywater, A.G. (1995) A simulation model of grazing sheep: II. Whole-farm model. *Agricultural Systems.* **48**: 27-50.

Caloin, M. (1994) Analysis of dry matter partitioning in *Dactylis glomerata* during vegetative growth using a carbon budget model. *Annals of Botany.* **73**: 665-669.

Carlson, D.H., Thurow, T.L. and Jones, C.A. (1993) Biophysical simulation models as research tools. *Decision support systems for the management of grazing lands: Emerging Issues.* (eds. J.W. Stuth and B.G. Lyons). pp 37-67.

Cayley, J.W.D. (1994) LOTUS programs for use with 'falling plate' pasture meter. *Pastoral and Veterinary Institute, Hamilton, Victoria.*

Cayley, J.W.D. and Bird, P.R. (1991) Techniques for measuring pastures. *Victorian Department of Agriculture, Technical report series* **No. 191**: 1-37

Colman, R.L., Lazenby, A., Grierson, J. (1974) Nitrogen fertiliser responses and seasonal production of temperate and warm climate grasses on the Northern Tablelands of New South Wales. *Aust. J. Exp. Agric. Anim. Husb.* **14**: 362-372.

Constable, G.A. (1976) Temperature effects on the early field development of cotton. *Aust. J. Exp. Agric. Anim. Hus.* **16**: 905-910.

Cook, S.J. (1974) *Some ecological aspects of pasture degradation.* A Ph. D. Thesis, UNE.

Cook, S.J., Lazenby, A. and Blair, G.J. (1976) Comparative responses of *Lolium perenne* and *Bothriochloa macra* to temperature, moisture, fertility, and defoliation. *Aust. J. Agric. Res.* **27**: 769-778.

Cook, S.J., Lazenby, A., and Blair, G.J. (1978) Pasture degeneration. I. Effect on total and seasonal pasture production. *Aust. J. Agric. Res.* **29**: 9-18.

Davidson and Philip (1958) cited in Donald, C.M. (1961) Competition for light in crops and pastures. *Symposia of the Soc. Exp. Bio.* **15**: 282-313.

Davies, A. (1993) Tissue turnover in the sward. *Sward Management Handbook* (ed. A. Davies, R.D. Baker, S.A. Grant and A.S. Laidlaw). Bri. Grassld. Soc. pp. 183-215.

Donald, C.M. (1961) Competition for light in crops and pastures. *Symposia of the Society for Experimental Biology.* **15**: 282-313.

Donald, C.M. (1963) Introduction: Competition among crop and pasture plants. *Adv. Agron.* **15**: 1-13.

Dowe, R., Johnston, V., Lowien, J. and Dent, B. (1995) Management of African love grass. *Grassld. Soc. NSW. Proc.* ***10th*** *Conf.* pp 96.

Doyle, P.T., Grimm, M. and Thompson, A. N. (1993) Grazing for pasture and sheep management in annual pasture zone. *Pasture Management Technology for the 21 Century* (eds. D.R. Kemp and D.L. Michalk). CSIRO Australia. pp 71-90.

Edwards, P.J. (1980) The use of stocking rate/animal performance models in research and extension. *Proc. Grassld. Soc. Sth. Afr.* **15**: 73-77.

El-Sharkway, M.A. and Hesketh, J. D. (1964) Effects of temperature and water deficit on leaf photosynthetic rates of different species. *Crop Sci.* **4**: 514-518.

Finlayson, J.D., Cacho, O.J. and Bywater, A.C. (1995) A simulation model of grazing sheep: I. Animal growth and intake. *Agricultural Systems.* **48**: 1-25.

FitzGerald, R.D. (1976) Effect of stocking rate, lambing time, and pasture management on wool and lamb production on annual subterranean clover pasture. *Aust. J. Agric. Res.* **27**: 261-275.

FitzGerald, R.D., Harris, C.A. and Ayres, J.F. (1995) Impact of drought on survival of pasture species. *Grassld. Soc. NSW. Proc. **10th** Conf.* pp 76.

Frame, J. (1993) Herbage mass. *Sward Measurement Handbook.* (2nd edition) (ed. A. Davis, R.D. Baker, S.A. Grant, A.S. Laidlaw). A Brit. Grassld. Soc. Pub. pp 39-67.

France, J. and Thornley, J.H.M. (1984) Role of mathematical models in Agriculture and Agriculture research. *Mathematical Models in Agriculture*. Butterworths. pp 1-13.

Gabriels, P.C.J., and Van Den Berg, J.V. (1993) Calibration of two techniques for estimating herbage mass. *Grass and Forage Sci.* **48**: 329-335.

Gay, A.P. (1993) Leaf area and light interception. *Sward Measurement Handbook* (2nd edition) (eds. A. Davies, R.D. Baker, S.A. Grant, A.S. Laidlaw) A Brit. Grassld. Soc. Publ. pp 121-137.

George, J.M. and Pearse, R.A. (1978) An economic analysis of a 10 year rate of stocking trial with fine-wool Merino sheep that lambed in winter, spring or summer. *Aust. J. Exp. Agric. Anim. Husb.* **18**: 370-380.

Gifford, R.M. (1974) A comparison of the potential photosynthesis, productivity and yield of plant species with different photosynthetic metabolism. *Aust. J. Plant Physiol.* **1**: 107-117.

Grant, S.A., Barthram, G.T. and Torvell, L. (1981) Components of regrowth in grazed and cut *Lolium perenne* swards. *Grass and Forage Sci.* **36**: 155-168.

Grant, S.A., Barthram, G.T., Torvell, L., King, J. and Elston, D.A. (1988) Comparison of herbage production under continuous stocking and intermittent grazing. *Grass and Forage Sci.* **43**: 29-39.

Grant, S.A., Barthram, G.T., Torvell, L., King, J., and Smith, H.K. (1983) Sward management, lamina turnover and tiller population density in continuously stocked *Lolium perenne*-dominated swards. *Grass and Forage Sci.* **38**: 333-344.

Greenwood, K. and Douglas, J. (1994) *Soil classification. Big Ridge 2.* "Chiswick" Armidale NSW.

Hamilton, B.A. (1973) *Factors determining the productivity of sheep grazing four temperate perennial grasses.* A Ph. D Thesis, UNE.

Hatch, D.M. (1971) Photosynthesis and the C_4 pathway. *CSIRO Australia, Div. Plant Indus. Ann. Rep.* pp. 19-26.

Haurwitz, B. and Austin, J.M. (1944) cited in Lovett, J.V. (1973) The environment- major climatic variables. *Intensive Pasture Production* (ed. A. Lazenby and F.G. Swain). Angus and Robertson. pp 3-26.

Hesketh, J.D. (1968) Effect of light and temperature during plant growth on subsequent leaf Co_2 assimilation rates under standard conditions. *Aust. J. Biol. Sci.* **21**: 235-241.

Hilder, E.J. (1964) In Soil and pasture research on the Northern Tablelands, *New South Wales, Agric. Liaison Section, CSIRO*, Melbourne.

Hodgson, J. (1990) Herbage production and utilisation. *Grazing Management, Science into Practice.* Longman Scientific and Technical. NY. pp 38-54.

Hoglund, J.H., Crush, J.R., Brock, J.L. and Ball, R. (1979) Nitrogen fixation in pasture. XII. General Discussion. *NZ. J. Experimental Agric.* **7**: 45-51.

Hurd, R.G. (1977) Vegetative plant growth analysis in controlled environments. *Ann. Bot.* **41**: 779-787.

Hutchinson, K.J. (1992) 'The Grazing Resource'. *Proc. 6th Aust. Soc. Agron. Conf.*, Armidale (ed. K.J. Hutchinson and P. Vickery).

Hutchinson, K.J. and King, K.L. (1980) The effects of sheep stocking rate on invertebrate abundance, biomass and energy utilisation in a temperate, sown grassland. *Journal of Applied Ecology.* **17**: 369-387.

Hutchinson, K.J. and King, K. (1993) In Robin Taylor (1993) Sustaining our temperate pastures. *Rural Research **No. 160**.* SPRING. pp 24-27

Hutchinson, K.J. and King, K. (1994) Biological process and the fertility of temperate and Mediterranean pastures, (ed. K.J. Hutchinson). *Australian Wool Corporation.* pp 82-84.

Jagusch, K.T., Rattray, P.V., MacLean, K.S., and Joyce, P.J. (1978) The dynamics of pasture production under sheep. *Proc. NZ. Soc. Anim. Prod.* **38**:129-138.

Johns, G.G. (1972) Water use in herbage production. *Intensive pasture production* (Ed. A. Lazenby and F.G. Swain). pp. 160-175.

Johns, G.G. (1973) Water use in herbage production. *Intensive Pasture Production.* (ed. A. Lazenby and F.G. Swain). Angus and Robertson, Syd. pp 160-175.

Johnson, I. (1991) Shoot:root partitioning during vegetative growth. *Agronomy 220-1 course notes.* UNE Armidale.

Johnson, I.R. and Parsons, A.J. (1985) A theoretical analysis of grass growth under grazing. *J. Theor. Biol.* **12**: 345-367.

Jones. C. (1995) Value, management and permanence of native grasses. *Proc. Ann. Conf. Victorian Grassld Society,* Tasmanian Branch, Launceston. pp 1-7.

Ketallapper, H.J. (1960) The effect of soil temperature on the growth of *Phalaris tuberosa* L. *Physiol. Plant.* **13**: 641-647.

King, K.L. (1991) The role of micrc arthopods in decomposition and nutrient cycling in temperate pastures. *Aust. J. Ecol.* **16**: 131-134.

Korte, C.J., Chu, A.C.P. and Field, T.R.O. (1987) Pasture production. Livestock feeding on pasture. (ed. A.M. Nicol). *N.Z. Soc. Anim. Prod.* Occasional Publ. No. **10**: 7-20.

Lamaire, G. and Salette (1982) The effects of temperature, and nitrogen fertiliser on the growth of two forage grasses in spring. *Grass and Forage Sci.* **37**: 191-198.

Lazenby, A. (1972) Epilogue: The environment and pasture growth. *Intensive pasture production.* (Ed. A. Lazenby and F.G. Swain). pp 285-303.

Lazenby, A. and Lovett, J.V. (1975) Growth of pasture species on the Northern Tablelands of New South Wales. *Aust J. Agric. Res.* **26**: 269-280.

Lazenby, A. and Swain, F.G. (1972) Pasture species: Species, Establishment and Nutrition. *Intensive pasture production* (Ed. A. Lazenby and F.G. Swain).

Lazenby, A. and Swain, F.G. (1973) Pasture species. *Intensive Pasture Production.* (ed. A. Lazenby and F.G. Swain). Angus and Robertson, Syd. pp 67-96.

Levitt (1980) **In** I. Johnson (1991) Leaf photosynthesis. *Agronomy 220-1 Course notes.* UNE.

Lile, F.D. and George, M.R. (1993) Prediction of pasture growth rates from climatic variables. *J. Prod. Agric.* **6**(1): 86-90.

Lodge, G.M.; Robinson, G.G. and Simpson, P.C. (1990) Agfact **P2.5.32**:*Grasses - Native and naturalised* (1st. edition). *NSW Agriculture and Fisheries.*

Lovett, J.V. (1973) The environment- major climatic variables. *Intensive Pasture Production* (ed. A. Lazenby and F.G. Swain). Angus and Robertson. pp 3-26.

Ludlow, M.M. (1978) Light relations of pasture plants. *Plant Relations in Pastures.* pp. 35-49.

Ludlow, M.M. and Wilson, G.L. (1971) Photosynthesis of tropical pasture plants. II Temperature and illuminance history. *Aust. J. Bio. Sci.* **24**: 1065-1075.

Ludwig, J.A. (1990) In: Decision support for grazing lands: An overview. *Decision support systems for the management of grazing lands: Emerging Issues.* (eds. J.W. Stuth and B.G. Lyons). pp 1-34.

MacNeil, M.D., Skiles, J.W. and Hanson, J D. (1985) Sensitivity analysis of a general rangeland model. *Ecological Modelling.* **29**: 57-76.

Marshall, R. and Nelson, N. (1995) Native pasture management in the Hunter Valley. *Grassld. Soc. NSW. Proc. 10th Conf.* pp 91.

McCall, D.G., Marshall, P.R. and Johns, K.L. (1991) In: Decision support for grazing lands: An overview. *Decision support systems for the management of grazing lands: Emerging Issues.* (eds. J.W. Stuth and B.G. Lyons). pp 1-34.

McDonald, W. (1995) Matching pasture production to livestock enterprise requirements for Tableland and Slopes districts of NSW. *NSW Agriculture.* **Nov**. 1995.

McWilliam, J.R. (1973) Influence of biological and environmental factors on pasture seed production. *Intensive Pasture Production* (ed. A. Lazenby and F.G. Swain). Angus and Robertson. pp 241-255.

McWilliam, J.R.(1978) Response of pasture plants to temperature. *Plant relations in pastures* (Ed. J.R. Wilson). CSIRO, Australia. pp 17-34.

Milligan, K.E., Brookes, I.M., and Thompson, K.F. (1987) Feed planning on pasture. Livestock feeding on pasture (ed. A.M. Nicol). *N.Z. Soc. Anim. Prod.* Occasional Publ. No. **10**: 75-88.

Mitchell (1956) cited in Lazenby, A. and Swain, F.G. (1973) Pasture species. *Intensive Pasture Production.* (ed. A. Lazenby and F.G. Swain). Angus and Robertson. pp 70.

Monsi and Saeki (1953) In Donald C.M. (1961) Competition for light in crops and pastures. *Symposia of the Soc. Exp. Bio.* **15**: 282-313.

Moore, A.D., Donnelly, J.R. and M. Freer (1996) GrazPlan: Decision support system for Australian grazing enterprises. III. Pasture Growth and Soil Moisture Sub-model, and the GrassGro DSS. *Ecological Modelling*. In press.

Murata, Y., Iyama, J. and Honma, T. (1966) Studies on the photosynthesis of forage crops. V. The influence of soil moisture content on the photosynthesis and respiration of seedlings in various forage crops. *Proc. Crop Sci. Soc.,* Japan. **34**: 385-390.

Narayanan, T.R. and Dabadghao, P.M. (1972) Perennial cultivated grasses. *Forage Crops in India.* Indian Council of Agricultural Research (ICAR), New Delhi. pp 147-174.

Neal, D.L. and Neal, J.L. (1973) Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 1. History and development. *J. Bri. Grassld. Soc.* **28**: 81-89.

Nix, H. (1981) Simplified simulation model based on specified minimum data sets. In Application of Remote Sensing to Agricultural Production Forecasting (ed. A. Berge). *A.A. Balkema, Rottherdam.* pp 151-169.

Northern Site Team (1995) Progress report submitted to MRC: Sustainability issues research ~ Northern Site ~ *UNE/CSIRO.*

Parsons, A.J. and Penning, P.D. (1988) The effect of the duration of regrowth on photosynthesis, leaf death and the average rate of growth in a rotationally grazed sward. *Grass and Forage Sci.* **43**: 15-27.

Parsons, A.J., Johnson, I.R. and Williams, J.H.H. (1988) Leaf age structure and canopy photosynthesis in rotationally and continuously grazed swards. *Grass and Forage Sci.* **43**: 1-14.

Parsons, A.J., Leafe, E. L., Collett, B., and Stiles, W. (1983) The physiology of grass production under grazing. I. Characteristics of leaf and canopy photosynthesis of continuously grazed swards. *J. Appl. Ecol.* **20**: 117-126.

Phillips, P.J. and McWilliam, J.R. (1971) cited in McWilliam, J.R. (1978) Response of pasture plants to temperature. *Plant relations in pastures* (Ed. By John R. Wilson). pp 17-34.

Radcliffe, J.E. and Baars, J.A. (1987) cited in Lile, D.F. and George, R.M. (1993) Prediction of pasture growth rates from climatic variables. *J. Prod. Agric.* vol. **6**(1): 86-90.

Rattray, P.V. and Clark, D.A. (1984) In Bircham and Korte (1984) Principles of herbage Production. *NZ. Agriculture Science.* **18(3):** 123-126.

Rhodes, I. and Stern, W.R. (1978) Competition for light. Plant *Relations in Pastures.* pp. 175-189.

Robinson, G.G. and Archer, A. (1988) Agronomic potential of native grass species on the Northern Tablelands of New South Wales. 1. Growth and herbage production. *Aust. J. Agric. Res.* **39**: 415-423.

Salisbury, B.F. and Ross, C. (1969) Physiological ecology. *Plant Physiology.* pp. 677-708.

Sanders, J.O. and Cartwright, T.C. (1979) A general cattle production systems model. I. Description of the model. *Agricultural Systems.* **4**: 217-227.

Schafer, B.M. (1980) A description of the soils on the CSIRO pastoral research laboratory property, Chiswick, Armidale, *NSW. CSIRO*, Australia.

Scott, J. and Virgona, J. (1994) DROUGHT: A difficult time for pastures and pasture management strategies. In *Temperate Pastures.* Issue No. **94/2**, May.

Sheath, G.W. and Bryant, A.M. (1984) In Bircham, J.S. and Korte, C.J. (1984) Principles of herbage production. *NZ Agriculture Science.* **18(3):** 123-126.

Sheehy, J.E. and Cooper, J.P. (1973) Light interception, photosynthetic activity, and crop growth rate in canopies of six temperate forage grasses. *J. Appl. Ecol.* **10**: 239-....

Skiles, J.W., Springer, E.P. and Richardson, C.W. (1987) cited in Stout, W.L., Vona, L.C., Skiles, J.W., Shaffer, J.A., Jung, G.A. and Reid, R.L. (1990) Evaluating SPUR model for predicting animal gains and biomass on Eastern Hill Land Pastures. *Agricultural Systems.* **34**: 169-178.

Smetham, M.L. (1990) Pasture management. *Pastures, their Ecology and Management* (ed. R.H.M. Lauger). Oxford University Press, Auckland. pp 197-240.

Snaydon, R.W. (1981) The ecology of grazed pastures. *World Animal Science (B1) Disciplinary Approach, Grazing Animals* (ed. F.H.W. Morley). University of Melbourne, Vic. 3030, Australia.

Stern, W.R. (1962) Light measurements in pastures. *Herbage Abstracts.* **32**(2): 91-96.

Stockdale, C.R. and Kelly, K.B. (1984) A comparison of a rising-plate meter and an electronic capacitance meter for estimating the yield of pastures grazed by dairy cows. *Grass and Forage Sci.* **39**: 391-394.

Stout, W.L., Vona, L.C., Skiles, J.W., Shaffer, J.A., Jung, G.A. and Reid, R.L. (1990) Evaluating SPUR model for predicting animal gains and biomass on Eastern Hill Land Pastures. *Agricultural Systems.* **34**: 169-178.

Stuth, J.W. and Smith, M.S. (1993) Decision support for grazing lands: An overview. *Decision support systems for the management of grazing lands: Emerging Issues.* (eds. J.W. Stuth and B.G. Lyons). pp 1-34.

Stuth, J.W., Scrifres, C.J., Hamilton, W.T. and Conner, J.R. (1991) Management systems analysis as guidance for effective inter-disciplinary grazing land research. *Agricultural Systems.* **36**: 43-63.

Thornley, J.H.M. (1976) Ideas and basic techniques. *Mathematical Models in Plant Physiology* (*A Quantitative Approach to Problems in Plant and Crop Physiology*). Academic Press, London. pp 1-35.

Thornley, J.H.M. and Johnson, I.R. (1990). Plant and Crop Modelling. (Oxford Univ. Press). p 89.

Vickery, P.J. (1981) Pasture growth under grazing. *World animal science (B1). Disciplinary approach, Grazing animals* (Ed. F.H.W. Morley). Univ. of Melbourne. Vic. 3030, Aust. pp 55-76.

Walker, B.H. (1980) Stable production versus resilience: A grazing management conflict? *Proc. Grassld. Soc. Sth. Afr.* **15**: 79-83.

Watkin, B.R. and Clements, R.J. (1978) The effects of grazing animals on pastures. *Plant Relations in Pastures* (ed. J.R. Wilson). CSIRO, Australia. pp 273-289.

Wilson, J.B. (1988) A review of evidence on the control of shoot:root ratio, in relation to models. *Annals of Botany.* **61**: 433-449.

Wilson, K., Morren, G.E.B. (1990) *Systems Approaches for Improvements in Agriculture and Resource Management.* Macmillan, New York, USA.

5. Appendices

Appendix 1. List of parameters of the three pasture types used in the simulation of results of the GrassGro model.

Editing Pasture Species, Screen (1)			
	Phalaris	White clover	*Eleusine*
Notional maximum NPP (kg ha^{-1} d^{-1})	160	180	400
Light intensity effect (MJ hr^{-1})	0.60	0.60	0.60
Biomass for LAI=1 (kg ha^{-1})	950	700	870
Light extinction coefficient	0.60-0.90	0.70-0.90	0.65-0.70
Species intake factor	1.70	1.70	1.70
Hight ratio	1.0	1.0	1.0
Protein content:			
80%	25%	33%	16%
70%	18%	24%	12%
60%	12%	16%	10%
50%	7%	9%	7%
40%	3%	4%	3%
Rumen degradable protein (RDP):			
80%	90%	90%	90%
70%	80%	80%	80%
60%	70%	70%	70%
50%	50%	60%	60%
40%	50%	50%	50%
Temperature response (°C):			
Low (5%)	2.0	3.0	5
Low (95%)	9.0	12.0	25
High (95%)	18.0	22.0	35
High (5%)	30.0	27.0	40
Soil moisture response	0.25	0.35	0.20
Transpiration response	0.35	0.35	0.35

Editing Pasture Species, Screen (2)			
Development:			
Vernalization required (?)	Yes *[1]	No	No
Reproduction trigger	DL 11 hr *[2]	DL 10.5 hr *[7]	150 (°D) *[2]
50% flowering point (°D)	100 *[2]	300 *[7]	1000 *[2]
End of reproduction (°D)	800 *[2], *[3]	2600 *[8]	2000 *[14]
Summer dormancy:			
Threshold temperature (°C)	17.0	--	--
ASW threshold	0.40	--	--
Initial requirement (d)	9.00	--	--
Breaks after (d)	110.00	--	--
Allocation:			
Target root/shoot ratio, start of reproduction	3.00	5.00	1.60
50% flowering	1.00	2.00	1.00
Maximum RGR of shoot (dormant)	0.50%	--	--
Maximum RGR of root (dormant)	0.20%	--	--
Growth factor for translocation	0.60	0.60	0.60
Maximum specific rate of translocation	1.00	2.00	1.00

contd..

Editing Pasture Species, Screen (3)			
	Phalaris	White clover	*Eleusine*
Maturation (digestibility unit, DU):			
Live	0.20 *[4]		0.20
Leaf, Live (White clover)	--	0.10 *[9]	
Stem, Live (do)	--	0.20 *[9]	
Scenescing	0.50 *[4]	3.00 *[9]	0.50
Q_{10}	2.00	2.00	2.00
Ageing of dead (DU)	0.10 *[5]		0.10
Leaf (White clover)		0.10 *[10]	
Stem (do)		0.10 *[11]	
Death (%):			
Live	0.30		1.00
Leaf, Live (White clover)		1.0	
Leaf, Senescing (do)		5.00	
Stem, Live (do)		1.0	
Stem, Senescing (do)		5.00	
Senescing	20.00		20.00
Fall (%)	3.00 *[6]		3.00
Leaf (White clover)		5.00 *[12]	
Stem (White clover)		5.00 *[13]	
Frost:			
5% (°C)	-3.00		0.00
95% (°C)	-11.00		-5.00
Hardening factor (°C)	1.00		0.00
Ageing of litter (DU):			
Dry maximum	0.20	0.40	0.20
Wet maximum	1.00	2.0	1.00
Temperature (°C):			
5%	0.00	0.00	0.00
95%	8.00	8.00	8.00
Root losses (%):			
At 10°C	0.30	0.25	0.50
Q_{10}	1.50	1.50	1.50

Legend:
NPP = Net primary production
DL = Day length
RGR = Relative growth rate
*[1] = *Vernalization index (VI) =* $0.050 * \exp(-0.100T\,\text{min.})$
*[2] = *Base temperature at 5°C*
*[3] = *At or below available soil water (ASW) 0.05*
*[4] = $[1 + 1.00(1 - zsm)]$
*[5] = $+0.30ASW(1)$
*[6] = $[1 - \exp(-0.10P)] + 0.010SR$, *Stocking rate (SR) (sheep equiv.)*
*[7] = *Base temperature at 0°C*
*[8] = *At or below ASW 0.08*
*[9] = $[1 + 1.00(1 - AT{:}PT)]$
*[10] = $+0.45ASW(1)$
*[11] = $+0.30ASW(1)$
*[12] = $[1 - \exp(-0.10P)] + 0.030SR$
*[13] = $[1 - \exp(-0.10P)] + 0.020SR$
*[14] = *At or below ASW 0.10*

Appendix 2. Description of soil at Big R dge 2.

Location: Pit above Plot 1, Big Ridge 1, "Chiswick", Armidale, NSW

Described by: Kerry Greenwood

Date: 12/12/93

Classification: Northcote Key: Db4.22
Great Soil Group: ? Grey podzolic
U.S.D A. Classification: ?

Horizon	Depth (cm)	Morphology
A_1	0-24	Brownish black (7.5YR 3/2) clay loam, fine sandy; few, fine, distinct red mottles; weak, 20-50 mm subangular blocky peds parting to moderate, 2-5 mm polyhedral peds; rough ped fabric; fine cracks, few, very fine macropores; very weak consistence (moist); common, fine manganiferous nodules. Abundant, very fine roots. Field pH 5.5.
		Smooth and gradual to:
A_{21}	24-37	Brownish grey (7.5YR 4/1) loamy clay; few, fine, distinct red mottles; weak, 10-20 mm subangular blocky peds parting to moderate, 2-5 mm subangular blocky peds; rough ped fabric; fine cracks, few, very fine macropores; very weak consistence (moist); many, fine manganiferous nodules. Abundant, very fine roots. Field pH 6.0.
		Smooth and gradual to:
A_{22}	37-50	Brown (7.5YR 4/3) light medium clay; very few, medium, moderately strong, dispersed, subangular pebbles; weak, 10-20 mm subangular blocky peds parting to moderate, 2-5 mm subangular blocky peds; rough ped fabric; fine cracks, few, very fine macropores; weak consistence (moist); many, fine ferromanganiferous nodules. Many, very fine roots. Field pH 6.5.
		Wavy and abrupt to:
B_{21}	50-8.	Brown (10 YR 4/4) medium heavy clay; common, fine distinct red mottles; strong, 50-100 mm prismatic peds parting to strong, 20-50 mm angular blocky peds, smooth ped fabric; many, prominent stress cutans; fine cracks; very strong consistence (dry); many, medium ferromanganiferous nodules. Many, very fine roots. Field pH 6.0.
		Smooth and gradual to:
B_{22}	88-120+	Brown (7.5YR 4/4) medium heavy clay; many, fine faint orange mottles; strong, 50-100 mm prismatic peds parting to strong, 20-50 mm angular blocky peds, smooth ped fabric; many, prominent stress cutans; fine cracks; very strong consistence (dry); common, medium ferromanganiferous nodules. Common, very fine roots. Field pH 7.0.

contd...

Location: Pit at lower end of Plot 4, Big Ridge 2, "Chiswick", Armidale, NSW

Described by: Kerry Greenwood and Janelle Douglas

Date: 25/3/94

Classification: Northcote Key: Dy5.42

Great Soil Group: ? Lateritic podzolic / Gray Brown Podzolic

U.S.D.A. Classification:

Horizon	Depth (cm)	Morphology
A_1	0-16	Greyish brown (7.5YR 4/2) clay loam; moderate, 20-50 mm subangular blocky peds parting to 2-5 mm subangular blocky peds; rough ped fabric; many, very fine macropores; weak consistence (moderately moist); few, fine manganiferous nodules. Abundant, very fine roots. Field pH 5.5.
		Smooth and clear to:
A_{2e}	16-26	Light grey (7 5 YR 5/3 -moist, 10YR 7/1 - dry). clay loam, sandy; moderate, 10-20 mm subangular blocky peds parting to 2-5 mm subangular blocky peds; rough ped fabric; few, very fine macropores; very firm consistence (dry); many, medium ferromanganiferous nodules. Many, very fine roots. Field pH 6.0.
		Smooth and gradual to:
B_{21}	26-47	Greyish brown (5YR 5/2) light medium clay; common, fine, distinct, red mottles; moderate, 10-20 mm subangular blocky peds parting to 2-5 mm subangular blocky peds; rough ped fabric; few, very fine macropores; very firm consistence (dry); common, fine ferromanganiferous nodules. Many, very fine roots. Field pH 6.5.
		Smooth and gradual to:
B_{22}	47-105	Ironstone layer with many, fine, distinct, red mottles; moderate, 5-10 mm subangular blocky peds (?), rough ped fabric; few, very fine macropores; strong consistence (dry); very many, medium ferromanganiferous nodules. Few, very fine roots. Field pH 6.0.
		Wavy and gradual to:
B_{23}	105-180+	Yellowish brown (10YR 5/8) heavy clay; few, coarse, prominent, grey colour patterns due to biological mixing of soil material from other horizons; strong, 50-100 mm subangular blocky peds parting to 20-50 mm subangular blocky peds, smooth ped fabric; many, prominent slickensides; strong consistence (dry); few, medium ferromanganiferous nodules. Few, very fine roots. Field pH 7.0.

Appendix 3. A summary of regression analysis: ($Y = a + bx$; $Y = a + bx + c\sqrt{x}$) obtained with the standard disc pasture meter in the Big Ridge 2 experiment, 1995.

Season/date	pasture type	r_1	r_2	a_1	a_2	b_1	b_2	c	n	Y_1 SE	Y_2 SE	F ratio	F reqd P <0.05
sum/21 Feb	degraded	0.82	0.82	786	5227	67	188	-1234		289	387	0.89	10.06
	phalaris	0.81	0.82	717	1675	87	163	-384		215	412	1.26	10.07
	WC+Phal	0.82	0.83	532	1754	93	182	-320		186	335	1.02	10.05
sum/21 Mar	degraded	0.81	0.82	698	5925	75	206	-1664	3	262	300	0.05	10.09
	phalaris	0.83	0.88	915	17549	60	673	-6451		245	236	1.31	10.09
	WC+Phal	0.90	0.90	1239	2922	49	110	-645		175	197	0.16	10.09
Aut/27 Apr	degraded	0.89	0.89	2266	2884	44	62	-224	1	420	457	0.06	6.58
	phalaris	0.88	0.88	651	824	83	91	-77		336	359	0.01	5.59
	WC+Phal	0.89	0.91	425	2375	73	164	-882		388	364	2.25	5.32
Aut/27 Apr	phalaris	0.90	0.91	734	1435	80	112	-309		281	296	0.20	5.59
	WC+Phal	0.92	0.95	441	2368	75	164	-872		324	285	3.56	5.32
Win/24 May	degraded	0.82	0.82	1726	385	83	39	507		930	981	0.19	5.59
	phalaris + WC+Phal	0.86	0.91	823	-1865	93	-37	1237		566	490	3.67	5.59
Win/3 Aug	degraded	0.93	0.93	1379	1049	59	48	125		377	402	0.04	5.59
	phalaris + WC+Phal	0.95	0.95	883	582	121	99	169		224	237	0.11	5.59
Spring/8 Sep	degraded	0.97	0.99	1532	-1080	55	0	795		314	205	13.23	5.32
	phalaris + WC+Phal	0.93	0.93	362	223	132	120	83		196	202	0.02	4.55
Spring/28 Oct	degraded	0.89	0.90	1820	4	58	8	622		395	402	0.69	5.32
	phalaris	0.85	0.87	1305	-120	59	-3	629		426	428	0.93	5.59
	WC+Phal	0.83	0.96	1594	-3616	66	-181	2333		334	181	17.90	5.97
Sum/5 Dec	degraded	0.94	0.94	2047	2595	55	64	-143	2	484	515	0.05	5.59
	phalaris	0.61	0.87	1856	-5797	34	-135	2335		665	405	14.52	5.59
	WC+Phal	0.94	0.95	1406	3946	51	108	-796		427	402	2.05	5.59

r_1 = Correlation coefficient for linear regression
r_2 = Correlation coefficient for curvilinear regression
a_1 = Constant for linear regression
a_2 = Constant for curvilinear regression
b_1 = X - coefficient for linear regression
b_2 = X - coefficient for curvilinear regression
C = Correction factor for curvilinear regression
n = No. of sample rejected
Y_1SE = Standard Err. of Y Est. for linear equation
Y_2SE = Standard Err. of Y Est. for curvilinear equation

* = + sign across the treatment indicates not a significant different between the two pasture types, and so the same equation was used for both the treatments

Y = Yield of herbage mass (DM kg ha^{-1}) and,

X = Settled height of disc (cm)

NB: Significant ($P<0.05$) F ratios indicate use of curvilinear model and non-significant inevitably for linear.