4.0 MODELLING PRIMARY PRODUCTIVITY USING THE GRASP MODEL

4.1 Introduction

The preceding chapter has demonstrated that primary production can be measured and related to water use (evapo-transpiration) over short periods of time for particular locations. Estimation of "safe" grazing capacities for individual properties requires extrapolation of these "point" results over time and space. The previous chapter suggests that simulation modelling offers the most promising procedure to do this, due to the complexity of the interrelationships governing plant growth.

In this chapter, modification of the GRASP (GRASs Production) computer model to south-west Queensland is described. Data collected and analysed in Chapter 3 are used to calibrate the model. Calibration results are presented and the model is validated with independent yield data collected in south-west Queensland. Historical rainfall records for twenty locations across the region are then used to extrapolate modelling results over time and space. These results are used in Chapter 5 for the estimation of sustainable grazing capacities for native pastures in south-west Queensland.

4.2 Materials and methods

4.2.1 Description of the GRASP model

The GRASP model uses a series of mathematical equations in a computer program to describe the biological processes of forage growth. The biology within the model is outlined in Section 2.5. It is written in the FORTRAN computer language and consists of a main program and a series of modules or sub-routines. The modules perform specific tasks and are called from the main program in a logical sequence. Many of the modules transfer information within the program while others describe the actual biology of forage growth. The roles of the main program and subroutines are described in Appendix 5.

4.2.2 Calibrating the GRASP model to south-west Queensland

The GRASP model calculates transpiration and soil evaporation on a daily basis. Transpiration efficiencies and rates of soil evaporation vary with different species/soil combinations. To facilitate calibration of the model to a range of sites, GRASP uses parameters to describe these and other factors (Appendix 6) e.g. the water use efficiency of a site can be measured directly as described in Chapter 3. However, the transpiration efficiency (parameter 7 in Appendix 6) needs to be estimated in a manual calibration. This is due to the dynamic nature of changing green cover of the forage and subsequent changes in soil evaporation.

Thus calibrating the GRASP model to a particular site requires the development of a parameter file containing parameters describing that site. Three steps are involved.

(1) Beginning with a default parameter file (best estimates derived from Johnston and Carter (1986) (Appendix 6), as many parameters as possible are derived from the field data (Chapter 3). These include depth of soil layers, maximum and minimum soil moistures, plant density, temperature response, timing of detachment of plant material, maximum N content, rate of decline of N in plant material and nearest climatic station. The methodology for formally measuring these parameters has been described by Day and Philp (1997).

(2) A number of parameters are derived from the literature. These include relationships describing runoff (Miles 1993), screen temperature at which plant material is frosted, detachment rates and maximum N uptake (Christie 1978, 1981).

(3) The third step is running the model and calculating additional selected parameters from model output. Examples of parameters derived this way are potential daily regrowth rate and transpiration efficiency. Due to the interaction between these parameters, factorial sensitivity analyses were performed to determine the appropriate combination. In calibration, particular attention was given to these parameters as they have a major impact on production (e.g. water use efficiency).

Regression analysis and the simultaneous F-test of unit slope and zero intercept (H_0 regression slope=1.0 and H_0 regression intercept=0.0) were used to compare modelled (simulated) and observed values as described by Mayer and Butler (1993) and Mayer *et al*. (1994). This form of calibration was used to obtain the best fit to all data placing emphasis on how well the model simulated the pattern of growth, rather than being biased towards prediction of peak yield. Results are presented graphically in conjunction with regression analyses.

Diaries describing model calibration for Biddenham and the Charleville site are presented in Appendix 7. Remaining sites were calibrated with the same approach. Parameter files for each site are also presented in Appendix 7. A critical appraisal of this calibration methodology is given in the discussion (Section 4.4).

4.2.3 Validation of the GRASP model with independent data from south-west Queensland

Validation tests using data independent of calibration examine the robustness of the model. Observed data from different time periods and locations were used in the model and comparisons of simulated and observed results made.

In south-west Queensland several independent data sets exist in the form of grazing trials or experiments examining forage growth. Data from the four treatments (20%,35%,50% and 80% utilisation) in the Arabella grazing trial (Beale 1985) and experiments measuring forage yield (Christie 1978,1981) for mulga and mitchell grass pastures were used to validate the GRASP model in south-west Queensland. Availability of validation data is presented in Table 4.1.

From data reported in the above papers, final reports and unpublished raw data, validation parameter and management files were compiled describing each data set. Parameter files derived during calibration for comparable forage types, were used as the basis for this compilation (Table 4.1). Validation parameter files were then used in the model with climatic records corresponding to the periods of field observations. Regression analysis and the Student's t tests (H_0 regression slope=1.0 and H_0 regression intercept=0.0) were used to compare simulated and observed values.

4.2.4 Extrapolation of model results over time and space

A series of simulations were conducted to examine the spatial and temporal variation in water use efficiency for each of the land systems examined in Chapter 3.

In these simulations, daily rainfall data for twenty locations in south-west Queensland from 1960 to 1992 were used (Table 4.2). Daily climatic data were only available for Charleville, and were used in preference to AUSTCLIM climatic averages (Keig and McAlpine (1969) due to the high correlation between pan evaporation, vapour pressure deficit and rainfall.

Table 4.1 Availability of data and appropriate calibration parameter data for validation of the GRASP model to south-west Queensland (y=data was available, n=no data available).

Site and reference	Parameter data set	Yields	Plant parameters	Soil moistures	Soil parameters	Green cover (%)	N (%)
Mulga pasture Arabella all treatments (Beale 1985)	Charleville site	y	n	n	n	n	n
Mulga pasture Charleville (Christie 1978)	Charleville site	y	y	y	y	n	n
Mulga pasture Louth (J. Noble pers. comm.)	Turn Turn site	y	n	y	n	y	n
Mitchell Grass Charleville (Christie 1981)	Biddenham site	y	y	y	y	n	n
Mitchell Grass Burenda (Christie 1981)	Biddenham site	y	y	n	n	n	n
Mitchell Grass Burenda (Beale 1985)	Biddenham site	y	y	n	n	n	n

Table 4.2 The 20 daily rainfall stations used in simulation studies examining the spatial and temporal variability of water use efficiencies for eight land systems in south-west Queensland.

Station Number	Daily Rainfall Station	Latitude	Longitude	Elevation (m)
44002	AUGATHELLA	25°48’	146°35’	328
44168	BAYRICK	25°28’	146°01’	350
36143	BLACKALL POST OFFICE	24°26’	145°28’	283
44009	BOATMAN	27°16’	146°55’	269
44010	BOLLON POST OFFICE	28°02’	147°29’	183
44021	CHARLEVILLE AMO	26°25’	146°16’	306
44004	CHEEPIE (BEECHAL)	27°08’	144°44’	Not available
44026	CUNNAMULLA POST OFFICE	28°04’	145°45’	189
45006	EROMANGA	26°40’	143°16’	152
44032	EULO POST OFFICE	28°10’	145°03’	137
44040	GUMBARDO	26°07’	144°52’	300
44042	HEBEL POST OFFICE	28°58’	147°48’	150
44181	HUNGERFORD POST OFFICE	29°00’	144°24’	130
44050	MORVEN POST OFFICE	26°25’	147°06’	423
44054	MULGA DOWNS	28°47’	146°54’	130
45003	QUILPIE (SOUTH COMONGIN)	26°54’	144°20’	183
35069	TAMBO POST OFFICE	24°53’	146°15’	395
45017	THARGOMINDAH POST OFFICE	28°00’	143°49’	125
38024	WINDORAH POST OFFICE	25°26’	142°39’	126
44076	WYANDRA POST OFFICE	27°15’	145°59’	237

A simulation consisted of each calibrated and validated parameter file being run across all 20 rainfall locations for the 32 years of available climatic data. Simulation results were analysed using regression analysis to examine the variation in water use efficiency over time and space (rainfall and evapo-transpiration), and to simplify the relationships between rainfall, evapo-transpiration and predicted growth. Temporal and spatial variability in annual, summer and winter water use efficiencies were then examined with the objective of determining a method to estimate an average annual water use efficiency (ARUE kg/ha/mm) for the eight land systems at any location in south-west Queensland. Latitude and longitude were chosen as proxies for rainfall in order to estimate water use efficiencies beyond the limited (20) number of available rainfall stations. These values were compared to corresponding values calculated in Chapter 3 (Tables 3.5 and 3.8).

4.3 Results

Each site is examined in detail to document performance of the model. As correlation coefficients (R^2) are not always appropriate for comparing accumulating yields, results of a simultaneous F-test of unit slope and zero intercept between predicted and observed data are also presented.

4.3.1 Calibration

Comparing the simulated (predicted) and observed total soil moistures across all sites and sampling times (Figure 4.1a), indicated the GRASP model overestimated soil moisture in "dry" profiles (for some sites up to 40 mm) and underestimated soil moisture in "wet" profiles (for some sites by up to 50 mm). Statistical analysis of the regression between predicted and observed values indicated the slope was significantly different to one, and the intercept was significantly different to zero. Despite this, seventy-four percent of simulated total soil moistures were within ± 20% of observed total soil moistures (Figure 4.2a).

A significant relationship between predicted and observed standing dry matter indicated the GRASP model successfully described forage growth when all nine sites from south-west Queensland were analysed together (a slope not significantly different to 1.0 and an intercept not significantly different to 0.0 ($P<0.05$) (Figure 4.1b). Fifty percent of simulated values were within ± 20% of observed values (Figure 4.2b).

Closer examination of the results was thus warranted (Table 4.3 and Figures 4.3 to 4.11). Each site is described in detail to document performance of the model.

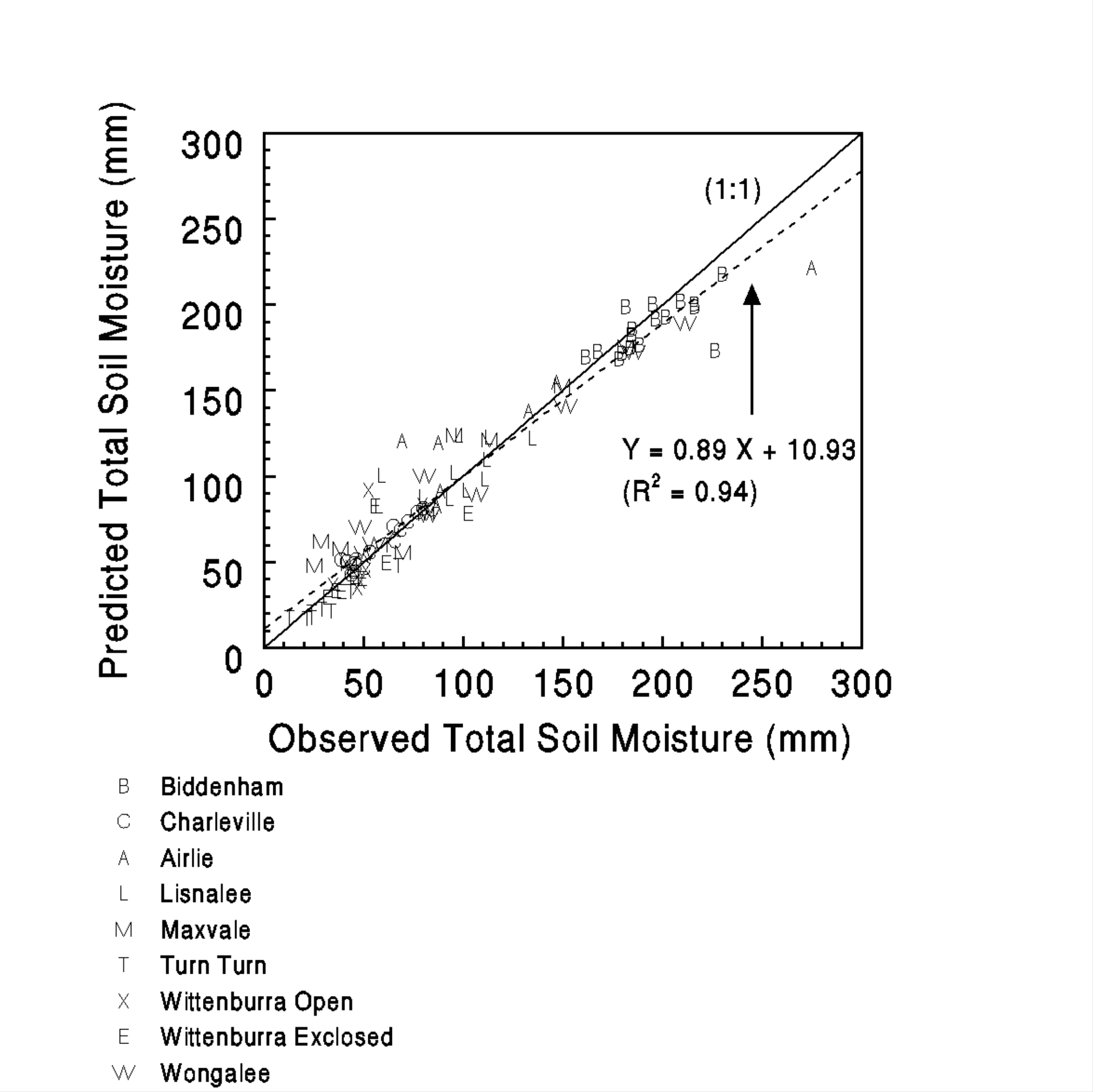

Figure 4.1a Comparison between predicted and observed total soil moisture (mm) following calibration of the GRASP model to nine sites in south-west Queensland during the period November 1986 to November 1990.

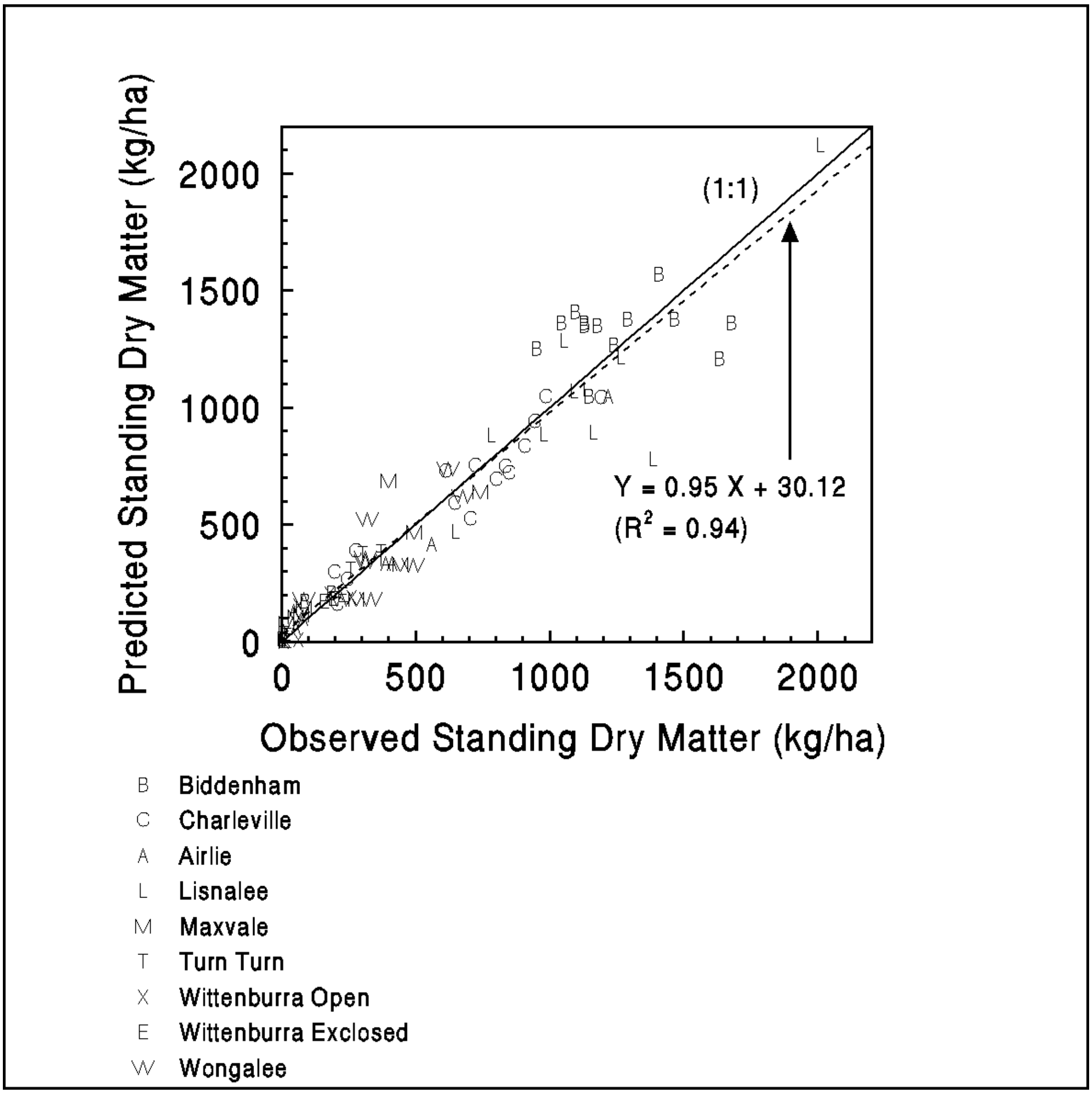

Figure 4.1b Comparison between predicted and observed standing dry matter (kg/ha) following calibration of the GRASP model to nine sites in south-west Queensland during the period November 1986 to November 1990.

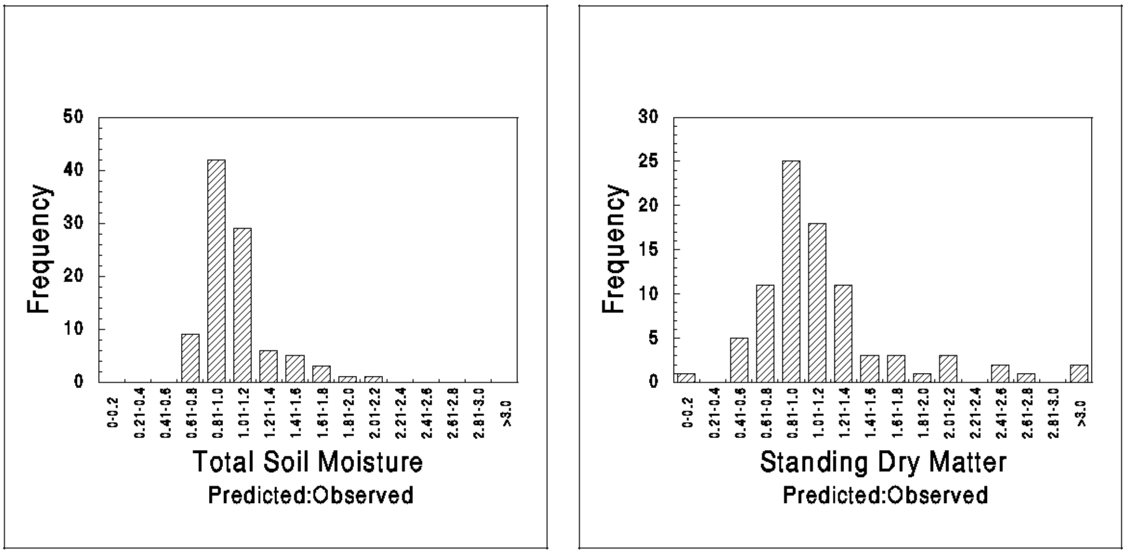

Figure 4.2 Frequency distribution of the ratio between (a) predicted and observed total soil moisture and (b) predicted and observed standing dry matter following calibration of the GRASP model to nine sites in south-west Queensland during the period October 1986 to November 1990.

4.3.1.1 Biddenham - Mitchell Grass

The time course of simulated total soil moisture at Biddenham generally followed observed values, (Figure 4.3a). Ninety-four percent (16 out of 17) of simulated values were within 10% of the observed (average sampling variation of 2.7% in the field). However, one observation (25/11/87) resulted in a low correlation between observed and predicted (slope significantly different to 1.0 and an intercept significantly different to 0.0) (Table 4.3). On this occasion, an observed rapid wetting of the profile was underestimated by the model. Evapo-transpiration from late October to November was low (0.5 mm/day or 5% of pan evaporation) despite high soil water. For this period the model simulated 2 mm/day of evapo-transpiration (24% of pan evaporation). The results suggest the sward was dormant and not transpiring. However, simulated evapo-transpiration for the entire period of observation was within 3% of observed evapo-transpiration.

At Biddenham, the GRASP model and parameters describing plant growth resulted in a significant comparison between simulated and observed standing dry matter (kg/ha) (Figure 4.3d and Table 4.3).

However, caution is required when interpreting these results as the majority of yield observations at Biddenham were clustered in the range 1000-1500 kg/ha. A cluster of low values and a cluster of high values can produce a significant regression when comparing simulated and observed values. Closer examination of the time course of simulated yield is therefore warranted, and indicated only 53% of simulated values were within one standard error either side of the observed values.

The observed pattern of growth at Biddenham showed three bursts of growth and rapid detachment of some yield components (e.g. inflorescence and leaf). The calibrated model showed only two growth periods (Figure 4.3c). The chosen temperature response for C4 grass (Christie 1978, McCown 1980 and McKeon *et al.* 1988) suggested that temperatures were too low for growth to occur in winter (June to

August) (Figure 4.3c). However, during this period an observed yield increase occurred in green stem but not in forbs or green leaf. This dry matter growth disappeared in spring possibly due to translocation, detachment and/or consumption by insects.

As the transitory components of yield do not contribute to end of season standing crop or dry season carry over feed, the failure of the model to simulate these components is not regarded as a major limitation. Implications for future model development are detailed later (Chapter 6).

Table 4.3 Regressions of predicted (Y) and observed (X) standing dry matter yields and total soil moistures from the GRASP grass production model for nine sites in south-west Queensland from October 1986 to November 1990. Student's t test calculated to determine whether slope nsd 1.0 (y or n) and intercept nsd 0.0 (y or n) at the 5% and 1% level.

Site	Regression	R^2	Slope $P<0.05$	Slope $P<0.01$	Intercept $P<0.05$	Intercept $P<0.01$
Standing Dry Matter						
Biddenham	Y = 0.81 X + 282.60	0.75	y	y	y	y
Charleville	Y = 0.84 X + 84.55	0.91	n	y	y	y
Airlie	Y = 0.81 X + 30.91	0.98	n	y	y	y
Lisnalee	Y = 0.94 X + 141.45	0.65	y	y	y	y
Maxvale	Y = 0.83 X + 69.96	0.76	y	y	y	y
Turn Turn	Y = 1.05 X + 13.52	0.97	y	y	y	y
Wittenburra open	Y = 0.82 X + 15.06	0.72	y	y	y	y
Wittenburra enclosed	Y = 0.94 X + 4.75	0.98	y	y	y	y
Wongalee	Y = 0.93 X + 31.00		y	y	y	y
Total Soil Moisture						
Biddenham	Y = 0.49 X + 91.92	0.44	n	n	n	n
Charleville	Y = 0.87 X + 9.64	0.91	y	y	n	y
Airlie	Y = 0.61 X + 55.94	0.87	n	y	n	y
Lisnalee	Y = 0.31 X + 55.47	0.27	n	y	n	y
Maxvale	Y = 0.85 X + 22.53	0.92	y	y	n	y
Turn Turn	Y = 0.76 X + 2.12	0.87	y	y	y	y
Wittenburra open	Y = 1.16 X - 4.49	0.47	y	y	y	y
Wittenburra enclosed	Y = 0.72 X + 10.87	0.61	y	y	y	y
Wongalee	Y = 0.80 X + 20.31	0.96	n	y	n	y

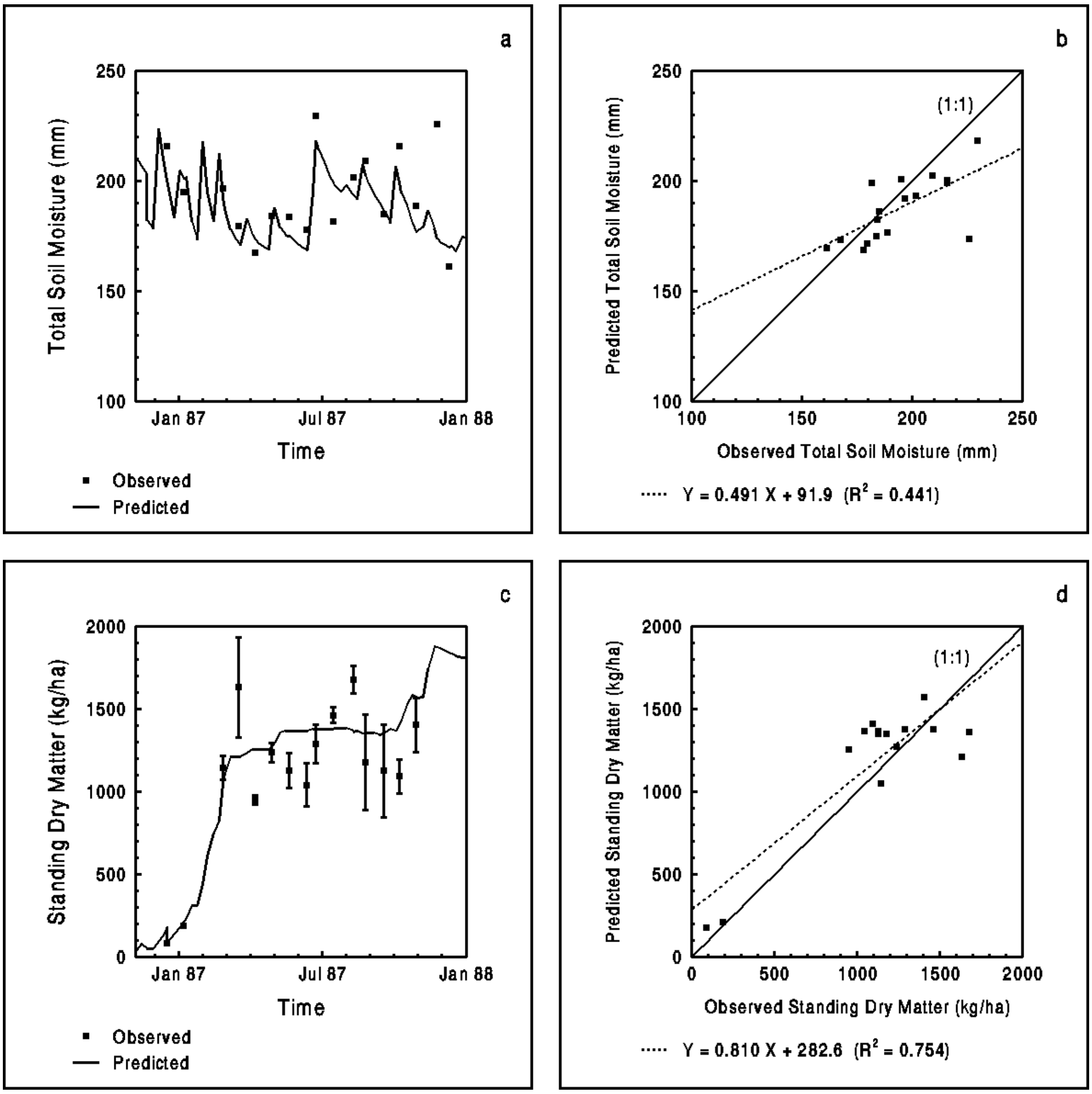

Figure 4.3 Predicted and observed standing dry matter and total soil moisture at the Biddenham undulating downs site during the period November 1986 to December 1987. Error bars indicate ± one SE.

4.3.1.2 Charleville site - Mulga Grasses

The simulated time course of total soil moisture at the Charleville site was comparable to observed values (Slope nsd 1.0 (5% level)) (Figure 4.4 a&b and Table 4.3). Eighty-three percent (15 out of 18) of simulated values were within 10% of observed (average sampling variation of 4.5%). However, the intercept was significantly greater than 0.0 (5% level) indicating the model was overestimating soil moisture (by up to 13mm or 34%) when dry conditions prevailed.

At the Charleville site the slope of the regression between simulated and observed standing dry matter was significantly comparable to 1.0 only at the 1% level (Figure 4.4c and Table 4.3). However, the intercept was not significantly different to 0.0. Sixty-seven percent of simulated dry matter yields were within one standard error of observed yields.

The simulated time course of dry matter yield at the Charleville site corresponded to the two periods of significant observed increase in yield (between 11.02.87 and 04.03.87, and between 04.03.87 and 23.09.87). During each of these periods, significant increases in green cover (Chapter 3) corresponded to simulated increases in green cover (Appendix 8). However, the loss of material observed was not simulated by GRASP. As for Biddenham the calibration procedure underestimated the observed peak yield at the end of both growth phases (by 176 kg/ha or 25% and by 145 kg/ha or 12% respectively).

4.3.1.3 Airlie - Mitchell Grass

The time course of simulated total soil moisture at Airlie generally followed observed values (Figure 4.5a). However, the regression between simulated and observed soil moisture was only significant at $P<0.01$ (Figure 4.5b and Table 4.3). Fifty-seven percent (4 out of 7) of simulated values were within 10% of observed (average sampling variation of 8.3%). The GRASP model underestimated the moisture content of wet profiles (by 53 mm or 19%) and overestimated the moisture content in dry profiles (by 42 mm or 56%). This indicates the model did not simulate the apparent rapid drying or wetting of the profile. This may be the result of large cracks developing in this soil and subsequent spatial variability in soil water over short distances (<1m) which was not adequately described by GRASP or observed in the field (little variation in soil moisture between cores >5m apart (Appendix 3, Table 8.2)). A greater sampling density with improved methods for estimating dry profiles (e.g. neutron moisture meter) would assist in describing the soil water relationships for these soils.

The observed pattern of growth at Airlie showed two bursts of growth (between 10.04.89 and 03.07.89, and between 25.09.89 and 28.11.89). Both were simulated by the model (Figure 4.5c). As for Biddenham and the Charleville site, GRASP model (GVT74) underestimated the peak yield and the end of each of these periods (Table 4.4). However, the simulated first peak yield was within one standard error of the observed peak yield.

A significant decline in observed dry matter yield at Airlie in early Autumn (between 27.02.89 and 10.04.89 at 1%/day) was not simulated by GRASP. This was due to a decline in grass yield, possibly through detachment. No attempt was made to calibrate variable timing of detachment in GRASP.

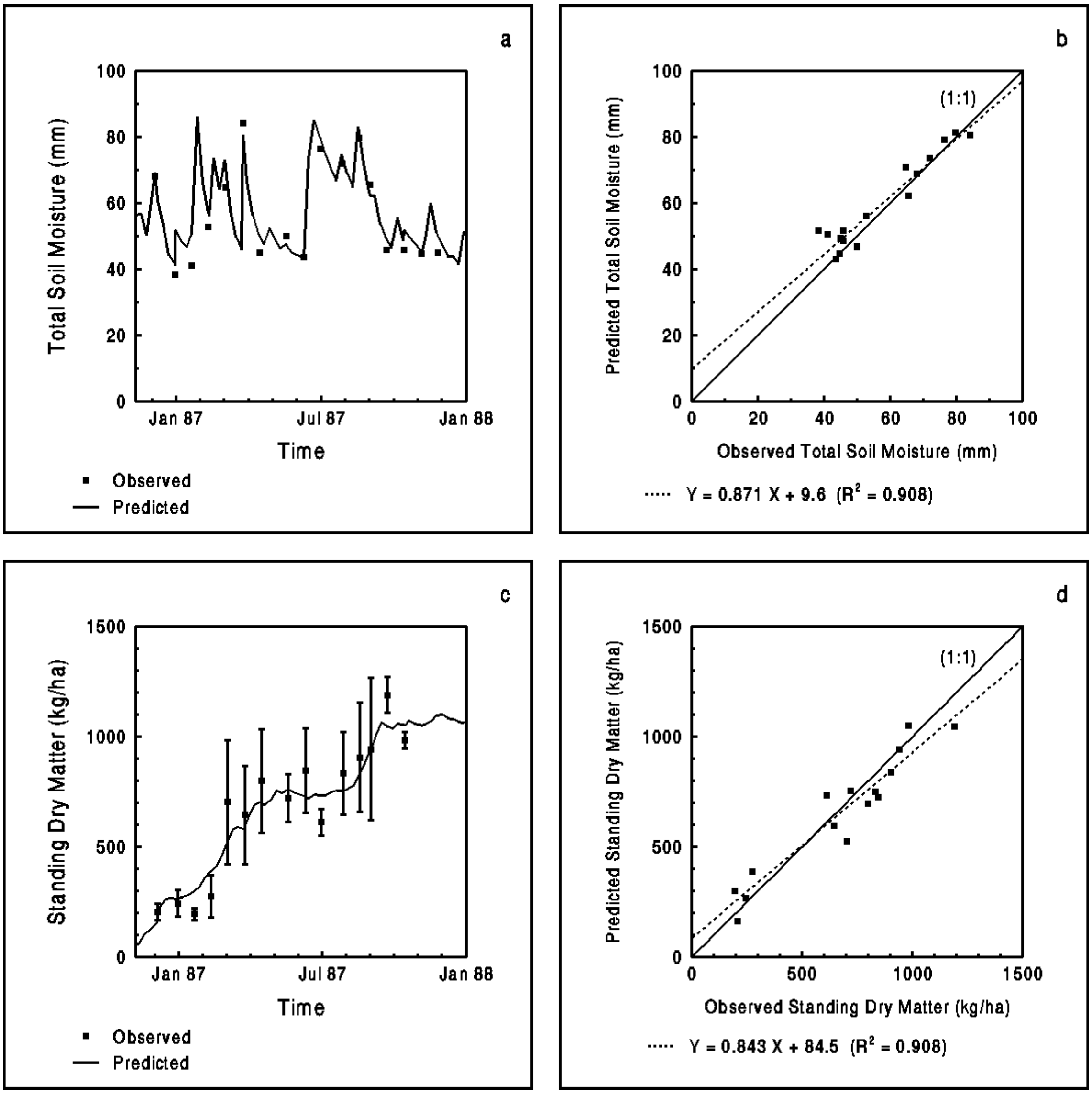

Figure 4.4 Predicted and observed standing dry matter and total soil moisture at the Charleville mulga sandplain site during the period November 1986 to December 1987. Error bars indicate ± one SE.

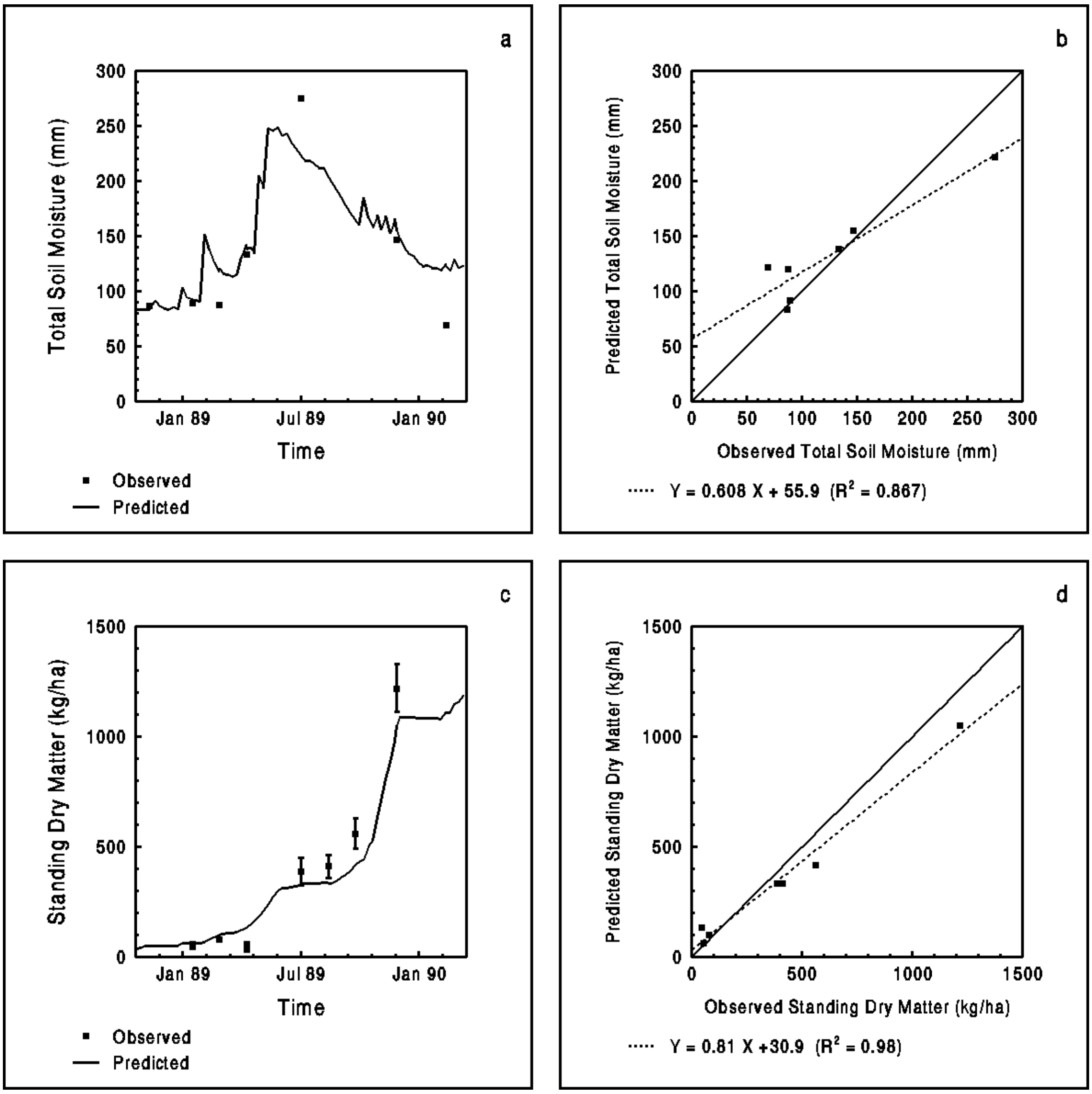

Figure 4.5 Predicted and observed standing dry matter and total soil moisture at the Airlie alluvial plains site during the period November 1988 to February 1990. Error bars indicate ± one SE.

4.3.1.4 Lisnalee - Buffel Grass

The time course of total soil moisture at Lisnalee generally followed observed values (Figure 4.6a). Seventy-three percent (8 out of 11) of simulated values were within 15% of observed soil moistures (average sampling variation of 5.2%). However, the regression was only significant at the 1% level (Figure 4.6b and Table 4.3). As for other sites on clay to clay-loam soils in this study (Biddenham and Airlie), GRASP overestimated the moisture content of dry soils (by up to 41 mm or 70%) and underestimated moisture in wet soils (by up to 12mm or 9%) at Lisnalee.

The observed pattern of growth at Lisnalee showed three bursts of growth (between 02.03.89 and 14.04.89, between 17.08.89 and 28.09.89 and between 20.02.90 and 11.05.90). The time course of simulated yield corresponded with the first and third of these (Figure 4.6c). The second growth phase (early spring) not simulated by the model was associated with an increase in observed green cover. It is possible this was the result of the growth of green stems as described for the Biddenham site, as the C4 temperature response used in calibration suggests temperatures were too low for leaf growth. As for Biddenham this material disappeared over late spring and summer possibly through translocation, detachment and/or consumption by insects.

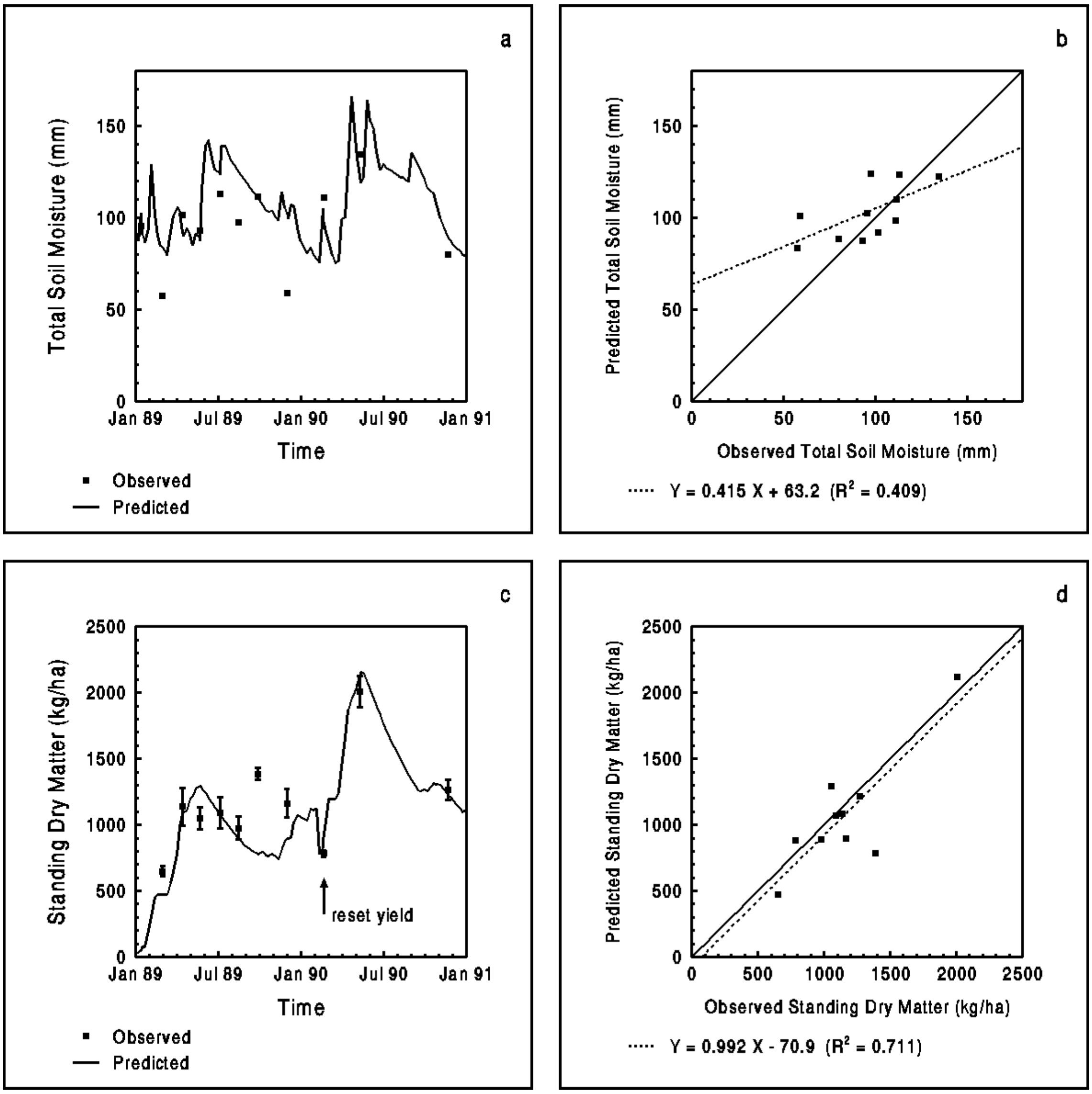

Figure 4.6 Predicted and observed standing dry matter and total soil moisture at the Lisnalee buffel grass site during the period January 1989 to November 1990. Error bars indicate ± one SE.

4.3.1.5 Maxvale - Mulga Grasses

The simulated time course of total soil moisture at Maxvale was comparable to observed values (Figure 4.7a and Table 4.3). However, the model failed to simulate the early period of drying when there were low yields and covers. Due to the lack of grass cover, water use at this stage was most likely evaporation from soil and transpiration from trees (one *Eucalyptus populnea* tree located outside the enclosure may have had roots in the plot). When grass cover was present simulated soil moisture was comparable to observed values.

The observed pattern of growth at Maxvale showed two periods of growth (between 09.12.88 and 19.01.89 and between 13.04.89 and 22.05.89) and a period of yield decline (possibly through detachment) (between 28.09.89 and 01.12.89). The calibrated model simulated these growth periods but did not simulate the loss of material during spring (Figure 4.7c). No attempt was made during the calibration to account for detachment occurring in spring. Green cover was overestimated by the model during late winter, and an observed significant decline in green cover during spring (between 28.09.89 and 01.12.89) (again possibly via detachment) was not simulated by the model (Appendix 8).

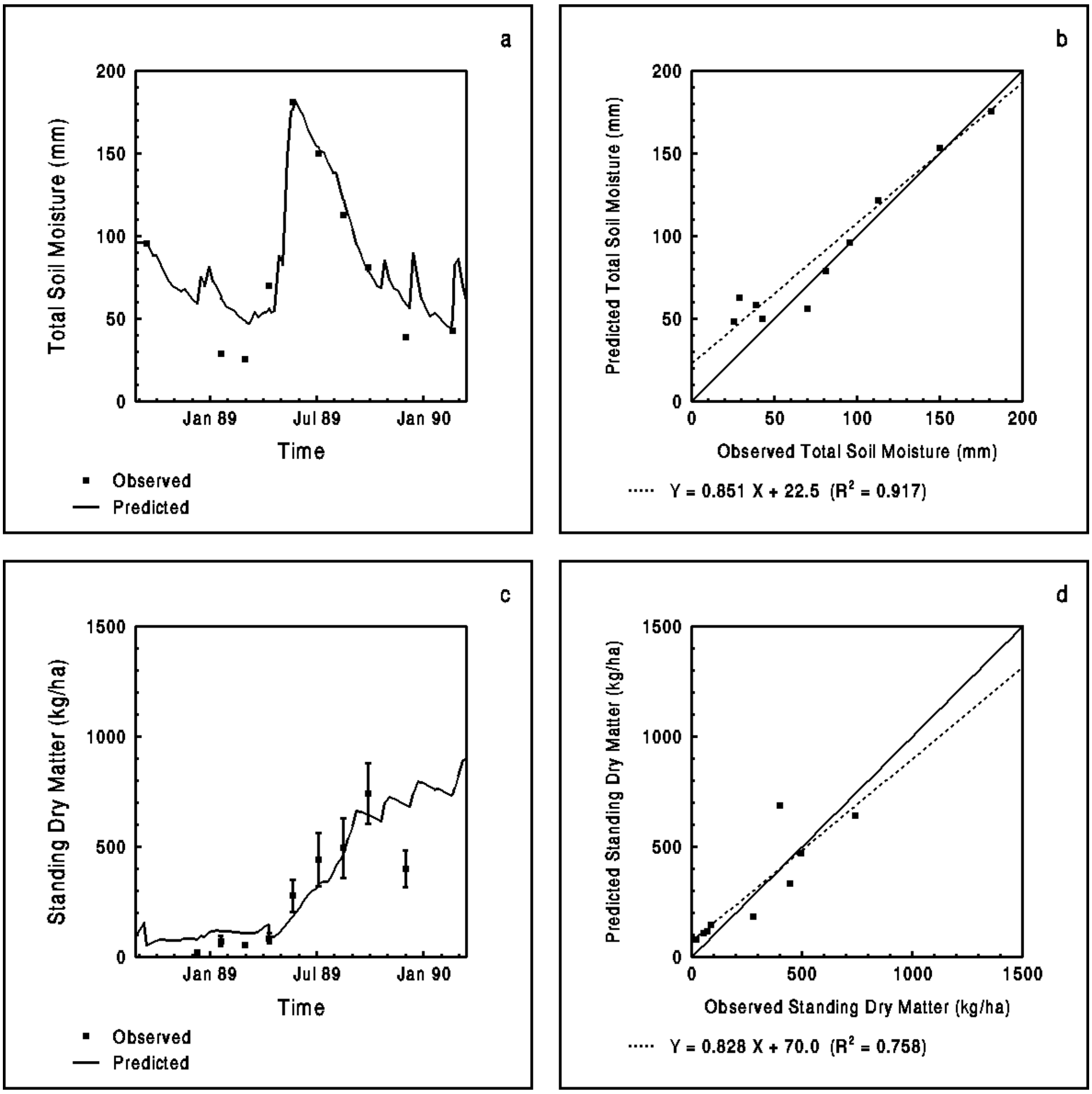

Figure 4.7 Predicted and observed standing dry matter and total soil moisture at the Maxvale soft mulga site during the period September 1988 to February 1990. Error bars indicate ± one SE.

4.3.1.6 Turn Turn - Mulga Grasses

The simulated time course of total soil moisture at Turn Turn was comparable to observed values (Figure 4.8a and Table 4.3). In contrast to the Maxvale site, the calibration of GRASP adequately simulated the drying of the soil profile over the summer of 1988/89. However, the simulated timing of drying in winter was 26 days too early in comparison to that observed in the field.

The observed pattern of growth at Turn Turn showed one major growth phase with material disappearing (predominantly forbs) shortly after the peak yield was attained. The calibrated model matched the observed yields with 88% of simulated values within one standard error of observed values (Figure 4.8c).

Simulated green covers at Turn Turn corresponded to those observed in the field (Appendix 8).

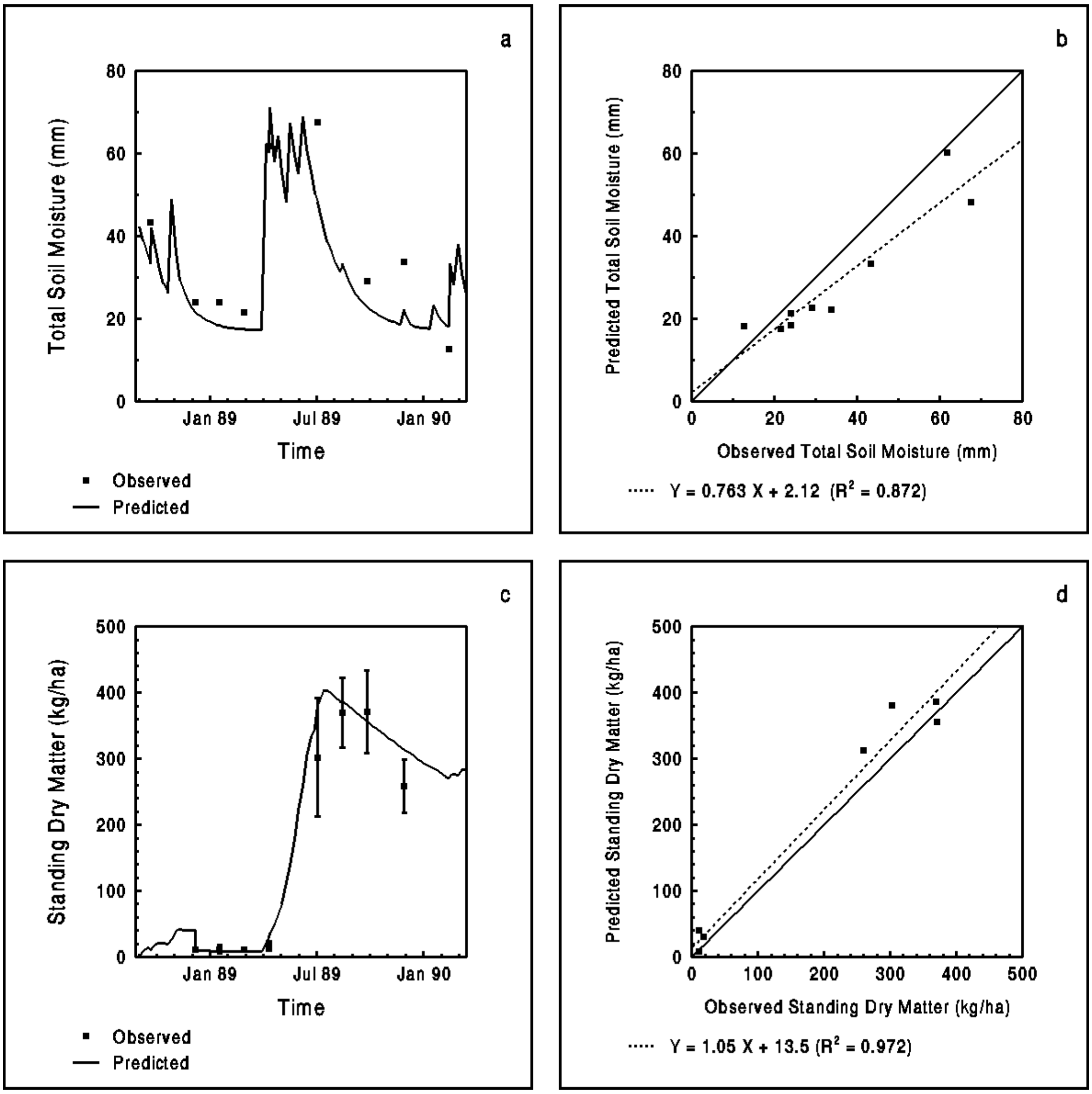

Figure 4.8 Predicted and observed standing dry matter and total soil moisture at the Turn Turn mulga sandplain site during the period September 1988 to February 1990. Error bars indicate ± one SE.

4.3.1.7 Wittenburra - Mulga Grasses

At each of the Wittenburra sites, the time course of simulated total soil moistures was similar and comparable to observed values (Figures 4.9a and 4.10a). However, there was one major outlier on 11/04/89 when the predicted value was greater than the observed (40 mm at the open site and 27 mm at the enclosed site). This may be explained by a possible mis-timing of the rainfall event (localised storm or shower) leading to the increased soil moisture near this date. As accurate daily rainfall was unavailable at the site, the timing of rainfall was estimated from nearby rainfall stations (Eulo and Hungerford). Soil moistures in the enclosed site were generally lower than those in the open site (due to the presence of trees in the enclosure).

At each of the Wittenburra sites, regression analysis indicated a significant relationship between observed and simulated dry matter yield (Figures 4.9c and 4.10c and Table 4.3). As for Biddenham, caution is required when interpreting these data due to the clustering of low and high values and the magnitude of the standard errors.

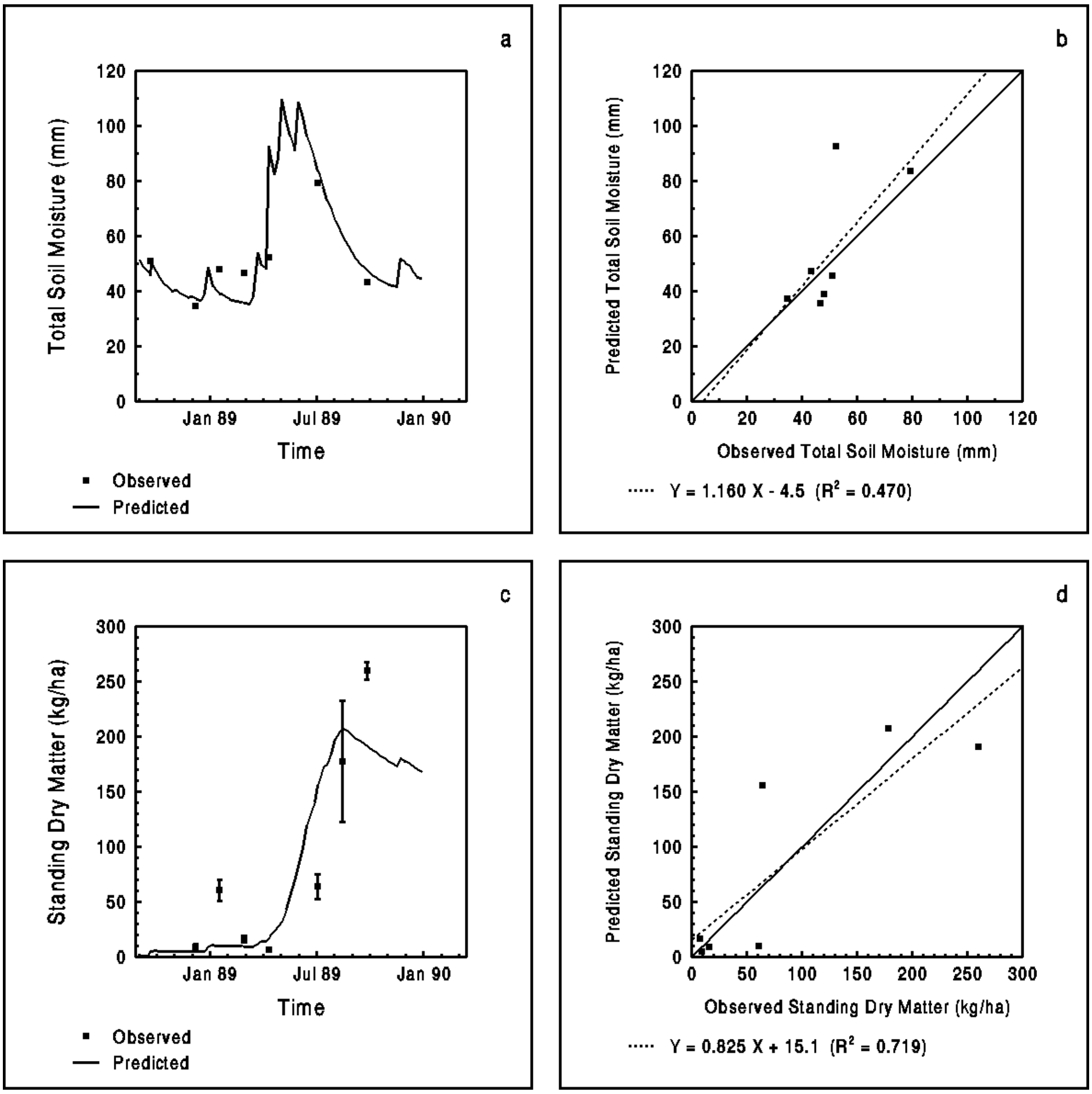

Figure 4.9 Predicted and observed standing dry matter and total soil moisture at the Wittenburra Open hard mulga site during the period September 1988 to September 1989. Error bars indicate ± one SE.

The observed pattern of growth at Wittenburra Open showed two bursts of growth. The first peak in summer was followed by a rapid loss of some yield component (e.g. inflorescence and leaf). The calibrated model did not show this growth phase (Figure 4.9c). The forage at this stage was dominated by ephemeral grasses which characteristically disappear rapidly on completion of flowering and seeding. As these species make only a short term contribution to animal nutrition, the inability of GRASP to simulate these species was not considered a major limitation. The second and larger growth phase over autumn and winter was simulated by the calibrated model. However, the peak yield was not simulated as the model predicted a loss of material in August 1989 not observed in the field. As for other sites, the calibration procedure did not concentrate on tuning on the time of detachment, occasionally resulting in differences between simulated and observed yields late in the sampling period.

At the enclosed Wittenburra site the pattern of growth was simulated by the calibrated model (Figure 4.10c and Table 4.3). The simulated peak yield (188 kg/ha) was within one standard error of the observed peak yield (193 kg/ha) (Table 4.4). Simulated green cover values were comparable to those observed in the field (Appendix 8).

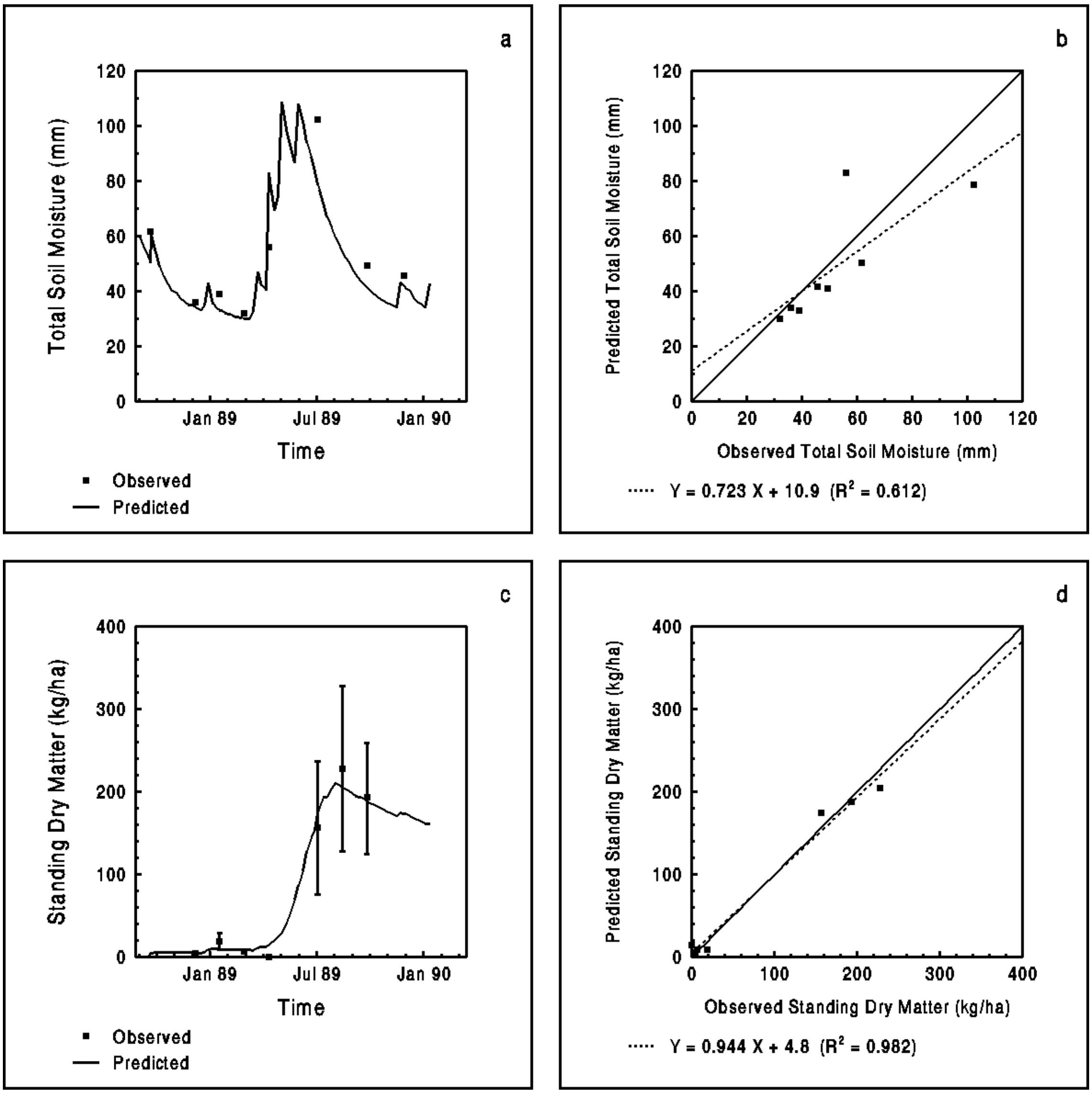

Figure 4.10 Predicted and observed standing dry matter and total soil moisture at the Wittenburra Enclosed hard mulga site during the period September 1988 to November 1989. Error bars indicate ± one SE.

4.3.1.8 Wongalee - Spinifex

The simulated time course of soil moisture at Wongalee appeared to correspond well to observed values (Figure 4.11a). However, regression analysis of simulated and observed values indicated the slope and intercept were significantly different to 1.0 and 0.0 respectively, despite a high correlation (R^2 0.96) (Figure 4.11b and Table 4.3). As for other sites in this study the GRASP model overestimated soil moisture in dry profiles and underestimated the moisture content of wet profiles.

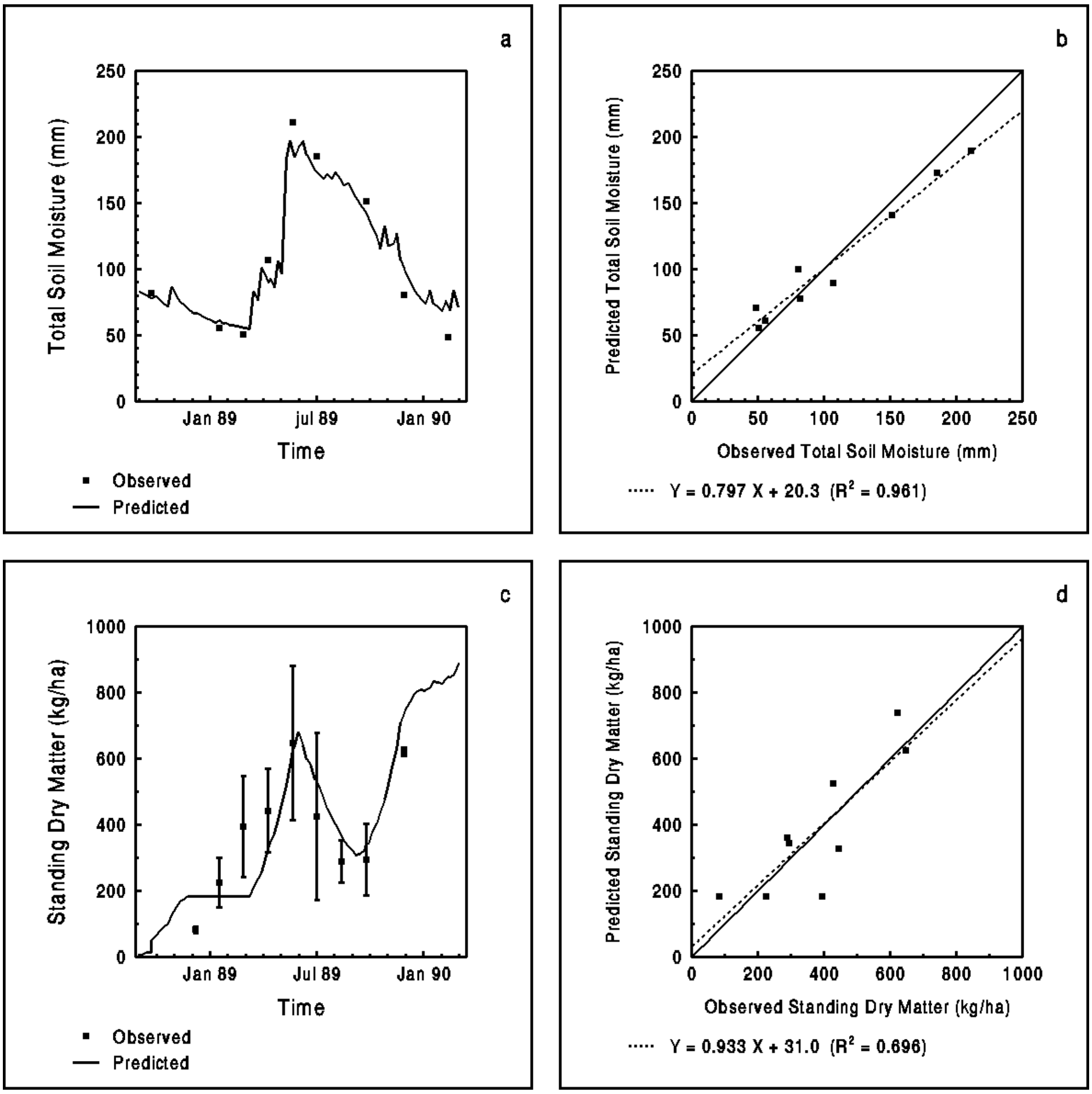

Figure 4.11 Predicted and observed standing dry matter and total soil moisture at the Wongalee spinifex heathland site during the period September 1988 to February 1990. Error bars indicate ± one SE.

The pattern of growth at Wongalee showed two, almost linear bursts of growth (Figure 4.11c). The first (between 07.12.88 and 22.05.89) at 3.6 kg/ha/day and the second (between 25.09.89 and 28.11.89) at 4.8 kg/ha/day. The calibrated model showed each of these growth periods. The commencement of both growth phases occurred during periods of either low or declining soil moisture (Figure 4.11a). Spinifex growth at Wongalee therefore appears independent of moisture availability in the surface 100cm. Either moisture for spinifex growth is being supplied from below 100cm (possible on this land system) or spinifex growth can occur at low moisture potentials and is more influenced by the C4 temperature response chosen for calibration. In contrast to relating spinifex growth to soil moisture, Griffin and Allen (1984) used spinifex cover (%) and cover (%) of other plants to predict the yield of spinifex communities in relation to fuel loads and fire management in central Australia.

Following the first growth phase, a rapid loss of material (8.5 kg/ha/day or 1.26%/day) was observed (between 22.05.89 and 03.07.89). For model calibration detachment was estimated at 1%/day. These high rates of loss are explained by the loss of the tall and heavy seed heads and stalks of spinifex.

Table 4.4 Predicted and observed peak yields for nine sites in south-west Queensland from October 1986 to November 1990. (Observed peak yields from Table 3.5 in Chapter 3.)

Site	Predicted Peak Yield (kg/ha)	Observed Peak Yield (kg/ha)	Difference (%)
Biddenham	1364	1678	19
Charleville	1045	1190	12
Airlie	1049	1216	14
Lisnalee	1073	1092	2
Maxvale	643	742	13
Turn Turn	356	371	4
Wittenburra open	191	260	27
Wittenburra enclosed	188	193	3
Wongalee	739	621	-19

4.3.2 Validation

At sites where soil moisture data were available for validation (estimated from published figures) there was a poor correlation between simulated and observed values (Table 4.5 and Figures 4.14a and 4.16a).

The observed pattern of growth at each of the validation sites was adequately simulated by GRASP (slope nsd 1.0 and intercept nsd 0.0 at 5% level) (Table 4.5 and Figures 4.12 to 4.17).

Each site will be described individually to document performance of the model.

4.3.2.1 Arabella - Mulga pasture (Beale 1985)

At Arabella, stocking rates and estimates of tree density (m^2/ha) in each of the treatments were included in the parameter file. The observed pattern of growth in each treatment was adequately simulated by GRASP (slope nsd 1.0 and intercept nsd 0.0 1%) (Figures 4.12 and 4.13). The highest correlations between simulated and observed yields (r^2 0.78 and 0.74) were recorded in the treatments receiving the lowest and highest grazing pressures (20% and 80% utilisation respectively) (Table 4.5). In the 35%, 50% and 80% treatments simulated yields were consistently less than observed values over the three years 1984 to 1986. In each of these treatments Orr *et al.* (1993) reported an increase in the basal area of *Aristida* spp. from 1982. By 1984 approximately half the basal area in the 50% and 80% treatments comprised *Aristida* spp. This suggests the chosen C3 temperature response for Arabella was too low to simulate the observed growth of the increasing density of the C4 *Aristida* spp. in these treatments.

The simulated utilisation (eaten/grown*100) of average growth was 15.5, 27.6, 27.9 and 39.1% for the 20, 35, 50 and 80% treatments respectively.

Table 4.5 Regressions of predicted (Y) and observed (X) standing dry matter yields and total soil moistures from the GRASP grass production model for five sites in south-west Queensland where data was available for validation of the model. Student's t test calculated to determine whether slope nsd 1.0 (y or n) and intercept nsd 0.0 (y or n) at the 5% and 1% level.

Site and reference	Regression	R^2	Slope nsd 1.0		Intercept nsd 0.0	
			P<0.05	P<0.01	P<0.05	P<0.01
Standing Dry Matter						
Mulga pasture Arabella all (Beale 1985)	Y = 0.81 X + 26.13	0.66	y	y	y	y
Mulga pasture Arabella 20% (Beale 1985)	Y = 0.74 X + 159.98	0.78	y	y	y	y
Mulga pasture Arabella 35% (Beale 1985)	Y = 0.47 X + 105.02	0.33	y	y	y	y
Mulga pasture Arabella 50% (Beale 1985)	Y = 0.59 X + 64.46	0.31	y	y	y	y
Mulga pasture Arabella 80% (Beale 1985)	Y = 0.86 X - 26.62	0.74	y	y	y	y
Mulga pasture Charleville (Christie 1978)	Y = 1.33 X - 86.53	0.88	n	n	y	y
Mulga pasture Louth (J.Noble pers. comm.)	Y = 0.81 X + 39.16	0.91	y	y	y	y
Mitchell Grass Charleville (Christie 1981)	Y = 0.94 X - 0.46	0.62	y	y	y	y
Mitchell Grass Burenda (Christie 1981)	Y = 1.23 X - 292.8	0.83	y	y	y	y
Mitchell Grass Burenda (Beale 1985)	Y = 0.28 X +1033.09	0.15	n	n	n	n
Soil moisture						
Mulga pasture Charleville (Christie 1978)	Y = 0.18 X + 44.46	0.11	n	n	n	n
Mitchell Grass Charleville (Christie 1981)	Y = 0.44 X + 155.91	0.63	n	n	n	n

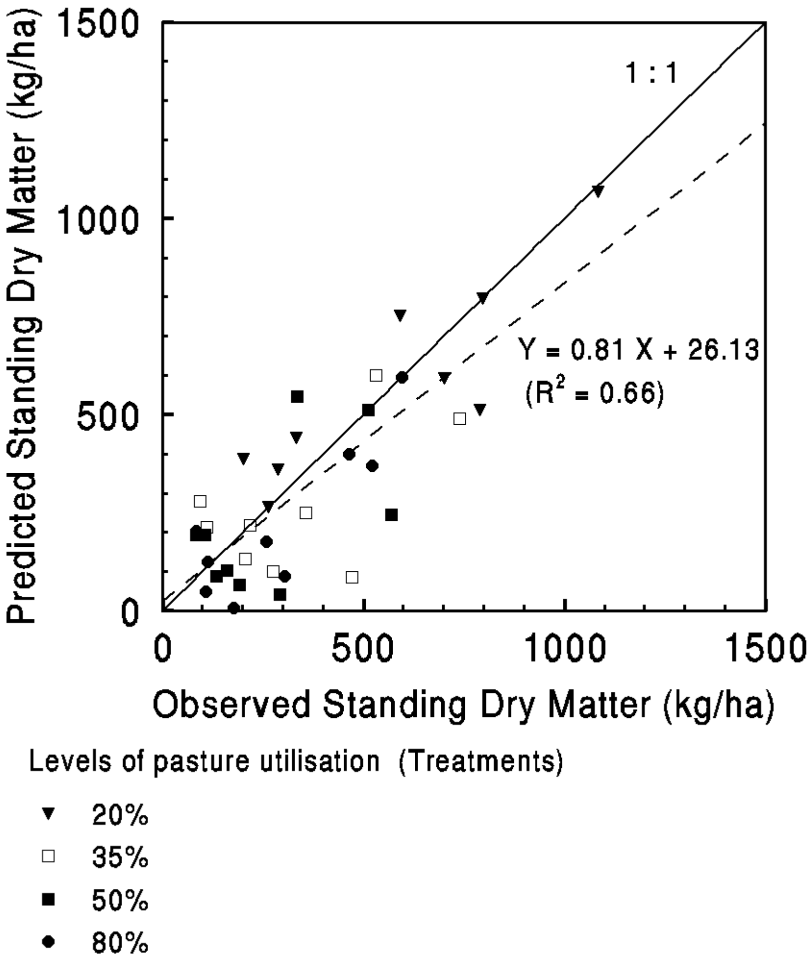

Figure 4.12 Comparison of predicted and observed standing dry matter yields (kg/ha) from validation of the GRASP model with data from all of the treatments in the Arabella grazing trial (Beale 1985) on mulga pastures near Charleville in south-west Queensland.

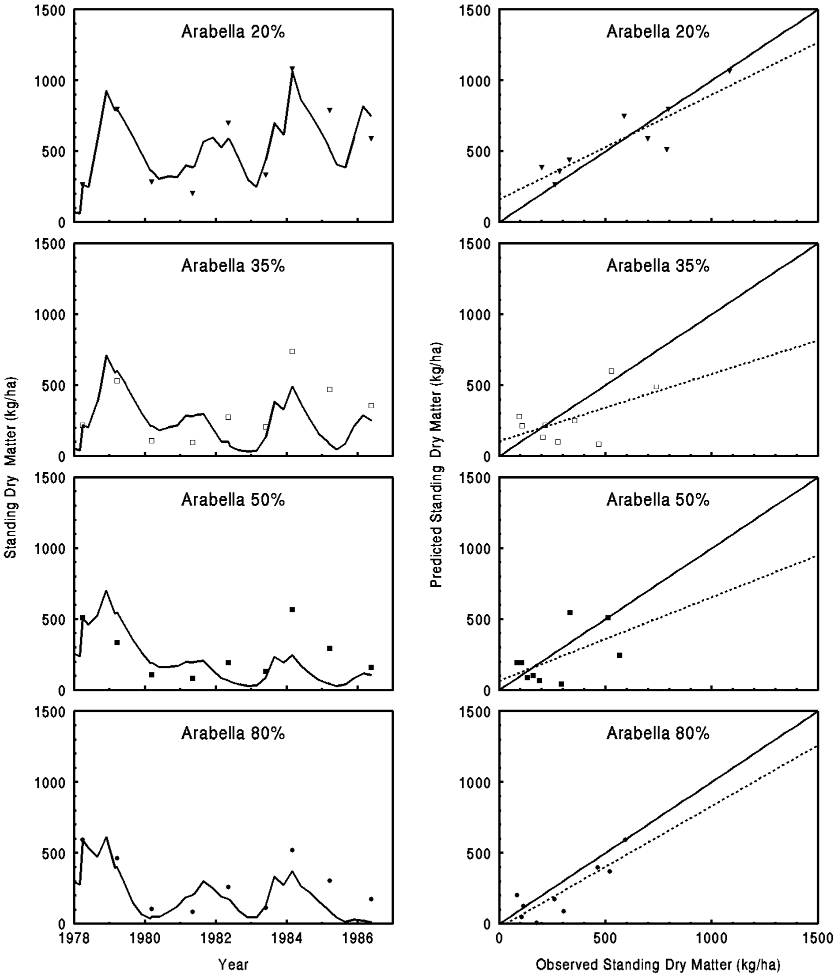

Figure 4.13 Comparison of predicted and observed standing dry matter yields (kg/ha) from validation of the GRASP model with data from each of the grazing utilisation treatments in the Arabella grazing trial (Beale 1985) on mulga pastures near Charleville in south-west Queensland.

4.3.2.2 Charleville - Mulga pasture (Christie 1978)

The time course of simulated soil moisture at this site differed significantly from that reported by Christie (1978) (slope sd 1.0 and intercept sd 0.0) (Figure 4.14a and Table 4.5). Variance was most noticeable from May to November 1974 when simulated soil moistures were consistently 13 to 28 mm greater than reported values. Over this period evapo-transpiration averaged 23% of pan evaporation, with most of the moisture losses occurring from the 10-75cm layer in the soil profile. This indicates high rates of soil evaporation were occurring over this winter period which was not simulated by the GRASP model. The density of trees at this site was unknown. Trees if present would influence the soil water balance and may explain some of the variation between observed and simulated.

The pattern of growth reported by Christie (1978) showed three bursts of growth and two periods of rapid loss of some yield components. The calibrated model showed each of these periods of growth (Figure 4.14c). However, the first growth period was over predicted by the model by 400 kg/ha. With good summer rain in 1974, soil moisture was not limiting and high yields were simulated by GRASP despite a limit on nitrogen uptake by mulga grasses to 21 kg N/ha in the model. For C3 mulga pastures Christie (1981) suggests phosphorus is the major limiting nutrient. The inclusion of Christie's (1978) ceiling on phosphorus uptake for this pasture of 1.1 kg/ha in the model may constrain the over prediction of yield.

The rapid loss of material in April 1974 and August 1974 was not simulated by the model. As a result of this, successful simulation of the growth bursts required the resetting of yields to levels reported at the start of each growth phase. Subsequent simulated peak yields at the end of the second and third growth periods were comparable to the observed values.

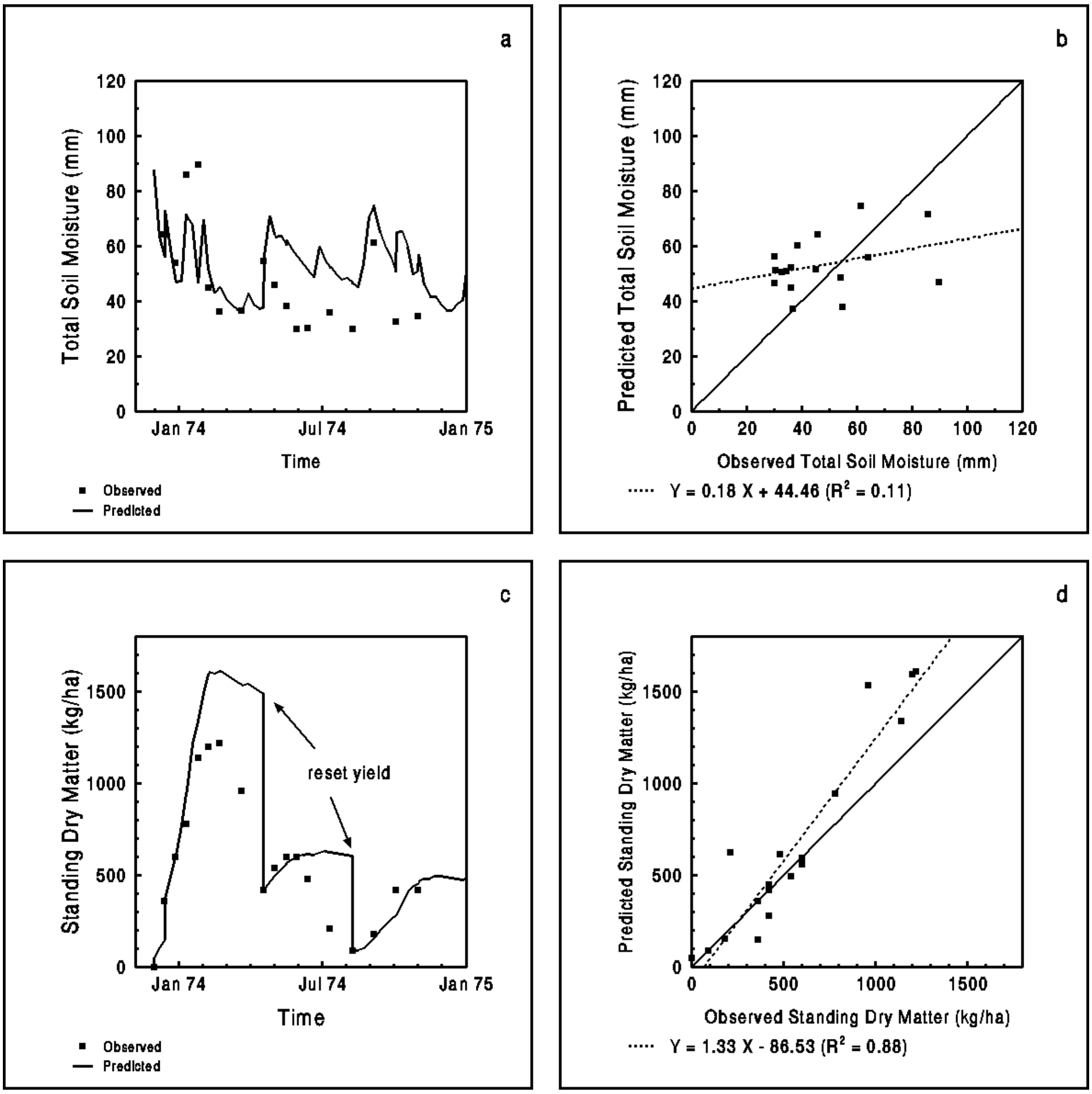

Figure 4.14 Predicted and observed standing dry matter and total soil moisture using the data of Christie (1978) to validate the GRASP model to mulga pastures near Charleville in south-west Queensland.

4.3.2.3 Louth - Mulga pasture (Noble pers. comm.)

The pattern of growth at the Louth site (Noble pers comm) showed a period of gradual growth over summer 1989 with a burst of growth in late winter 1989 (Figure 4.15). The calibrated model based on parameters from Turn Turn adequately simulated both periods of growth (slope nsd 1.0 and intercept nsd 0.0) (Table 4.5).

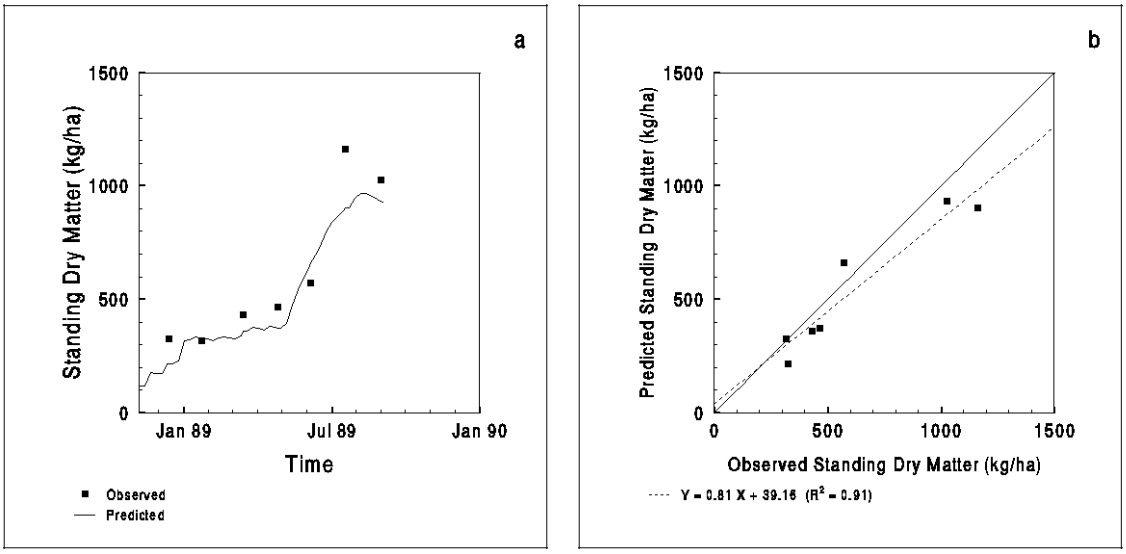

Figure 4.15 Predicted and observed standing dry matter using the data of Noble (1992) (pers. comm.) to validate the GRASP model to mulga pastures near Louth in north-west New South Wales.

4.3.2.4 Charleville - Mitchell grass (Christie 1981)

The time course of simulated soil moisture at Christie's (1981) Charleville mitchell grass site generally followed reported values (Figure 4.16a). The available water range reported by Christie (1981) was used in validation. Despite this, GRASP underestimated the soil moisture content by an average 30 mm during January 1976. Most of these errors were noted in the 50-100cm layer where rapid wetting of the profile could occur via large cracks in the soil.

The observed pattern of growth reported by Christie (1981) at his Charleville mitchell grass site showed one burst of growth followed by a rapid loss of material (Figure 4.16c). Initial validation using these data (using parameters from the Biddenham site) over estimated yield by 365 kg/ha as the maximum nitrogen uptake was calibrated at 21 kg/ha. Using the nitrogen uptake of 16 kg/ha reported by Christie (1981) for this site, a closer estimation of peak yield was simulated (within 5% of the observed value). However, the rapid loss of material (e.g. inflorescence and leaf) was not simulated by the model.

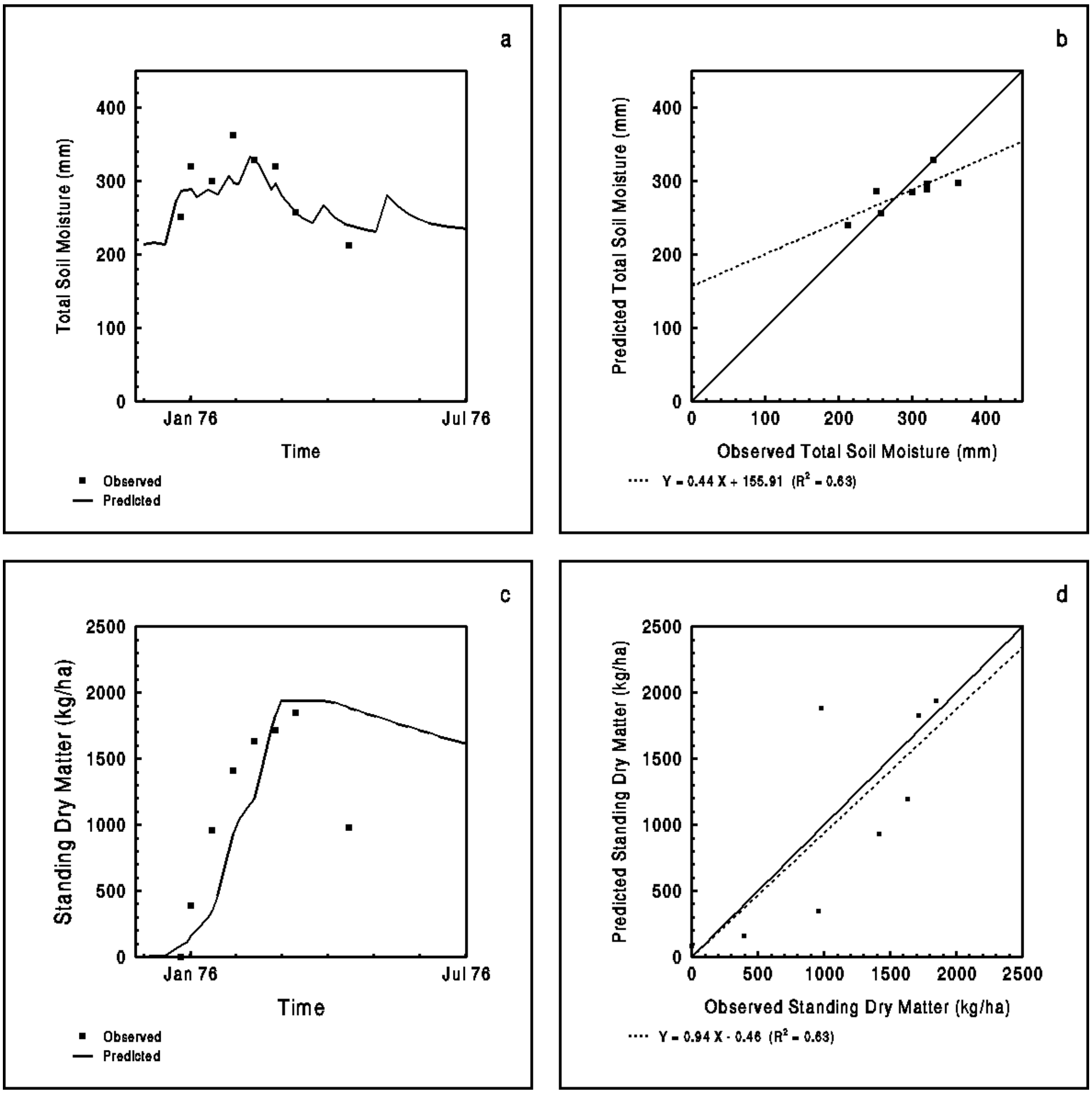

Figure 4.16 Predicted and observed standing dry matter and total soil moisture using the data of Christie (1981) to validate the GRASP model to mitchell grass pastures near Charleville in south-west Queensland.

4.3.2.5 Burenda - Mitchell grass (Christie 1981)

At Burenda, Christie (1981) reported end of season yields from October 1974 to March 1977 for the grass and forb component of the forage. Yields reported were end of summer and winter season "peak live biomass" following mowing back at the start of each growing season. Only the grass component was used in the validation exercise, where yields were reset to 100 kg/ha at the end of each summer and winter growing season to simulate the mowing back. The validated model showed each of these growth phases but over estimated yields at each observation (Figure 4.17a). Actual dates for yield observations and mowing back were not reported making it difficult to draw further conclusions.

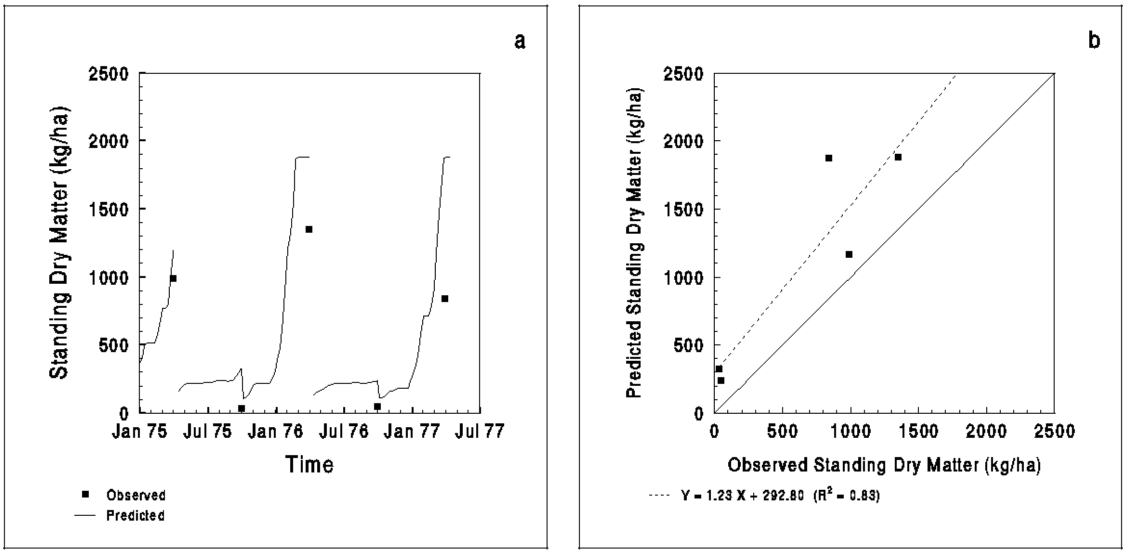

Figure 4.17 Predicted and observed standing dry matter using the data of Christie (1981) to validate the GRASP model to mitchell grass pastures on Burenda near Augathella in south-west Queensland.

4.3.2.6 Burenda - Mitchell grass (Beale 1985)

The reported pattern of growth in the 10% treatment of the Burenda grazing trial (Beale 1985) was characterised by marked fluctuations in end of summer yield (five fold variation between 1982 and 1983) (Figure 4.18). The calibrated model (based on Biddenham parameters) adequately simulated end of summer yield in eleven of the fourteen years of the trial. Each year is described to document performance of the model under a dynamic grazing regime.

In 1976 the simulated yield was 23% greater than the observed value (observed-predicted/observed*100). Examination of Figure 4.18 at this time indicates the quantity of simulated dry matter was declining. An excess of material at this time indicates the simulated rate of detachment was too low to meet the observed yield (i.e. too much material (e.g. leaf, inflorescence and stem) was retained in the simulated forage). Without data on the various yield components it is difficult to determine what material was being lost. However, the above average rainfall in 1976 (Figure 4.19) contributing to this yield was due to above average summer rainfall. Following these conditions it was likely most tussocks flowered and seeded profusely. The rapid loss of inflorescence would result in a sharp decline in yield. This suggests detachment rates were perhaps too low either during or shortly following the wet summer.

In 1977 the simulated yield closely matched the observed value.

In 1978 the simulated yield was 18% below the observed value. Both the annual and summer rainfall for the periods associated with this yield were below average (Figure 4.19). The growth simulated by the model never approached the observed yield indicating there was insufficient retention of material by the end of the previous growing season. This suggests over the dry summer either the simulated detachment rates were too high or the simulated uptake of nitrogen was too low.

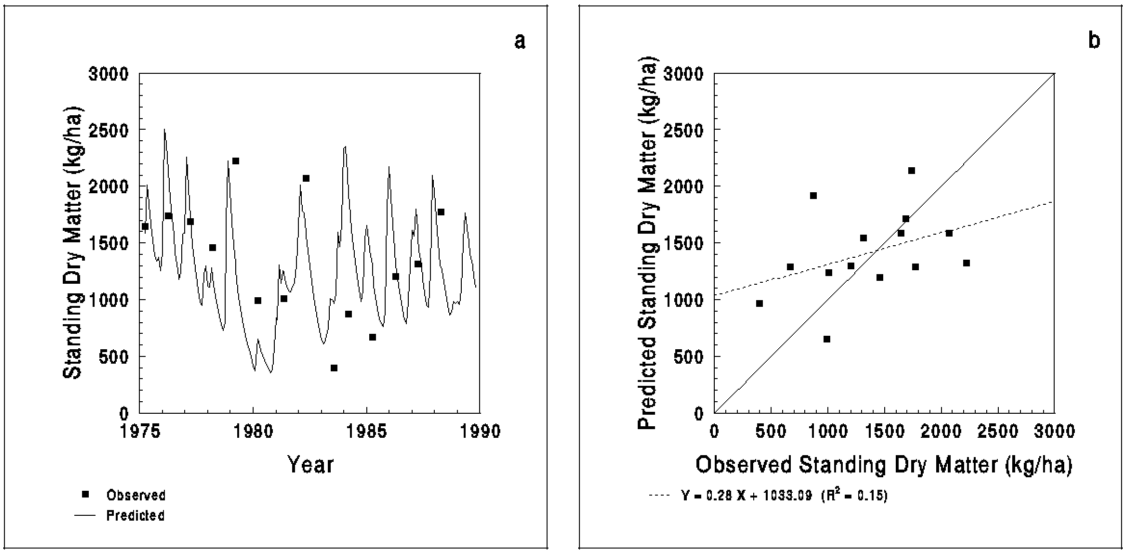

Figure 4.18 Predicted and observed standing dry matter using the data reported by Beale (1985) to validate the GRASP model to mitchell grass pastures in the grazing utilisation trial on Burenda near Augathella in south-west Queensland.

Yield was again under predicted in 1979 (by 40%). Above average rainfall in winter 1978 (Figure 4.19) resulted in a simulated yield at the end of November 1978 comparable to that observed at the end of March 1979 (Figure 4.18). However, the rapid loss of material simulated by the model over the dry summer of 1979 resulted in the under prediction of the observed yield.

In 1980 the simulated yield was 35% below the observed value. Insufficient carry over of material from the previous year (detachment too high) associated with below average summer rainfall in 1980 contributed to the under prediction of yield.

In 1981 the simulated yield closely matched the observed value.

Yield was again under predicted in 1982 (by 23%). With the above average rainfall in winter 1981 and summer 1982 and potentially greater quantity of nitrogen available after the drought of 1980 and 1981 simulated yields could have been greater. This indicates the need for a more dynamic nitrogen model as a component of GRASP. However, the simulated yield at the end of November 1981 was comparable to that observed at the end of March 1982. Again the rapid loss of material simulated by the model over the summer of 1982 resulted in the under prediction of the observed yield.

The model over predicted yields by 144%, 119% and 93% in the years 1983,1984 and 1985 respectively (Figure 4.18). Between 1982 and 1983 a five fold reduction in yield was reported. Below average summer rainfall in 1983 and below average winter rainfall in 1982 (Figure 4.19) and an observed reduction in perennial grass basal area (Beale 1985) would have contributed to the low observed yield. Despite the high detachment rates and dynamic basal area model within GRASP, the model could not match the observed yield decline.

In 1984 the biggest over prediction of yield was observed (Figure 4.18). This followed a very wet winter in 1983 and good summer rain in 1984 (Figure 4.19). The low basal areas reported for 1984 in combination with a potential lack of nitrogen (due to profuse forb growth in winter 1983) may explain the low observed yield. Again a more dynamic nitrogen model may have resulted in a simulated yield closer to the observed.

In 1985 yield was again over predicted (Figure 4.18). The above average rainfall in winter 1984 and low summer rainfall in 1985 (Figure 4.19) may again have resulted in a lack of available nitrogen for grass growth. The basal area of grasses may also have still been low (due to low summer rainfall), contributing to low observed yields.

In 1986 and 1987 simulated yields were comparable to observed values (Figure 4.18).

Yield was again under predicted in 1988 (by 27%) (Figure 4.18). Above average rainfall in winter 1987 (Figure 4.19) resulted in a simulated yield at the end of November 1987 comparable to that observed at the end of March 1988. However, the rapid loss of material simulated by the model over the dry summer of 1988 resulted in the under prediction of the observed yield.

The simulated utilisation (eaten/grown*100) of average growth was 11.9, 19.5, 29.9, 37.1 and 36.8% for the 10, 20, 30, 50 and 80% treatments respectively.

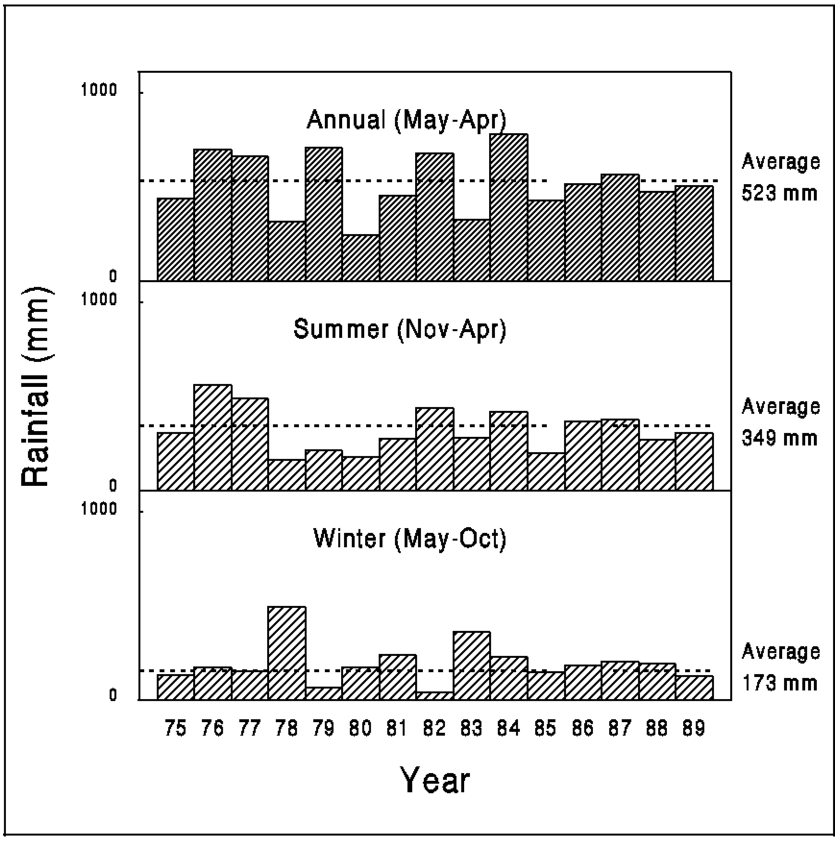

Figure 4.19 Annual, summer and winter rainfall between 1975 and 1989 and long-term average rainfall for Burenda (25°46’ S 146°44’ E) near Augathella in south-west Queensland.

4.3.3 Extrapolation over time and space

Simulated forage growth during the thirty-two years 1960 to 1992 reflected the rainfall sequence for the corresponding period (Figure 4.20). Only the results for one site are presented graphically (Charleville site). The remaining sites displayed a similar pattern. Marked fluctuations in growth were observed, with three periods of substantial growth (early 1960's, early 1970's and the late 1980's) separated by three periods of low yields (mid to late 1960's, early 1980's, and early 1990's). Yield observations reported for May 1963 by Ebersohn (1970), February 1972 by Beale (1975) and end of summer 1974-77 by Christie (1978b) are in close agreement with those simulated by the model (Figure 4.20 b). At this stage of model development, GRASP does not predict growth of annual and ephemeral species.

In simplifying the simulation results there was a positive relationship between evapo-transpiration and rainfall and simulated growth for each of the thirty-two years and twenty rainfall locations (Charleville site data presented in Figure 4.21). However, the correlation between cumulative evapo-transpiration and simulated growth was greater than that between cumulative rainfall and simulated growth (Table 4.6). The slope of the regression using these data represents an average annual water use efficiency (growth per unit of water used) for the Charleville site for the geographical area covered by the twenty rainfall locations, and for the thirty-two years 1960 to 1992. However, the scatter of points in Figure 4.21 and correlation coefficients in Table 4.6 indicated variability in water use efficiencies (water used per unit of growth).

Examination of this relationship at only one rainfall location (Charleville) also indicated a range of water use efficiencies (Figure 4.22 and Table 4.7). Water use efficiency varied from year to year (Figure 4.23). The range of annual, summer and winter water use efficiencies were 4.0-0.2, 3.8-0.2 and 6.4-0.2 (kg/ha/mm) respectively. From these data an "average" water use efficiency for one location (Charleville) was estimated (slope of regressions in Table 4.7).

Average water use efficiencies for the thirty-two years were compared across the twenty rainfall locations (Charleville site results presented in Figure 4.24 as an example). There was a positive relationship between annual water use efficiency (growth per unit rainfall) and longitude and latitude (proxies for rainfall) for all parameter sites except Maxvale (Table 4.8). At Maxvale the relationship between annual water use efficiency and latitude was not significant.

When conducted for the other sites these analyses have simplified the variability in water use efficiency for the eight land systems examined in Chapter 3 based on the temporal and spatial variability in rainfall across the twenty locations used. The regressions in Table 4.8 enable the estimation of an average rainfall use efficiency for the eight land systems at any location in south-west Queensland. However, these regressions have not accounted for the spatial variability in vapour pressure deficit across the region as only vapour pressure deficit data for Charleville was used for each of the simulations.

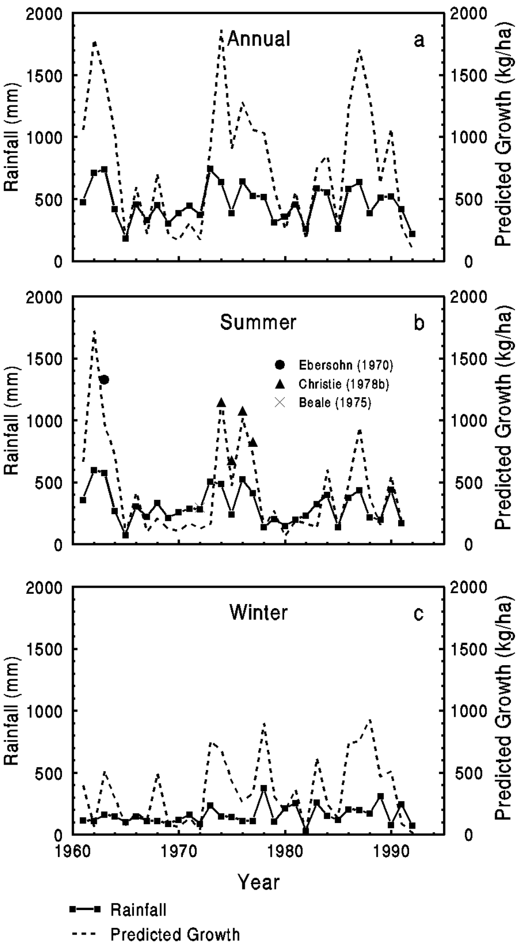

Figure 4.20 Rainfall and predicted growth from the GRASP forage production model for the Charleville site between 1960 and 1992 using climatic data for Charleville. Data reported by Ebersohn (1970), Beale (1975) and Christie (1978b) are shown for validation.

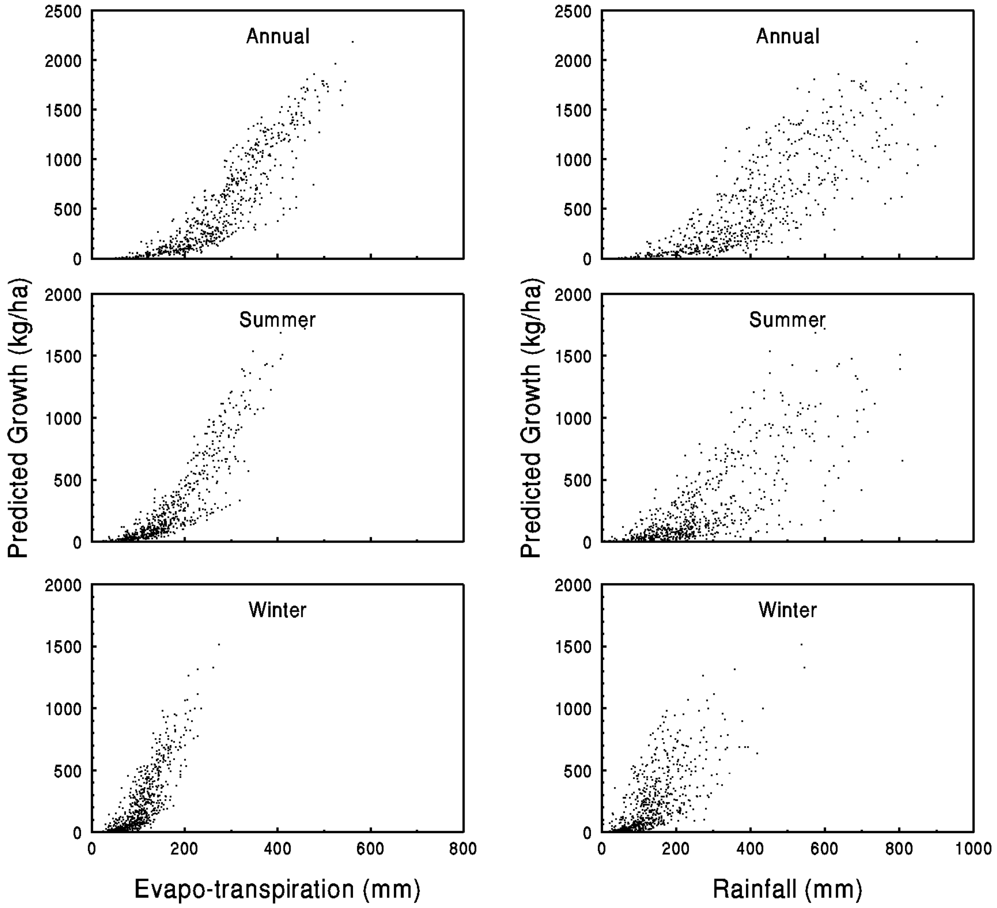

Figure 4.21 The relationship between predicted growth and cumulative evapo-transpiration and rainfall for twenty rainfall locations for the years 1960 to 1992 for parameters describing the Charleville site from simulations using the GRASP forage production model.

Table 4.6 Spatial regressions using data for twenty rainfall locations between growth (kg/ha)(G) simulated by the GRASP model and cumulative rainfall (Ra) and evapo-transpiration (ET) in south-west Queensland for 32 years (1960-92) using parameters describing the Charleville site.

Season	Regression (Ra)	R^2	Regression (ET)	R^2
Annual	G = 2.24 * RA - 360.27	0.65	G = 4.25 * ET - 627.00	0.79
Summer	G = 1.73 * Ra - 172.91	0.57	G = 3.79 * ET - 351.79	0.77
Winter	G = 2.39 * Ra - 71.37	0.50	G = 4.78 * ET - 251.80	0.68

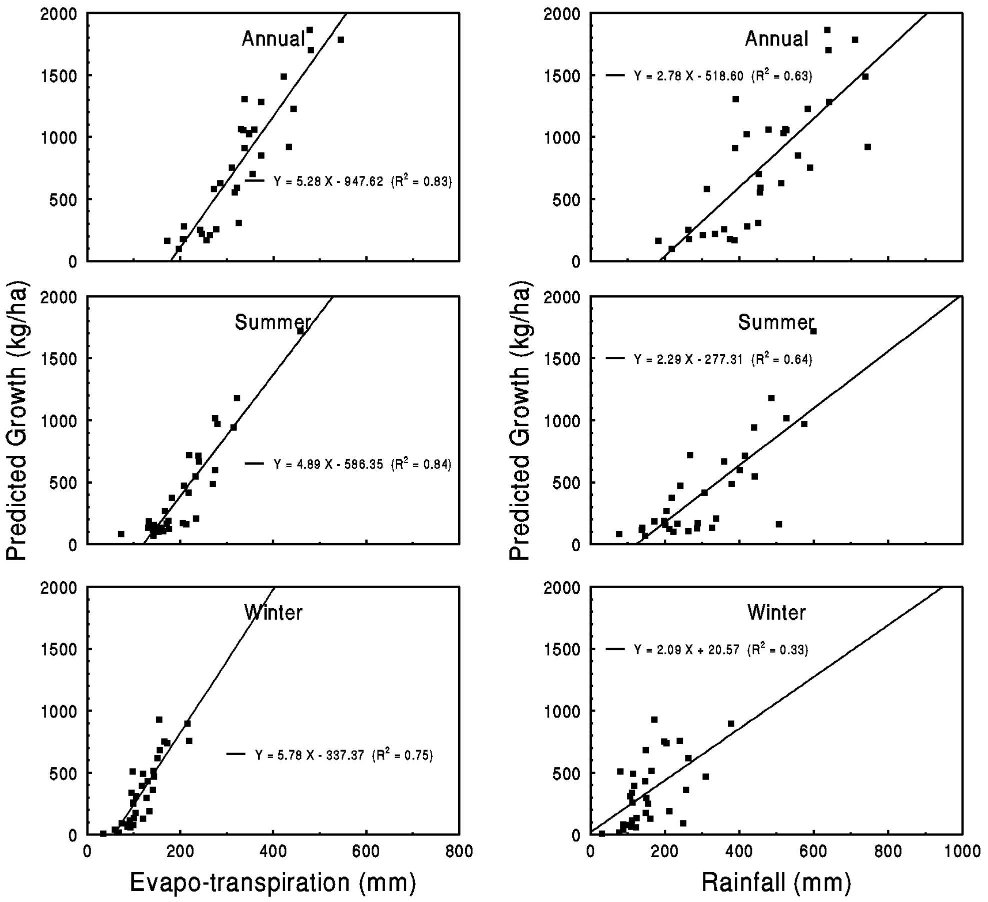

Figure 4.22 The relationship between growth simulated by the GRASP forage production model for the 32 years 1960 to 1992 and cumulative evapo-transpiration and cumulative rainfall using the Charleville rainfall location and parameters describing the Charleville site.

Table 4.7 Temporal regressions for 32 years (1960-92) at one location (Charleville) between growth (kg/ha)(G) simulated by the GRASP model and cumulative rainfall (Ra) and evapo-transpiration (ET) using parameters describing the Charleville site.

Season	Regression (Ra)	R^2	Regression (ET)	R^2
Annual	G = 2.78 * RA - 518.60	0.63	G = 5.28 * ET - 947.62	0.83
Summer	G = 2.29 * Ra - 277.31	0.64	G = 4.89 * ET - 586.35	0.84
Winter	G = 2.09 * Ra - 20.57	0.33	G = 5.78 * ET - 337.37	0.75

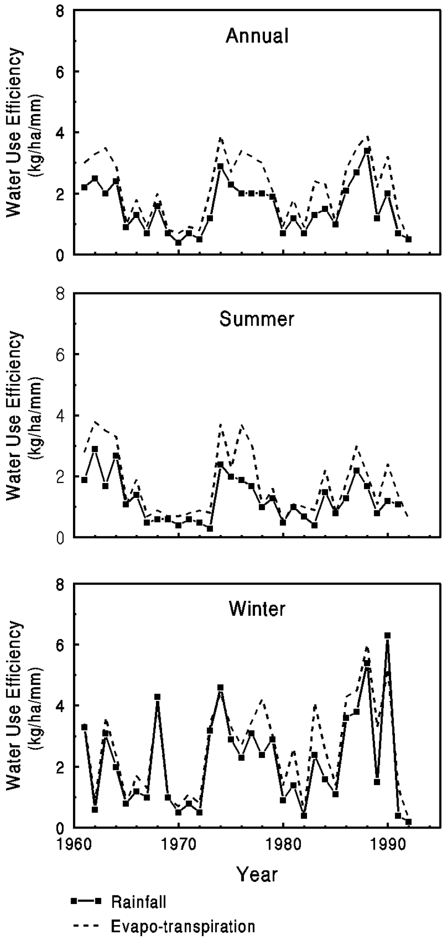

Figure 4.23 The temporal variation in water use efficiency (kg/ha/mm) (evapo-transpiration and rainfall) calculated from output from the GRASP forage production model over the period 1960 to 1992 using the Charleville rainfall location and parameters describing the Charleville site.

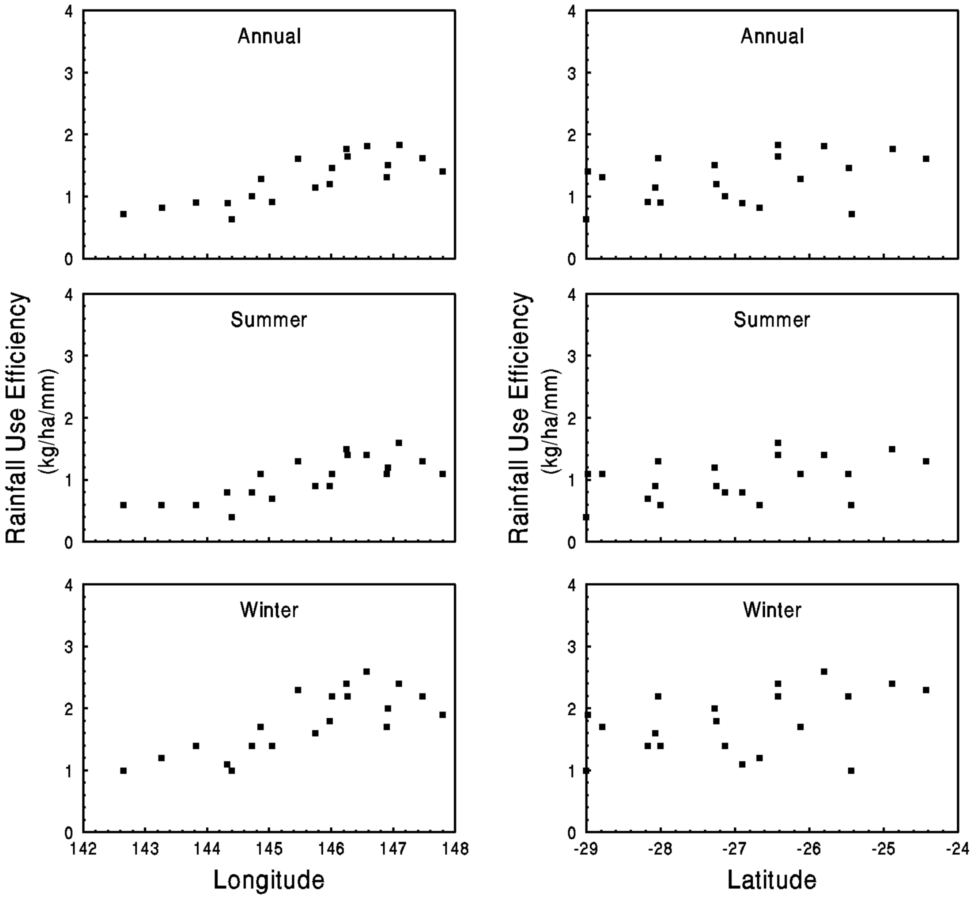

Figure 4.24 The spatial variation in rainfall use efficiency over the study region in south-west Queensland using growth simulated by the GRASP model for twenty locations for the 32 years 1960 to 1992 using parameters describing the Charleville site.

Table 4.8 Regressions between Longitude (Long), Latitude (Lat) and average rainfall use efficiencies (RUE) (kg/ha/mm) for the 32 years 1960-92 derived from simulation studies using the GRASP model with rainfall data from twenty locations in south-west Queensland and regional overall average rainfall use efficiency (ARUE).

Site and Season	Regression	R^2	ARUE (kg/ha/mm)
Annual			
Biddenham	RUE = 0.414*Long - 0.265*Lat - 50.17	0.93	2.94
Charleville	RUE = 0.242*Long - 0.154*Lat - 29.74	0.94	1.28
Airlie	RUE = 0.295*Long - 0.234*Lat - 34.55	0.92	2.10
Lisnalee	RUE = 0.325*Long - 0.299*Lat - 36.32	0.93	3.00
Maxvale	RUE = 0.082*Long - 10.28	0.71	1.63
Turn Turn	RUE = 0.138*Long - 0.073*Lat - 16.84	0.89	1.23
Witten Open	RUE = 0.160*Long - 0.049*Lat - 19.85	0.83	2.16
Witten Enc.	RUE = 0.221*Long - 0.120*Lat - 27.36	0.93	1.65
Wongalee	RUE = 0.078*Long - 0.039*Lat - 8.22	0.70	2.17
Summer			
Biddenham	RUE = 0.526*Long - 0.310*Lat - 64.76	0.93	3.49
Charleville	RUE = 0.209*Long - 0.145*Lat - 25.56	0.91	1.02
Airlie	RUE = 0.410*Long - 0.268*Lat - 49.92	0.90	2.56
Lisnalee	RUE = 0.466*Long - 0.366*Lat - 54.00	0.95	3.96
Maxvale	RUE = 0.136*Long - 0.057*Lat - 16.87	0.77	1.42
Turn Turn	RUE = 0.147*Long - 0.110*Lat - 17.47	0.92	1.00
Witten Open	RUE = 0.205*Long - 0.120*Lat - 24.78	0.93	1.83
Witten Enc.	RUE = 0.226*Long - 0.168*Lat - 26.98	0.95	1.35
Wongalee	RUE = 0.086*Long - 10.02	0.57	2.45
Winter			
Biddenham	RUE = 0.275*Long + 0.077*Lat - 36.23	0.81	1.79
Charleville	RUE = 0.309*Long - 0.211*Lat - 37.52	0.91	1.78
Airlie	RUE = 0.114*Long - 0.106*Lat - 12.51	0.78	1.28
Lisnalee	RUE = 0.128*Long - 0.097*Lat - 14.99	0.81	1.02
Maxvale	RUE =-0.035*Long + 0.096*Lat + 4.45	0.30	2.00
Turn Turn	RUE = 0.098*Long - 12.53	0.43	1.69
Witten Open	RUE = 0.072*Long - 7.67	0.16	2.87
Witten Enc	RUE = 0.192*Long - 25.63	0.65	2.28
Wongalee	RUE = 0.111*Long - 0.061*Lat - 12.95	0.79	1.55

4.4 Discussion

4.4.1 Calibration of the GRASP model

In general, the GRASP model adequately described the broad seasonal pattern of annual forage growth, in terms of reflecting the significant increases in yield described in Chapter 3. In semi-arid regions forage production is characterised by marked fluctuations in response to large variations in seasonal rainfall (Orr *et al.* 1993). Results from this Chapter indicate the GRASP model was capable of describing the rapid increases in forage production but had difficulty simulating high rates of detachment. As the calibration procedure did not concentrate on either the timing or rate of detachment the model cannot be critically assessed in this area. To achieve this, closer examination of the timing and rates of detachment of various plant components (leaf, stem and inflorescence) would be required. This would vary between species and depend on climatic factors. Under grazing, detachment rates would also be dependent on grazing pressure.

Simulated peak yields were comparable to observed peak yields (Table 4.4). During calibration, the GRASP model tended to underestimate yields late in the growing season, while overestimating yield early in the growing season. This indicates the GRASP model was conservative when estimating forage production on an annual or longer term basis. In some instances the GRASP model failed to describe some short term (less than 6 months) but still significant yield fluctuations. This was most notable on sites characterised by large tussock C4 grasses (*Astrebla* spp. at Biddenham and Airlie, and *Triodia* spp. at Wongalee).

At these sites, inter-tussock grasses and herbs can contribute to the dry matter yield of the forage depending on season. During winters receiving above average rainfall, these species can contribute in excess of 10% of annual forage production (Silcock *et al.* 1985). In the form used here, the GRASP model (version GVT74) was based on parameters describing a mono-specific sward (e.g. only one temperature response and one rate of nitrogen uptake). As a result it was not possible to predict the growth of annuals and ephemerals. If the model was capable of describing a mixed sward (C3/C4), short term yield fluctuations due to growth of less dominant species could be potentially estimated.

For most sites the simulated time course of soil moisture reflected observed values. For all sites except Wittenburra enclosed, the GRASP model overestimated soil moisture in dry profiles and underestimated moisture in wet profiles. The GRASP model had greatest difficulty predicting soil moisture at sites with cracking clay soils (Biddenham, Airlie and Lisnalee). The cracking nature of these soils may explain the rapid wetting and drying of the soils observed. Under dry conditions cracks would allow water to wet the profile at depth at the same time as surface layers. Cracks would also allow air to dry the soil at depth to low levels. Further application of the model to cracking clay soils will require modification of soil evaporation functions and also allow infiltration to lower soil layers (for example Clewett 1985).

However, in this study, the GRASP model was not used in the expectation of describing either the detailed pattern of forage growth or the daily fluctuations in soil water at each location. The objective of calibrating and using GRASP was to extrapolate data reported in Chapter 3 over time and space to examine the key plant production relationships (e.g. water use efficiency, impact of trees, basal area and N uptake). If the traditional scientific model was followed, further research would be conducted to refine the model used. The major criteria in determining success of this operation was whether the broad pattern of growth was described. The calibration procedure chosen, and the results presented above indicate this objective was achieved. This enabled the necessary validation and extrapolation steps to proceed in order to meet the objective of estimating grazing capacities of individual properties through the examination of these key plant production relationships.

4.4.2 Validation of the GRASP model

Validation results support the conclusion above with reasonable agreement between simulated forage yields and those reported by a variety of authors. The ability of the GRASP model to describe patterns of forage production in general terms, from treatments and locations external to data used in calibration indicates the robustness of the GRASP model.

However, the model again underestimated dry matter yields observed late in the growing season. As in the calibration stage, the GRASP model was conservative when estimating forage production on an annual or longer term basis. Where soil moisture data were available for validation, simulated soil water was not significantly correlated to observed values, though the simulated time course of soil moisture generally followed the observed. The model tended to underestimate and overestimate the moisture content of wet and dry profiles respectively. This may be largely due to the quality of soil moisture data, as it was estimated directly from figures in the papers of Christie (1978 and 1981) and was not actual data. In addition, the published description of soil parameters in these papers was insufficient to satisfactorily describe soil characteristics required for the GRASP model.

Refinements to the GRASP model subsequent to the work described in this Chapter have resulted in an improved prediction of the data of Christie (1981) (Figure 4.14) and validation against an additional two grazing trials conducted in south-west Queensland ('Eastwood' on Buffel grass on cleared gidyea (Orr et al*. in prep.) and 'Gilruth Plains' on mitchell grass (Roe and Allen (1945, 1993)) (See Appendix 10). At the time of writing, refinement of the GRASP model continues. Improvements to the model largely derive from its application to a wide range of native pasture communities across Australia in exercises similar to that described in this Chapter (G.M. McKeon pers. comm.).*

The capability of the GRASP model to account for removal of forage by grazing animals was supported by the validation results from the Arabella grazing trial. At light grazing pressure (20% removal of end of growing season standing dry matter by sheep) and heavy grazing pressure (80% removal of end of growing season standing dry matter by sheep) simulated yields were well correlated with those observed in the paddocks, despite fluctuations in basal area and species composition of perennial grasses described by Orr *et al.* (1993).

However, the yields observed in the paddocks are a combination of current seasons growth and carry over material from the previous year. From this data it is difficult to determine whether the desired levels of forage utilisation were achieved due to the growth occurring during the year. While it was an objective of these grazing trials to treat this additional forage production as a bonus, an understanding of the utilisation of this growth would be valuable in comparing treatments. Using the GRASP model an examination of the actual utilisation of current years forage growth was possible. In the highest grazing pressure treatments (80% removal of end of growing season standing dry matter by sheep) at Arabella and Burenda, average utilisation of growth in the trial period did not exceed 40% (39.1 and 36.8% respectively).

4.4.3 Extrapolation of the GRASP model

Chapter 3 demonstrated that primary production could be measured and related to water use (growth per unit of evapo-transpiration or unit of rainfall) over short periods of time. This concept is not new. Le Houerou (1984) documents over 100 similar attempts to relate range production to rainfall either on a seasonal or an annual basis. In these attempts, significant to very highly significant correlations have been found in arid and semi-arid zones of the world. Under comparable management situations, throughout the various arid zones of the world, with totally different floras and vegetation types Le Houerou (1984) reports surprising consistency in rainfall use efficiencies in the range 0.5 to 10 kg/ha/mm of rain. However, most of these relate to one site and one range type or to a very limited number of sites (Le Houerou *et al.* 1988). Lauenroth and Sala (1992) highlight the need to recognise the impact of spatial and temporal variability when estimating long term forage production.

This was examined in this study using simulations based on the successful calibration and validation of the GRASP model using data from nine sites. Extrapolation results indicated the difficulty in determining an "average" water use efficiency for a forage type due to the variation in water use efficiency over time and space (Table 4.8). Spatial and temporal variation in rainfall, influenced both evapo-transpiration use efficiency and rainfall use efficiency. However, as climatic data from only one location (Charleville) were used in these simulations the spatial effect of a variable vapour pressure deficit on rainfall use efficiencies has not been included. The impact of the VPD on growth was described in Chapter 3 and would need to be included in a method for examining forage growth across south-west Queensland. The annual range reported in Table 4.8 (1.23 - 3.00 kg/ha/mm) approximates that originally proposed by Noy-Meir (1973) (0.5-2.0 kg/ha/mm) and fits within the range summarised by Le Houerou (1984) (0.5-10 kg/ha/mm).

Water use efficiencies would also be expected to vary with landscape factors not included in the analyses in this Chapter. Topography, groving of vegetation, soil type, soil surface characteristics, soil depth and the proportions of run-on and run-off areas are examples of landscape characteristics that are likely to influence water use efficiencies.

Water use efficiencies calculated as unit growth per unit of water used (either evapo-transpiration or rainfall) indicate forage growth would be expected on even the smallest amounts of water used. Examination of Figure 4.22 indicate 186 mm of rain or 179 mm of evapo-transpiration was required before any yield was simulated. This "ineffective" rainfall is greater than that reported by Noy-Meir (1973) (25-75 mm/year) and by Sala *et al.* (1988) (56 mm/year). For different seasons and different forage types, analysis of simulation results reported in this Chapter indicates varying levels of water are required before growth occurs. Therefore, in calculating forage production based on water used (either evapo-transpiration or rainfall) it would be more appropriate to use the estimated regressions rather than one water use efficiency value.

The question also arises as to which water use efficiency best describes growth. The discussion in Chapter 3 alluded to the variation in definition and interpretation of water use efficiencies. Chapter 3 also estimated several water use efficiencies for each site based on these definitions. Analysis of simulation results in this Chapter has identified a degree of temporal and spatial variability in water use efficiencies, yielding a range of water use efficiencies for each site (Table 4.9).

Table 4.9 Comparison of annual, summer and winter water use efficiencies (evapo-transpiration) for the Charleville site derived from (1) experimental data from Chapter 3 (Tables 3.5 and 3.8), (2) simulation using 32 years of Charleville daily climate (1960 to 1992), (3) average from twenty locations in south-west Queensland (Table 4.2) over 32 years (1960 to 1992), (4) slope of the regression between growth and evapo-transpiration at Charleville (Table 4.7) and (5) slope of the regression between growth and evapo-transpiration for twenty locations in south-west Queensland over 32 years (1960 to 1992) (Table 4.6).

Site	(1)			(2)			(3)			(4)			(5)		
	An	Su	Wi	An	Su	Wi	An	Su	Wi	An	Su	Wi	An	Su	Wi
Charleville	2.2	2.0	0.9	2.3	2.0	2.9	1.0	0.9	2.1	5.3	4.9	5.8	4.3	3.8	4.8

In order to estimate long term "safe" grazing capacities of properties in south-west Queensland, it would be appropriate to use a model which predicts forage growth based on the spatial and temporal rainfall and vapour pressure deficit variability experienced in the region. Lauenroth and Sala (1992) highlight the variation between existing spatial and temporal models for North American grasslands. The variation is based on differences in vegetation structure ("reflected in abundance of life forms and species and in the density of seeds and tillers") and the impact these differences have on estimates of long term forage production. The spatial model described by these authors utilises the primary production of an ecosystem with a different vegetation structure at each value of precipitation. Conversely the temporal model relates annual rainfall to primary production for the same vegetation structure through time.

In GRASP, a dynamic grass basal area model partially addresses this issue. Grass basal area is calculated at the end of each summer growing season and is then used in the calculation of potential regrowth for the next growing season (Littleboy and McKeon 1996). The vegetation structure for each of the nine sites used in the extrapolation exercise fluctuates (in terms of basal area) as rainfall varies both spatially and temporally. The regressions predicting rainfall use efficiency in Table 4.8 integrate the spatial and temporal factors influencing production based on the years 1960 to 1992. However, these regressions represent an estimate of rainfall use efficiency for only 8 of the 180 land systems found in south-west Queensland. Estimating grazing capacities on individual properties with a wider range of land systems than sampled in Chapter 3 will require estimates of rainfall use efficiencies for these land systems. This is examined in Chapter 5.

4.4.4 Conclusions or, "Were the modelling objectives met"?

The preceding chapter suggested that simulation modelling was the most promising procedure to estimate above-ground net primary production due to the complexity of interrelationships between factors governing forage growth (Lauenroth *et al.* (1986) and Redman (1992)). When calibrated to and validated against a range of pasture communities across south-west Queensland the GRASP model (version GVT74) adequately described the pattern of annual forage production for communities dominated by C3 or C4 species. For a number of sites where annual/ephemeral species contributed to the pasture community (e.g. the mulga pastures at the Wittenburra outside site and the Burenda mitchell grass sites of Christie (1981) and Beale (1985)) or where the proportions of C3 and C4 species changed over time (e.g. the 35%, 50% and 80% treatments of the Arabella grazing trial (Beale 1985)) the GRASP model did not predict the pattern of forage production as well. This may limit the application of the current GRASP model (version GVT74) to other pasture communities (e.g. chenopod shrublands and annual pastures).

With a number of limitations in the GRASP model identified, the question arises as to what level of accuracy is required. Singh *et al.* (1975) indicates one must choose methods for sampling and calculating above-ground net primary production which are at a similar level of resolution as the objectives of the study. In order to estimate long term "safe" grazing capacities of properties in south-west Queensland to review carrying capacities and guide strategic (20-30 years) stocking decisions, it is desirable to predict the long term fluctuations in forage production. While short term fluctuations in forage production are important for tactical (annual or seasonal) stocking rate decisions they are less important for examining long term resource capability required for a review of grazing capacities.

Calibration, validation and extrapolation results presented in this Chapter indicate that the GRASP model is appropriate for predicting long term patterns of forage production in south-west Queensland. Simulations using the calibrated GRASP model enabled the estimation of parameters describing growth (water use efficiencies) on a regional scale for selected land systems. However, the approach is still confined to the selected land systems for which primary production data was collected. To review grazing capacities on individual properties requires extrapolation of parameters estimating average growth to other land systems. In the following Chapter these predictors of growth were derived and used to estimate the grazing capacities of native pastures for individual properties in south-west Queensland.