3.0 PRIMARY PRODUCTIVITY OF NATIVE PASTURES

3.1 Introduction

The above review and system analysis established a need for measuring net primary production from the major land systems found in south-west Queensland. This chapter describes the collection of those data from eight land systems over the period 1986 to 1990. An approach examining soil-plant-water relations similar to that of Christie (1978 and 1979) and McKeon *et al.* (1982b and 1990) was employed. The spatial and temporal variability in production is highlighted.

In Chapter 4, the data were used to adapt the GRASP computer model (McKeon *et al*. 1982b and 1990) to south-west Queensland pasture types. The role of this model in estimating sustainable grazing capacities for native pastures in the region is then explored in Chapter 5.

3.2 Materials and methods

Nine sites (Figure 3.1, Table 3.1) representative of eight land units found in south-west Queensland were selected for primary productivity measurements. Each of these units represented between 55% to 90% of the area of eight land systems with one exception. The land unit on which site 4 was located represented only 5% of the B1 land system but was chosen for the uniformity across the site. Sites were located on areas of uniform vegetation and soil and were fenced to exclude all grazing animals. Level sites were chosen to minimise the effects of rainfall run-on and run-off. There was no replication of sites due to time constraints. The technique for productivity measurements for sites 1 and 2 varied slightly from the remaining sites in terms of plot layout and sampling frequency and intensity. Sites 1 and 2 were observed over the period October 1986 to December 1987 (First observation period). Sites 3 to 9 were observed within the period October 1988 to November 1990 (Second observation period). Other variations are detailed below.

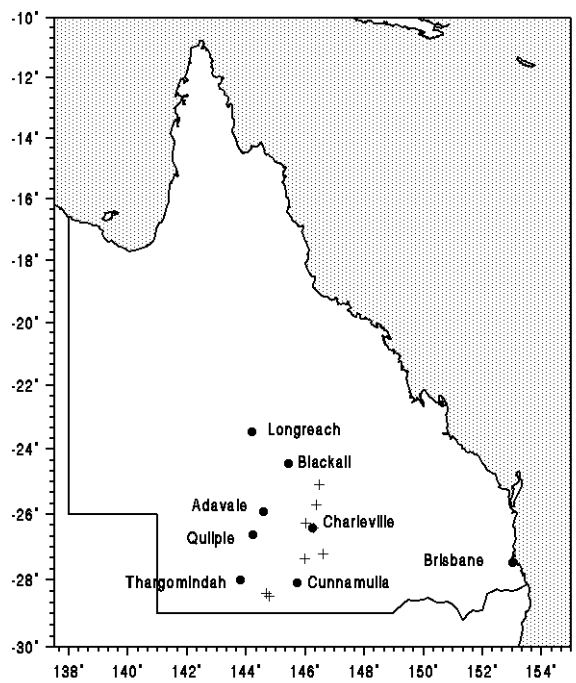


Figure 3.1 Location (+) of the nine sites for primary productivity measurements on native pastures in south-west Queensland during the period October 1986 to November 1990.

For sites 1 and 2, three plots (8m x 15m) were selected within the enclosure aiming to avoid micro-site variation. The three plots were mown at the start of the growing season (October) to a grass tussock height of 5cm with a lawn mower. Detached plant material was then removed from the site. At three week intervals, pasture data were collected from four quadrats (1.0 x 0.5m) in each plot. Quadrats were placed along a sampling front in each plot. The sampling front moved in a different direction for each plot to avoid possible edge effects. Soil moisture to 1m was measured from two hand augured cores in each plot. Quadrat and core placement were designed to avoid trampling of material awaiting future observation. (See Appendix 1 for site and plot layout and direction of sampling fronts.)

For sites 3 to 9, four plots (4 x 10m) were selected within enclosures. The four plots were mown at the start of the growing season (October) to a tussock height of 5cm with a whipper snipper mounted with a brush cutting blade. This method gave better control over cutting height and reduced tussock "trauma" compared to the lawn mower. Detached material was removed. At six week intervals, pasture data were collected from two quadrats (1.0 x 0.5m) in each plot. Quadrats were placed along a sampling front in each plot. Only one soil core to 1m was sampled for soil moisture in each plot. (See Appendix 2 for site and plot layout and direction of sampling fronts.)

3.2.1 Plant sampling and analysis

At each sampling the following parameters were recorded for each quadrat:

- visual estimate of species composition (by dry biomass yield);
- visual estimate of green cover %;
- visual estimate of bare soil %;
- plant height (cm) using a ruler and constant weight;
- slide photograph from above quadrat for additional estimates of bare soil %, green cover %, dead cover % and litter cover % using a point quadrat on projected slide image in laboratory; and,
- dry matter yield of grass and herbage (kg/ha) clipped to 5cm using hand-shears and oven dried at 80^{o}C.

The visual estimates were made as a backup for the other recordings.

For sites one and two, sub-samples of harvested material were separated into green leaf, dead leaf, green stem, dead stem, inflorescence, and dicotyledons (forbs). Nitrogen concentration of grasses was determined for entire plant tops using the technique of Kerr and von Steiglitz (1938). Perennial grass basal area (%) was recorded once at the end of the growing season at each site using a point frame (Brown 1954). Tree basal area (m^2/ha) was also measured at the same time using a Bitterlich gauge.

A mean and standard deviation for each parameter at each sampling event was calculated. Plots were analysed as replicates to examine the degree of site variability. A one way analysis of variance was used to test for significant ($P<0.05$) changes in yield and green cover over time. Transformations were performed to normalise the yield data (ln yield) and green cover data (arc sin SQRT(green cover/100) prior to analysis in order that the assumptions for an analysis of variance were met (normal distribution of data) (Goulden 1952).

Table 3.1 Site descriptions for primary productivity measurements in south-west Queensland.

No.	Site	Latitude	Longitude	Land Zone WARLUS	Land System WARLUS*	Land Unit WARLUS*	Prop. of Land System (%)	Soil Type	Perennial Grasses	ppf
1	Biddenham	25°43'	146°24'	Undulating Downs	IV F1	IV 1	80	Grey/brown cracking clay	Astrebla spp.	Ug 5.21
2	Charleville	26°25'	146°18'	Mulga Sandplains	III S1	III 45	85	Sandy red earth	Mulga grasses #	Uc 1.43
3	Airlie	27°21'	146°0'	Alluvial Plains Open	III A2	III 16	55	Grey cracking clay	Astrebla spp.	Ug 5.24
4	Lisnalee	25°5'	146°30'	Undulating Brigalow	IV B1	IV 20	5	Loamy red earth	Cenchrus ciliaris	Gn 2.12
5	Maxvale	26°16'	146°3'	Soft Mulga Lands	III M3	III 52	85	Loamy red earth	Mulga grasses#	Um 1.43
6	Turn Turn	28°29'	144°49'	Mulga Sandplains	I S2	I 61	70	Sandy red earth	Mulga grasses#	Gn 2.12
7	Wittenburra Open	28°29'	144°42'	Hard Mulga Lands	I H2	I 51	70	Loamy red earth	Mulga grasses#	Gn 2.11
8	Wittenburra Enclosed	28°29'	144°42'	Hard Mulga Lands	I H2	I 51	70	Loamy red earth	Mulga grasses#	Gn 2.11
9	Wongalee	27°12'	146°37'	Spinifex Sandplains	III N1	III 64	90	Yellow earthy sand	Triodia spp.	Uc 1.23

* Western Arid Region Land Use Studies, (Dawson 1974, Turner 1978 and Mills *et al*. 1990)
\# *Thyridolepis mitchelliana*, *Monachather paradoxa*, *Digitaria* spp., *Eragrostis* spp. and *Aristida* spp.

3.2.2 Soil sampling, analysis and additional data sources

Soil moisture was measured in 10cm intervals to a depth of 1m at each sampling. Samples were oven dried (100^{o}C) and gravimetric moisture content calculated. Results were converted to volumetric values using bulk density data for each soil type. A one way analysis of variance was used to test for significant ($P<0.05$) changes in soil moisture over time. Bulk density at 10 cm increments down the profile was measured at sites 1 and 2 by pressing tobacco tins of known volume into the side of a freshly excavated pit. The bulk density for other sites was estimated from site 1 and 2. Total soil nitrogen (N%), total soil phosphorus (P%), soil pH, organic carbon (OrC%), coarse sand (CS%), fine sand (FS%), silt (SI%) and clay (CL%) data were obtained from profile descriptions of the main land units comprising each land system in the Western Arid Region Land Use Studies (WARLUS) (Dawson 1974, Turner 1978 and Mills *et al*. 1990).

3.2.3 Climatic data

Daily rainfall was measured at each site or at a near-by homestead. As no weather station was located ate each site the following daily climatic data for Charleville were used:

- 9am dry bulb temperature (^{o}C)
- 9am wet bulb temperature (^{o}C)
- 3pm dry bulb temperature (^{o}C)
- 3pm wet bulb temperature (^{o}C)
- Daily maximum temperature (^{o}C)
- Daily minimum temperature (^{o}C)
- Daily terrestrial minimum temperature (^{o}C)
- Daily pan evaporation (mm)
- Daily vapour pressure deficit (hPa)*

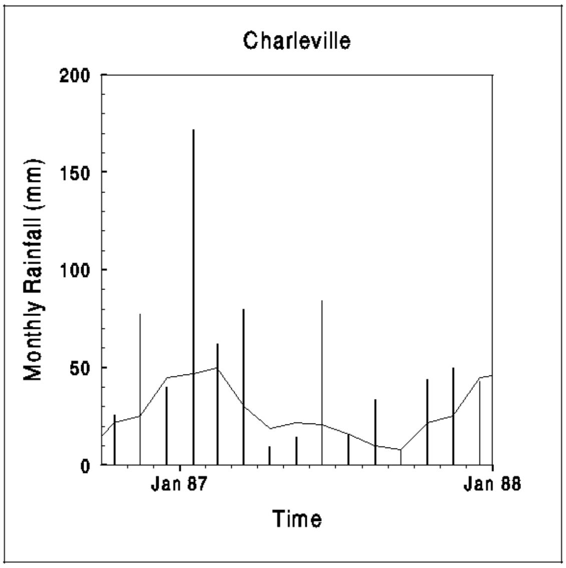
*The average daily vapour pressure deficit was calculated after Tanner and Sinclair (1983) as:

$$\mathbf{VPD=Vpsat_{(tmin)}+(Vpsat_{(tmax)}-Vpsat_{(tmin)})*0.75-Vpactual}$$

3.3 Results of primary productivity experiments

3.3.1 Weather conditions during observation periods

Rainfall varied considerably among sites and observation periods. For sites one and two, monthly rainfall was generally equivalent to or above the long-term median monthly rainfall (Figure 3.2). The seasonality of the rainfall during the first observation period approximated the distribution of median rainfall. For the second observation period, rainfall was erratic and unseasonal, with monthly totals either well below or above the long-term median (Figure 3.3). Over the entire measurement period at each site, observed rainfall totals varied +/- 25% from the long-term median (Table 3.2).



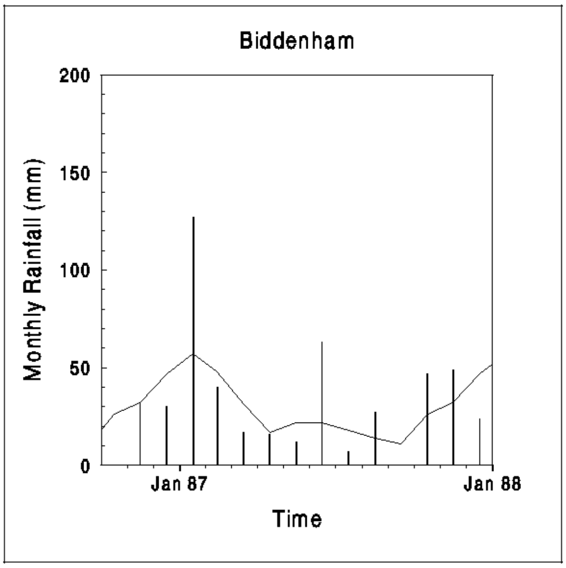


Figure 3.2 Monthly (vertical lines) and long-term median monthly (continuous line) rainfall at the Biddenham and Charleville native pasture primary productivity sites for the first observation period October 1986 to December 1987.

Table 3.2 Comparison of rainfall totals (mm) for each site over the observation periods with average and median values for corresponding periods from the nearest long-term recording stations. Deviation from median shown.

Site	Period	Observed	Average	Median	Deviation (%)
Biddenham	14 months	480	594	574	-16
Charleville	14 months	640	576	542	+18
Airlie	17 months	698	620	575	+21
Lisnalee	23 months	967	992	930	+4
Maxvale	18 months	594	723	672	-12
Turn Turn	18 months	358	514	475	-25
Wittenburra Open	13 months	281	345	314	-11
Wittenburra Enclosed	15 months	303	392	363	-17
Wongalee	18 months	537	626	527	+2

Air temperature, pan evaporation and vapour pressure deficit data for Charleville are presented in Figure 3.4 for both observation periods. Generally the summers were hotter than average, with both daily maximum and minimum temperatures above average. The winters were milder with daily maximum temperatures either approximating or below the long-term average, while daily minimum temperatures were generally warmer than average. The deviations from the long-term average for these parameters are shown in Figure 3.5.

Pan evaporation approximated the long-term average over both observation periods, while the vapour pressure deficit was greater than average (Figure 3.5), especially during the summers.

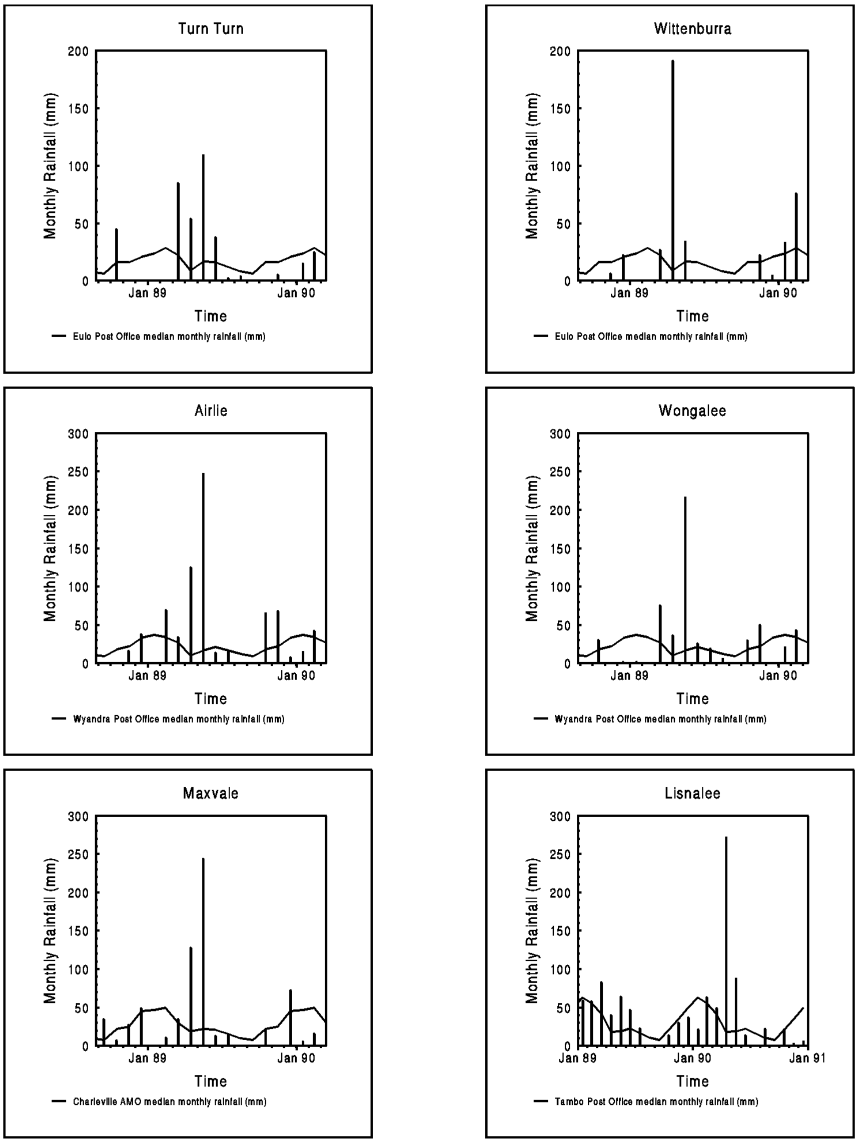
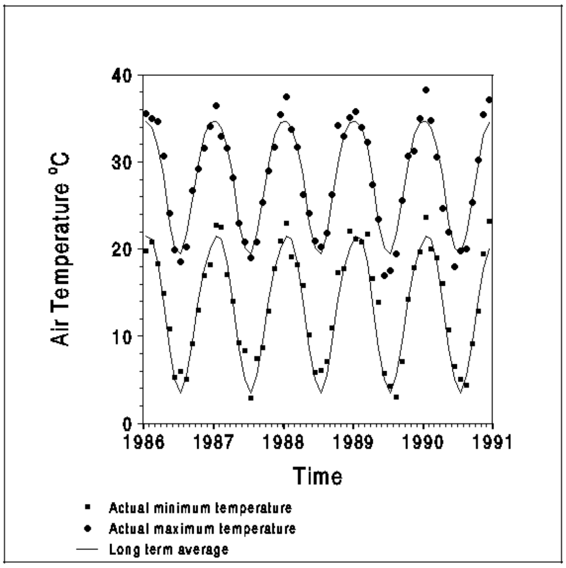


Figure 3.3 Monthly (vertical lines) and long-term median monthly (continuous line) rainfall for the Turn Turn, Wittenburra, Airlie, Wongalee, Maxvale and Lisnalee pasture primary productivity sites in south-west Queensland for the second observation period October 1988 to November 1990 (median rainfall from nearest long-term station).



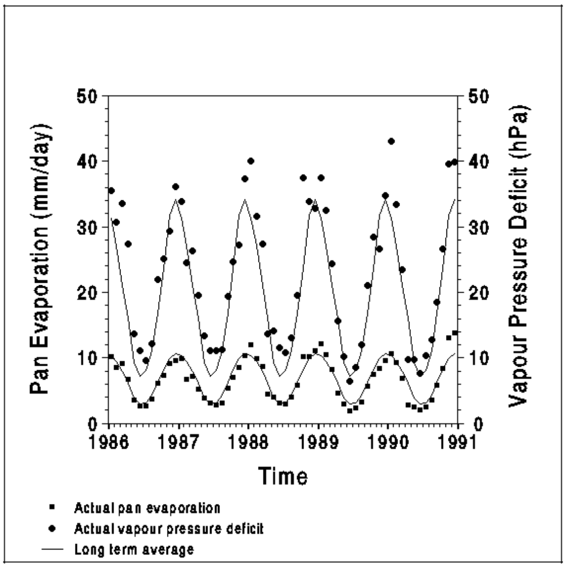


Figure 3.4 Temperature, pan evaporation and vapour pressure deficit over both observation periods at Charleville, October 1986 to November 1990. (Bureau of Meteorology).

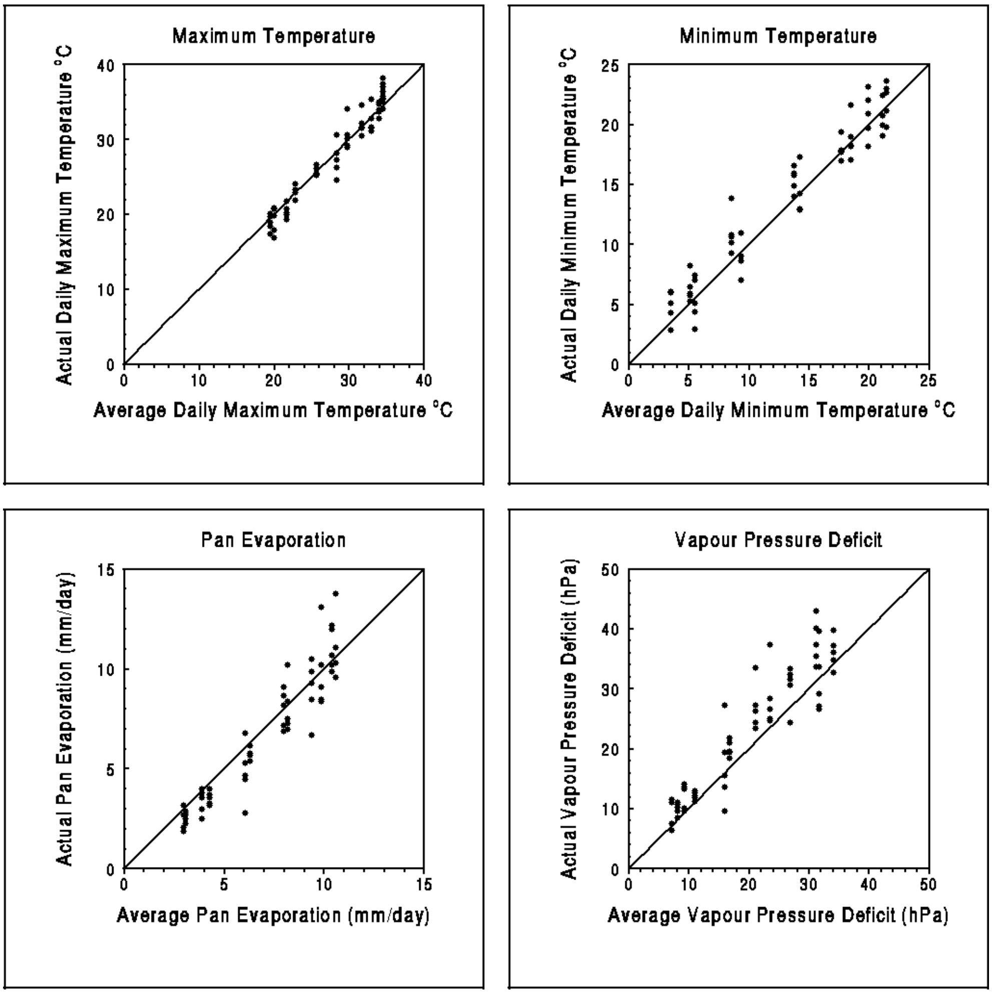


Figure 3.5 Deviations from average climatic conditions for Charleville over both observation periods October 1986 to November 1990. (Bureau of Meteorology).

3.3.2 Pasture yields and growth patterns

This section describes (1) the time course of pasture yield, green cover and nitrogen uptake; and (2) the relationships between yield, evapo-transpiration and site characteristics.

Basal area of perennial grasses ranged from 0.5% on the hard Mulga land system at Wittenburra to 6.2% on the Buffel grass on the undulating Brigalow and Gidyea land system at Lisnalee (Table 3.3).

Table 3.3 Perennial grass basal area (%) and tree basal area (m^2/ha) of sites measured once at the end of the growing season.

Site	Grass Basal Area (%)	Tree Basal Area (m^2/ha)
Biddenham	4.0	0.0
Charleville site	4.3	0.5
Airlie	4.0	0.0
Lisnalee	6.2	0.0
Maxvale	2.7	0.8
Turn Turn	1.6	2.0
Wittenburra Open	0.5	0.0
Wittenburra Enclosed	0.5	1.5
Wongalee	2.7	0.5

Primary productivity data are summarised in Table 3.4. Detailed data are presented in Appendix 3. Volumetric soil moisture was calculated for the full depth of the profile (0-100cm) using the bulk densities measured (Table 3.5). A significant variation ($P<0.05$) in soil moisture between plots was only observed at the Airlie site (cracking clay soil). At some sampling dates for most sites, when dry conditions prevailed, lower layers in the profile could not be sampled as the auger failed to retain the dry soil. Moisture content for these layers was extrapolated in order to present a complete data set for analysis. The extrapolation assumed the top half of the profile contained a proportion of the total moisture in the entire profile. Although the proportion of soil moisture in this half varied with each site, variation among sampling times was small (Appendix 4), allowing total soil moisture to be estimated when the whole profile was not able to be sampled. This approach allowed the calculation of evapo-transpiration for all sampling times. Evapo-transpiration was calculated as follows;

$$\mathbf{ET = SMt_1 - SMt_2 + RAIN}$$

where:

- ET = Evapo-transpiration (mm)
- SM = Soil Moisture (mm)
- RAIN = Rainfall (mm) between $Time_1$ and $Time_2$ (t_1 and t_2)

The loss or gain in soil moisture due to run-off, run-on and drainage below 1m and lateral movement was unable to be estimated and was not included the calculation of ET.

Standing dry matter yields varied among sites, reflecting differences in basal area (Table 3.3), species of perennial grasses, rainfall and soil type. Yields increased with time from initial mowing (Figure 3.6a and b). At the Charleville and Wongalee sites the dry matter yield varied significantly across plots ($P<0.01$ and $P<0.05$ respectively) reflecting possible problems of sampling on fronts and micro-site variation. A significant variation ($P<0.01$) in green cover(%) across plots was observed at the Charleville site only.

Table 3.4 Summary of primary productivity results, rainfall, soil moisture and calculated evapo-transpiration (ET Cum.) (calculated between sample dates) for nine sites in south-west Queensland from October 1986 to November 1990 (Legend at the end of Table 3.4).

Site and Date	Dry matter Yield (kg/ha)		Green Cover (%)		N Conc. (%)	Rain Cum. (mm)	Total Soil Water (mm)		ET Cum. (mm)
Biddenham							0-85cm		
21.11.86						0.0	175.4	+	0.0
17.12.86	86	a	13.1	fg	2.57	62.0	215.8	ef	21.7
07.01.87	187	b	16.5	g	2.12	103.5	194.9	ac	84.1
26.02.87	1144	c-f	44.9	h	1.23	228.5	196.6	bc	207.4
18.03.87	1633	ef	16.8	g	0.82	228.5	179.5	a	224.5
08.04.87	950	c	6.8	d-f	0.66	245.5	D		NC
29.04.87	1238	c-f	4.1	b-e	M	269.5	184.3	ab	260.7
21.05.87	1129	c-e	2.9	a-d	0.59	273.2	183.6	ab	265.1
12.06.87	1040	c	0.6	a	0.64	273.2	178.0	a	270.6
24.06.87	1289	c-f	2.0	a-c	0.74	336.2	229.6	g	282.0
16.07.87	1463	d-f	1.2	ab	0.64	336.2	181.6	a-c	330.1
11.08.87	*1678	f	3.9	bc	0.64	343.2	201.5	c-e	317.1
26.08.87	1177	c-e	7.9	ef	0.63	370.2	D		NC
18.09.87	1127	c-e	5.5	c-e	0.65	370.2	D		NC
08.10.87	1093	cd	5.3	b-e	0.63	420.0	215.9	d-f	379.5
29.10.87	1405	c-f	7.0	d-f	0.65	426.2	188.5	bc	413.2
25.11.87 #						476.2	226.3	fg	425.4
10.12.87 #						479.7	D		NC
Charleville							0-100cm		
24.10.86						0.0	50.1	bc	0.0
05.12.86	206	a	16.7	de	2.46	120.4	68.1	+	102.3
31.12.86	243	a	9.1	bc	1.79	125.4	38.4	a	137.1
21.01.87	195	a	8.9	bc	1.77	145.4	41.2	ab	154.3
11.02.87	275	a	19.6	e	2.08	276.4	53.1	c	273.1
04.03.87	703	b	29.3	f	2.42	338.4	64.5	de	323.8
26.03.87	645	b	17.1	de	1.20	395.4	84.1	g	361.4
16.04.87	799	bc	18.4	de	1.26	395.9	44.9	a-c	400.5
20.05.87	720	bc	6.6	b	1.04	416.9	49.9	bc	417.1
11.06.87	847	bc	0.0	a	1.02	416.9	43.5	a-c	423.5
01.07.87	612	bc	10.4	b-d	1.45	495.9	76.5	fg	469.5
29.07.87	834	bc	11.3	b-e	1.38	503.3	71.9	ef	481.4
19.08.87	905	bc	12.5	c-e	1.67	536.9	79.7	fg	507.2
02.09.87	943	bc	16.3	de	1.72	536.9	65.5	de	521.5
23.09.87	*1190	e	16.6	de	1.24	545.4	45.7	a-c	549.7
15.10.87	985	bc	8.9	bc	0.83	595.9	45.8	a-c	600.5
05.11.87 #						605.4	44.7	a-c	610.7
26.11.87 #						640.4	45.0	a-c	645.4

Table 3.4 Continued

Site and Date	Dry Matter Yield (kg/ha)		Green Cover (%)		Rain Cum. (mm)	Total Soil Water (mm)		ET Cum. (mm)
Airlie						0-100cm		
10.11.88					0.0	86.5	+	0.0
16.01.89	53	a	2.3	a	53.3	88.6	+	51.2
27.02.89	80	a	2.6	a	122.3	87.6	+	121.2
10.04.89	45	a	6.8	b	183.5	132.9	+	137.1
03.07.89	388	b	12.2	c	543.3	274.7	+	355.1
14.08.89	411	b	14.5	cd	560.1	M		NC
25.09.89	560	b	21.3	d	560.1	40.8	+	605.8
28.11.89	*1216	c	33.6	e	694.1	146.9	+	633.7
12.02.90 #					698.1	69.3	+	715.3
Lisnalee						0-100cm		
13.01.89						95.5	+	0.0
02.03.89	648	a	24.2	c	31.5	43.6	+	83.4
14.04.89	1137	b-e	59.1	e	174.5	101.3	+	168.7
23.05.89	1052	b-d	43.0	d	228.5	93.2	+	230.8
06.07.89	1092	b-d	0.0	a	308.5	112.8	b	291.2
17.08.89	976	b-c	2.1	a	331.5	97.7	a	329.3
28.09.89	*1385	e	7.5	b	331.5	111.6	ab	315.4
01.12.89	1163	c-e	10.2	b	375.5	47.9	+	423.1
20.02.90	782	a	0.2	a	483.0	110.8	+	467.7
11.05.90	2009	f	81.6	f	816.0	134.6	c	777.7
22.11.90	1267	de	M		966.8	79.7	+	982.6
Maxvale						0-100cm		
14.09.88					0.0	95.7	a	0.0
09.12.88	20	a	0.3	ab	35.4	M		NC
19.01.89	72	b	2.6	cd	84.2	28.7	+	151.2
01.03.89	54	ab	0.2	a	90.4	25.3	+	160.8
13.04.89	85	b	7.0	d	140.5	69.8	+	166.4
22.05.89	278	c	M		333.9	181.0	d	248.5
05.07.89	444	de	26.7	f	410.3	149.8	c	356.2
17.08.89	495	c-e	19.6	ef	426.0	113.1	b	408.6
28.09.89	*742	e	16.7	e	429.0	81.3	+	443.4
01.12.89	399	cd	3.1	bc	483.7	38.6	+	540.8
20.02.90 #					593.9	42.7	+	646.9
Turn Turn						0-100cm		
20.09.88					0.0	43.6	+	0.0
07.12.88	11	a	0.2	a	45.0	24.0	+	64.6
17.01.89	11	a	0.5	a	46.0	24.0	+	65.6
28.02.89	11	a	1.1	a	46.0	21.6	+	68.0
11.04.89	17	a	1.6	ab	139.0	61.8	+	120.8
04.07.89	302	b	21.4	d	334.0	67.5	+	310.2
15.08.89	370	b	18.2	d	338.0	M		NC
26.09.89	*371	b	7.0	c	338.0	29.1	+	352.6
29.11.89	259	b	5.0	bc	343.0	33.8	+	352.8
13.02.90 #					358.0	12.6	+	389.0

Table 3.4 Continued

Site and Date	Dry Matter Yield (kg/ha)		Green Cover (%)		Rain Cum. (mm)	Total Soil Water (mm)		ET Cum. (mm)
Wittenburra Open						0-50cm		
21.09.88					0.0	33.0	+	0.0
07.12.88	9	a	0.3	a	6.0	19.7	+	19.3
17.01.89	61	b	3.4	b	28.0	27.1	+	33.9
28.02.89	16	a	0.3	a	28.0	22.8	+	38.1
11.04.89	7	a	0.5	a	105.0	34.4	+	103.6
04.07.89	64	b	6.7	bc	281.0	59.4	+	254.5
15.08.89	178	c	10.7	c	281.0	M		NC
26.09.89	*260	c	5.9	bc	281.0	25.2	+	288.7
Wittenburra Enclosed						0-50cm		
21.09.88					0.0	36.4	+	0.0
07.12.88	4	a	0.0	a	6.0	20.5	+	21.8
17.01.89	19	a	1.1	a	28.0	21.8	+	42.6
28.02.89	7	a	0.3	a	28.0	18.7	+	45.7
11.04.89	0	a	0.7	a	105.0	34.7	+	106.7
04.07.89	157	b	16.4	b	281.0	59.0	+	258.5
15.08.89	228	b	10.4	b	281.0	M		NC
26.09.89	*192	b	0.5	a	281.0	28.5	+	288.9
29.11.89 #					303.0	29.6	+	309.8
Wongalee						0-100cm		
22.09.88					0.0	82.1	a	0.0
07.12.88	83	a	4.5	a	31.5	M		NC
16.01.89	225	ab	6.0	a	33.5	25.4	+	90.2
27.02.89	395	bc	8.5	a	33.5	20.8	+	94.8
10.04.89	443	bc	4.9	a	112.5	106.8	b	87.9
22.05.89	648	c	M		309.5	231.0	+	160.6
03.07.89	426	bc	8.9	a	388.5	185.7	d	284.9
14.08.89	288	bc	9.4	a	406.5	M		NC
25.09.89	295	bc	13.6	ab	413.0	151.5	c	343.5
28.11.89	*621	bc	27.3	b	493.0	80.2	a	494.8
12.02.90 #					536.5	18.4	+	600.2

Legend for **Table 3.4**

- M Missing value
- NC Not Calculated due to missing value
- D Profile too dry to sample by hand auger
- W Profile too wet to auger
- SD Based on 12 quadrats for Biddenham and Charleville (0.5*1.0m), based on 8 quadrats for remaining sites (0.5*1.0m)
- * Peak yield used to calculate water use efficiency (WUE)
- WUE Peak yield / Cumulative evapo-transpiration to peak yield
- + Insufficient samples to calculate LSD
- a Values followed by the same letter are not significantly different at P<0.05
- # Yield and green cover measurements not made.

Table 3.5 Bulk densities (g/cm^3) for the Biddenham (cracking clay) and Charleville (sandy red earth) sites at 10cm increments to a depth of 1m.

Layer	Biddenham	Charleville
0-10cm	1.33	1.21
10-20cm	1.35	1.23
20-30cm	1.39	1.24
30-40cm	1.39	1.23
40-50cm	1.40	1.22
50-60cm	1.40	1.22
60-70cm	1.40	1.21
70-80cm	1.20	1.20
80-90cm	1.20	1.18
90-100cm	1.20	1.10

The fluctuations in yield and green cover were examined in detail to determine periods of significant increase and decrease in yield. Significant changes in yield would be expected to be associated with changes in green cover. However, decline in green cover could occur through plant senescence or after frost without significant change in yield.

At Biddenham, there were two periods of significant increase in yield, each followed by a significant decline in yield. The first increase was rapid, occurring over a nine week period in summer at a calculated rate of 17.0 kg/ha/day (from 17.12.86 to 18.03.87). The second was more gradual, occurring over 18 weeks in winter at the rate of 5.8 kg/ha/day (between 08.04.87 and 11.08.87). Both these periods corresponded to significant increases in green cover of pasture (from 07.01.87 to 26.02.87, and 12.06.87 to 11.08.87).

However, the yield fluctuations in winter between each observation during this second period were not significantly different. This highlights the difficulty of measuring small changes in yield in highly variable tussock grasslands. Both these periods were followed by sharp significant declines in yield. A significant decline in yield of 42% (32.5 kg/ha/day or 2%/day) occurred in autumn between 18.03.87 and 08.04.87. A second significant yield decline of 30% (33.4 kg/ha/day or 2%/day) occurred in late winter between 11.08.87 and 26.08.87. Fluctuations in yield after 26.08.87 were not significant. Significant decline in green cover occurred in early autumn (26.02.87 to 08.04.87).

At the Charleville site, two significant periods of yield increase were observed. The first was rapid, over three weeks in late summer at a rate of 20.4 kg/ha/day between 11.02.87 and 04.03.87 (15 weeks since initial cutting back). The second, during winter was more gradual at 2.4 kg/ha/day over 29 weeks between 04.03.87 and 23.09.87. Fluctuations in yield between progressive observations were not significant. Yield declines measured after each of these periods of increase were not significant.

Significant changes in green cover at the Charleville site occurred more frequently than significant changes in yield (Figure 3.6a and Table 3.4). Both periods of significant yield increase corresponded to periods of significant increase in green cover. However, there were five periods of significant decline in green cover occurring in both summer and winter. These were not related to a significant decline in yield.

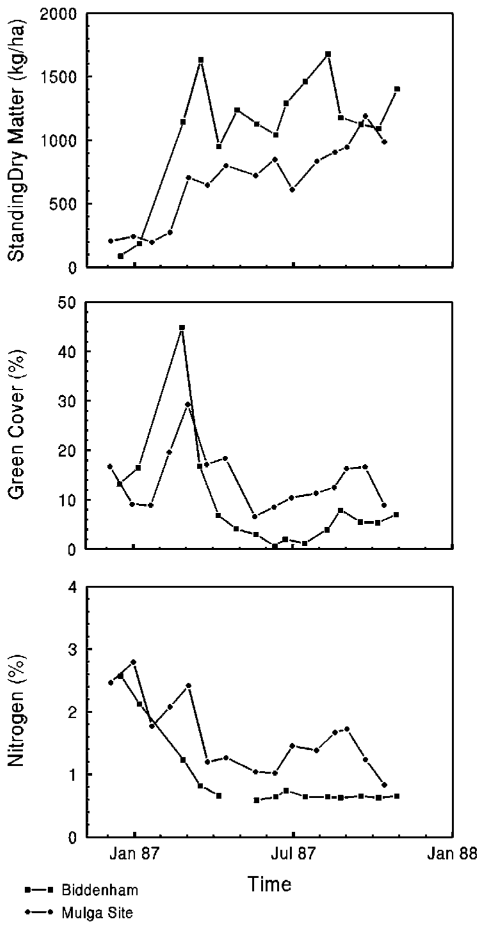


Figure 3.6a Change in standing dry matter yield (kg/ha), green cover (%) and nitrogen concentration of plant tops (%) at Biddenham and Charleville during the period November 1986 to December 1987.

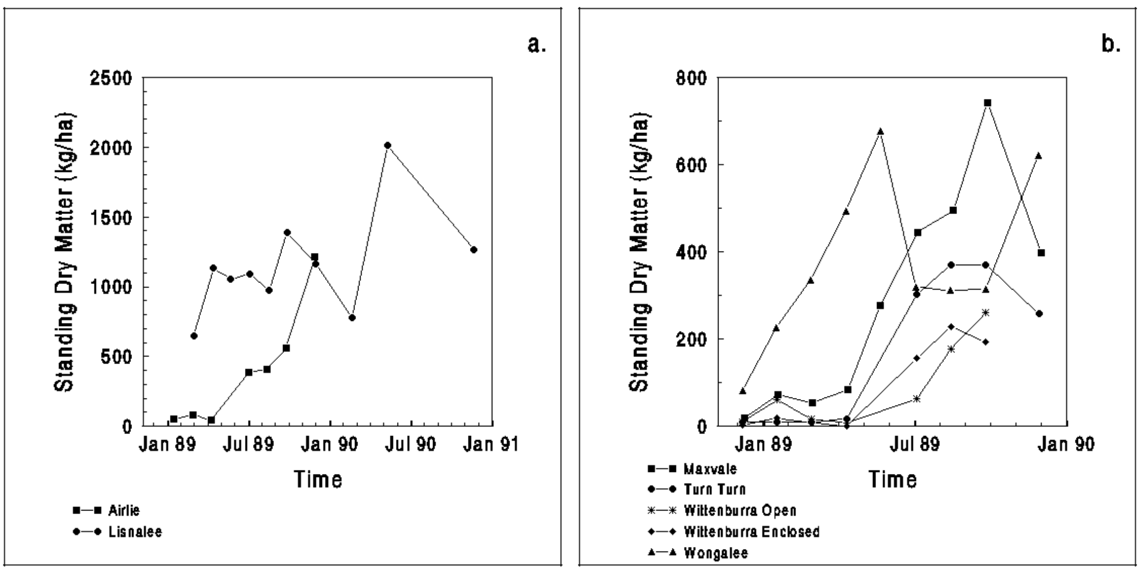


Figure 3.6b Change in standing dry matter yield (kg/ha) at (a) sites 3 and 4 and (b) sites 5 to 9 during the period September 1988 to November 1990.

At Airlie, a significant increase in yield occurred over 12 weeks during autumn and early winter at a rate of 4.1 kg/ha/day between 10.04.89 and 03.07.89 following 360 mm of rain (33 weeks since initial cutting back). A second significant yield increase occurred over nine weeks in spring, between 25.09.89 and 28.11.89 at a rate of 10.3 kg/ha/day. Three periods of significant increase in green cover were observed at Airlie. The second and third of these matched significant increases in yield. A decline in yield in early autumn prior to the main growth period (44% over six weeks from 27.02.89 to 10.04.89 at a rate of 0.8 kg/ha/day or 1%/day) was not significant.

Observations at Lisnalee spanned 23 months. During this period there were three periods of significant yield increase, and two periods of significant decline in yield. The first significant yield increase occurred over six weeks in the first summer between 02.03.89 and 14.04.89 at a rate of 11.4 kg/ha/day. The second significant increase in yield occurred over six weeks in the following spring between 17.08.89 and 28.09.89 at a rate of 9.7 kg/ha/day. This was closely followed by a significant decline in yield of 33% (4.7 kg/ha/day or 0.4%/day) in the latter half of the following summer (between the 01.12.89 and 20.02.90). Unseasonal rain in April 1990 (widespread flooding) resulted in the third significant increase in yield observed at Lisnalee. This occurred over 11 weeks in late autumn at a rate of 15.3 kg/ha/day between 20.02.90 and 11.05.90. A significant decline in yield (37%) followed at a rate of 3.8 kg/ha/day or 0.2%/day between 11.05.90 and 22.11.90.

Each of the three periods of significant increase in yield at Lisnalee corresponded with a significant increase in green cover. Three periods of significant decline in green cover were observed. However, only one of these (between 01.12.89 and 20.02.90) in mid-summer corresponded with a significant decline in yield.

At Maxvale, there were three periods of significant increase in yield. The first occurred over six weeks in summer between 09.12.88 and 19.01.89 at a rate of 1.3 kg/ha/day. The second occurred over six weeks in late autumn between 13.04.89 and 22.05.89 at a rate of 4.5 kg/ha/day. The third occurred over six weeks in winter between 22.05.89 and 05/07/89 at a rate of 3.9 kg/ha/day. A significant decline in yield of 46% occurred over nine weeks in early summer between 28.09.89 and 01.12.89 at a rate of 5.4 kg/ha/day or 0.7%/day.

Only the first two periods of significant increase in yield at Maxvale correspond with a significant increase in green cover. Two periods of significant decline in green cover were observed. However, only one of these (between 28.09.89 and 01.12.89) corresponded to a significant decline in yield.

At Turn Turn and the enclosed site at Wittenburra, a significant increase in yield was measured over 12 weeks in autumn and early winter from 11.04.89 to 04.07.89. At Turn Turn yield increased at a rate of 3.4 kg/ha/day, while at the enclosed Wittenburra site the rate was 1.9 kg/ha/day. Subsequent fluctuations in yield were not significant at either site. At both these sites the significant yield increase was matched by significant increases in green cover. However, the significant decline in green cover between 15.08.89 and 26.09.89 at both sites did not correspond to a significant decline in yield.

At the open (not enclosed) Wittenburra site, three periods of significant increase and one period of significant decrease in yield were observed. The first significant yield increase occurred over six weeks in summer between 07.12.88 and 17.01.89 at a rate of 1.3 kg/ha/day. This was followed immediately by a significant decline in yield of 74% between 17.01.89 and 28.02.89 at a rate of 1.1 kg/ha/day or 1.8%/day. This corresponded to a significant decline in green cover. The second period of significant yield increase was over 12 weeks in autumn (11.04.87 to 04.07.89) and early winter at a rate of 0.7 kg/ha/day. The third period of significant yield increase was over six weeks in late winter (04.07.89 to

15.08.89) at a rate of 2.7 kg/ha/day. While the first two periods of significant yield increase corresponded to significant increases in green cover there was no change in green cover during winter.

At Wongalee, yields fluctuated considerably. Yield increased significantly over 24 weeks in summer between 07.12.88 and 22.05.89 at a rate of 3.8 kg/ha/day. Over the next 38 weeks to the end of sampling, fluctuations in yield were not significant. This may be partly due to the difficulty in sampling *Triodia spp*. due to its large tussock habit, sampling on a front and the variability across plots. Only one period of significant increase in green cover was observed over the spring of 1989 (14/08/89 to 28/11/89). Increases in green cover corresponded to increased yield.

To better understand the variation in growth patterns identified above, the following section explores the relationships between growth and site characteristics.

3.3.3 Comparisons between sites

Standing biomass accumulated over approximately twelve months was used to compare productivity among sites. While short periods of rapid yield decline were observed at some sites (Section 3.3.2), the standing biomass at the end of a twelve month period represented the available forage production that is most relevant in rangeland grazing systems (Heady 1975, Holechek *et al.* 1990). Peak biomass yields in the first twelve months following mowing ranged from 193 kg/ha (Mulga grasses in the enclosure at Wittenburra) to 1678 kg/ha (Mitchell grass at Biddenham) (Table 3.6).

In Table 3.6, standing biomass is represented as net growth rate (kg/ha/day) and is presented with:

(1) other growth measures (water use efficiency (WUE kg/ha/mm) and perennial grass basal area measured at end of growth period (BA%));

(2) site characteristics (tree basal area (TBA m^2/ha), total soil nitrogen (N%), total soil phosphorus (P%), soil organic carbon (OrC %), soil particle size distribution (coarse sand (CS%), fine sand (FS%), silt (SI%) and clay (CL%)) and the available water range estimated from the wettest and driest profiles (AWR mm)); and,

(3) climatic variables (a moisture index calculated as the ratio of evapo-transpiration/ pan evaporation (ETP) and vapour pressure deficit (VPD hPa)).

Linear regression analysis indicated net growth rate was significantly correlated with basal area of perennial grasses, tree basal area, soil pH, the fine sand and clay content of the soil and the moisture index for the sites examined (Table 3.7, Figure 3.7). A correlation between net growth rate and water use efficiency (Table 3.7) is not biologically significant in this comparison as they are mathematically related. Latitude and longitude are also inappropriate variables to correlate with net growth rate as they indirectly reflect climatic (represented here as the ratio of calculated evapo-transpiration to pan evaporation (ETP)).

Multiple regression analysis indicated that a combination of soil, vegetative and climatic variables explained greater than 93% of the variation in annual net growth rates (Table 3.8).

Table 3.6 Comparison of peak yield (kg/ha) and net growth rate (kg/ha/day) to other growth measures, site characteristics and climatic variables.

Site No	Peak Yield (kg/ha)	Month of Peak Yield	Net Growth Rate (kg/ha/day)	Cum. ET (mm)	WUE at Peak Yield (kg/ha/mm)	ET/Pan To Peak Yield	Basal Area (%)	Tree Basal Area (m^2/ha)	Total* Soil N%	Total* Soil P%	AWR (mm)	Soil* ph	Organic* Carbon %	Coarse* Sand %	Fine* Sand %	Silt* %	Clay* %
			GRO	ETP	WUE	ETP	BA%	TBA	N%	P%	AWR	pH	OrC	CS	FS	SI	CL
1	1678	08/87	6.4	317	5.3	0.198	4.0	0.0	0.078	0.058	137	8.1	0.80	3	24	16	57
2	1190	09/87	3.6	548	2.2	0.271	4.3	0.5	0.053	0.023	51	5.2	0.78	51	30	5	14
3	1216	11/89	3.2	634	1.9	0.246	4.0	0.0	0.045	0.038	178	8.3	0.46	20	30	5	49
4	1385	09/89	5.4	315	4.4	0.225	6.2	0.0	0.040	0.068	73	5.8	0.50	38	34	7	23
5	742	09/89	2.0	443	1.7	0.169	2.7	0.8	0.050	0.033	85	5.6	0.81	23	47	11	19
6	371	09/89	1.0	353	1.1	0.137	1.6	2.0	0.045	0.059	66	6.1	0.55	28	49	7	20
7	260	09/89	0.7	289	0.9	0.112	0.5	0.0	0.055	0.049	39	5.1	0.63	15	51	8	28
8	193	08/89	0.5	289	0.7	0.112	0.5	1.5	0.055	0.049	40	5.1	0.63	15	51	8	28
9	621	11/89	1.4	495	1.3	0.162	2.7	0.5	0.026	0.013	160	5.9	0.54	59	29	4	9

* Data from profile descriptions of the main land units comprising each land system in Western Arid Region Land Use Studies, (Dawson 1974, Turner 1978 and Mills *et al*. 1990)

Table 3.7 Correlation matrix presenting Correlation Coefficients (R values) between net growth and other measures of growth, site characteristics and climatic variables. (Legend shown in Table 3.6)

** P<0.01 (0.6055)

* P<0.05 (0.4821)

GRO	1.00																
WUE	0.97a	1.00															
BA	0.86**	0.77**	1.00														
TBA	0.60*	0.54*	0.54*	1.00													
pH	0.56*	0.51*	0.39	0.37	1.00												
N%	0.40	0.44	0.08	0.14	0.29	1.00											
P%	0.31	0.43	0.09	0.06	0.16	0.41	1.00										
OrC	0.20	0.22	0.07	0.00	0.15	0.66**	0.17	1.00									
CS	0.10	0.18	0.30	0.03	0.39	0.77**	0.60*	0.23	1.00								
FS	0.76**	0.67**	0.76**	0.60**	0.61**	0.04	0.25	0.01	0.30	1.00							
SI	0.44	0.56*	0.01	0.12	0.32	0.82**	0.46	0.64**	0.73**	0.02	1.00						
CL	0.51*	0.50*	0.15	0.40	0.82**	0.68**	0.45	0.04	0.79**	0.32	0.58*	1.00					
Lat	0.87**	0.85**	0.89**	0.56*	0.27	0.12	0.08	0.28	0.17	0.66**	0.32	0.13	1.00				
Lon	0.71**	0.64**	0.84**	0.57*	0.37	0.17	0.34	0.12	0.46*	0.86**	0.02	0.01	0.86**	1.00			
ETP	0.71**	0.53*	0.87**	0.50*	0.41	0.00	0.19	0.04	0.34	0.77**	0.17	0.16	0.69**	0.74**	1.00		
AWR	0.34	0.28	0.37	0.40	0.80**	0.19	0.32	0.28	0.07	0.70**	0.01	0.41	0.26	0.60*	0.37	1.00	
VPD	0.06	0.13	0.34	0.03	0.42	0.59*	0.13	0.51*	0.45	0.19	0.63**	0.47	0.14	0.02	0.25	0.33	1.00
	GRO	WUE	BA	TBA	pH	N%	P%	OrC	CS	FS	SI	CL	Lat	Lon	ETP	AWR	VPD

a = GRO and WUE are mathematically related, therefore not compared.

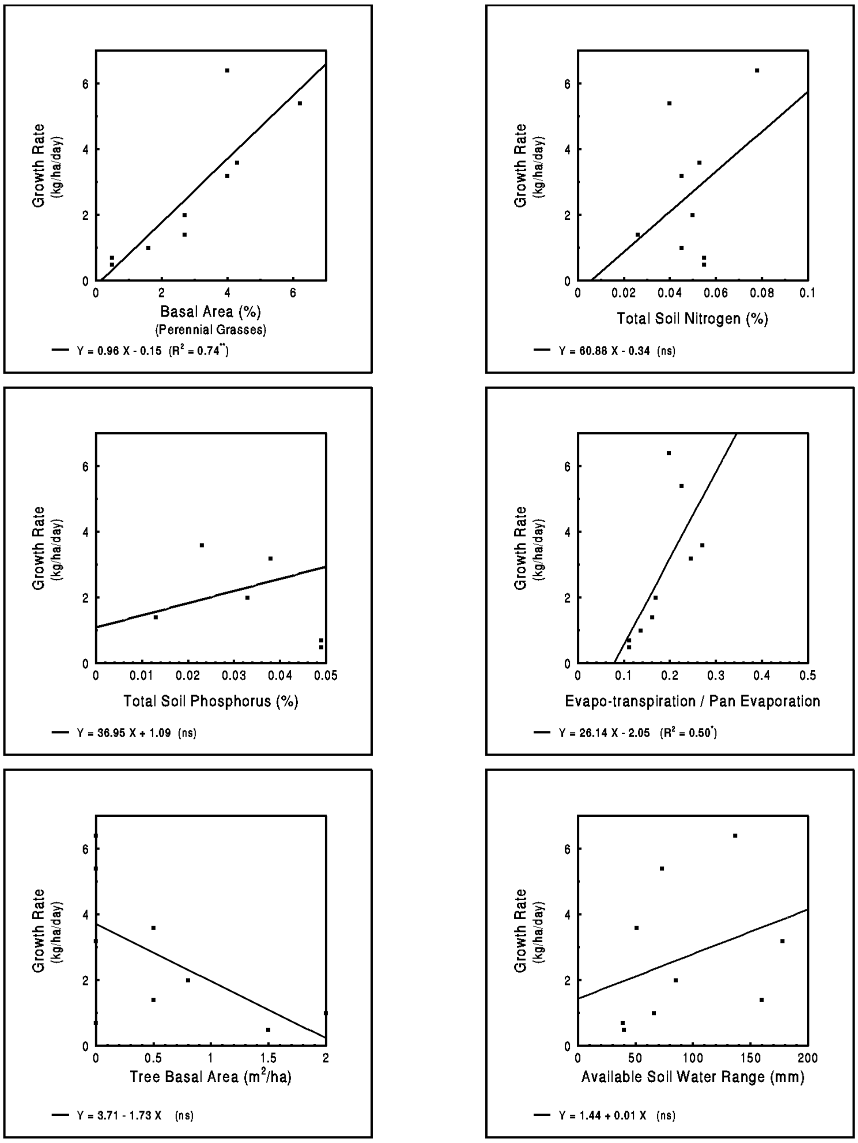


Figure 3.7 Relationship between net growth rate (kg/ha/day) and basal area of perennial grasses (%), total soil nitrogen (%), total soil phosphorus (%), a moisture index (calculated evapo-transpiration/pan evaporation), tree basal area (m^2/ha) and the available soil water range (mm) at nine sites in south-west Queensland from October 1986 to November 1990.

Table 3.8 Regression equations relating net growth rate to soil, vegetative and climatic variables.

	[a] ADJ R^2	[b] C_p
Soil variables		
GRO = 6.60 + 63.79 * P - 0.17 * FS#	0.81	0.6
GRO = 5.92 + 50.95 * P - 0.17 * FS + 0.13 * SI	0.83	1.7
GRO = 9.00 + 57.41 * P - 0.20 * FS + 0.15 * SI - 0.40 * PH	0.84	3.0
GRO = 8.87 + 57.18 * P - 0.20 * FS + 0.14 * SI - 0.40 * PH + 5.59 * N	0.79	5.0
GRO = 7.99 + 58.70 * P - 0.20 * FS + 0.13 * SI - 0.27 * PH + 13.28 * N - 0.01 * C	0.68	7.0
Vegetation and climatic variables		
GRO = -0.15 + 0.96 * BA	0.70	5.8
GRO = -8.14 + 1.12 * BA + 0.33 * VPD#	0.84	1.8
GRO = -7.52 + 1.34 * BA + 0.34 * VPD - 8.29 * ETP	0.83	3.3
GRO = -6.76 + 1.28 * BA + 0.33 * VPD - 8.56 * ETP - 0.30 * TBA	0.80	5.0
Soil, vegetation and climatic variables		
GRO = -10.17 + 33.67 * P + 1.10 * BA + 0.36 * VPD#	0.94	3.0
GRO = - 9.57 + 34.73 * P + 1.07 * BA + 0.35 * VPD - 0.01 * FS	0.93	5.0
GRO = - 3.80 + 71.16 * N + 1.00 * BA	0.94	12.0
GRO = - 6.33 + 56.85 * N + 1.06 * BA + 0.14 * VPD	0.95	8.7
GRO = - 8.08 + 37.91 * N + 1.07 * BA + 0.22 * VPD + 19.09 * P	0.97	6.0

Legend

- # Best subset model following stepwise regression.
- [A] The adjusted R^2 was used to accommodate for the varying number of independent variables in the models.
- [B] Mallows'C_p index of model bias. (Good models have C_p values near to or less than the number of parameters in the model (A.M. Kelly pers. comm.)).
- GRO Net growth rate (kg/ha/day)
- N Total Nitrogen (%)
- P Total Phosphorus (%)
- FS Fine Sand (%)
- SI Silt (%)
- C Clay (%)
- PH Soil pH
- ETP Moisture index (Cumulative evapo-transpiration / pan evaporation)
- BA Perennial grass basal area (%)
- TBA Tree basal (m^2/ha)
- VPD Vapour pressure deficit (hPa)

3.4 Nitrogen uptake

The nitrogen content of plant tops was measured at the Biddenham and Charleville sites. The concentration of nitrogen declined with time (Figure 3.6a). Towards the end of the growing season, lower concentrations were observed in the C4 mitchell grass plants at Biddenham than in C3 mulga grasses at the Charleville site.

3.3.5 Soil moisture, evapo-transpiration and water use efficiency

The above section has described the change in yield over time and has highlighted the variability among sites in terms of peak yield. The timing of the peak yield varied among sites, indicating differences in the patterns of growth. Seasonal distribution of rainfall and temperature were the most likely influences on growth patterns in south-west Queensland. Species composition (ratio of C3 to C4 species) may also have influenced the response at individual sites. To better understand growth patterns, net growth rates and water use efficiencies were compared (Table 3.9) with site characteristics and climatic variables over summer (November to April) and winter (May to October). At Airlie and Lisnalee significant growth periods during the second summer period were also examined.

Table 3.9 Comparison of standing dry matter yield (kg/ha) and net growth rates (kg/ha/day) with cumulative evapo-transpiration (ET)(mm), water use efficiency (WUE) (kg/ha/mm evapo-transpired water), a moisture index (ET/Pan) (cumulative evapo-transpiration/cumulative pan evaporation) and vapour pressure deficit (VPD) (hPa) over summer and winter at nine sites in south-west Queensland from October 1986 to November 1990.

	Summer						Winter					
Site No	Yield *	Net growth rate	ET	WUE	ET/ Pan	VPD	Yield +	Net growth rate	ET	WUE	ET/ Pan	VPD
1	1238	7.8	261	4.7	0.207	30.9	167	0.9	153	1.1	0.201	15.0
2	799	4.6	401	2.0	0.278	29.4	186	1.0	200	0.9	0.271	14.6
3	45	0.3	137	0.3	0.090	31.2	515	3.1	469	1.1	0.839	11.8
4	1137	12.5	169	6.7	0.199	28.3	248	1.5	147	1.7	0.266	11.9
5	85	0.4	166	0.5	0.081	31.4	657	3.9	277	2.4	0.489	11.9
6	17	0.1	121	0.1	0.060	31.9	354	2.1	232	1.5	0.416	11.8
7	7	0.0	104	0.1	0.052	31.9	253	1.5	185	1.4	0.332	11.8
8	0	0.0	107	0.0	0.053	31.9	193	1.1	182	1.1	0.326	11.8
9	492	2.5	88	5.6	0.044	32.5	0	0.0	256	0.0	0.459	11.8
3a.#	656	10.3	104	6.3	0.208	23.4						
4a.!	1227	15.3	310	4.0	0.799	19.5						
Long Term Average						26.9						12.7

- * Yield at the end of April
- \+ Change in yield from the end of April to the end of October
- \# Change in yield in Spring 1989 at Airlie (25.09.89 - 28.11.89)
- ! Change in yield in Autumn 1990 at Lisnalee (20.02.90 - 11.05.90)

The proportion of annual evapo-transpiration occurring in summer ranged from 23% to 67% (Table 3.9). Net growth rates over summer were significantly correlated with basal area of perennial grasses, the fine sand fraction, the moisture index and vapour pressure deficit (Table 3.10). Water use efficiency over summer was significantly correlated with basal area of perennial grasses, the fine sand fraction, latitude and longitude. During winter, net growth was significantly correlated with the moisture index only.

Table 3.10 Correlations between measures of growth over summer and winter of native pastures in south-west Queensland to site characteristics and climatic variables (Correlation Coefficient R shown).

Site Variable	SUMMER		WINTER	
	Net growth rate (kg/ha/day)	WUE (kg/ha/mm)	Net growth rate (kg/ha/day)	WUE (kg/ha/mm)
BA%	0.82**	0.68**	0.02	0.04
TBA	0.49	0.47	0.08	0.11
pH	0.16	0.16	0.19	0.12
N%	0.11	0.19	0.04	0.27
P%	0.39	0.05	0.12	0.50
OrC	0.02	0.11	0.05	0.27
CS	0.17	0.42	0.36	0.46
FS	0.58**	0.68**	0.34	0.50
SI	0.23	0.07	0.13	0.42
CL	0.12	0.06	0.17	0.08
Lat	0.84**	0.73**	0.02	0.19
Lon	0.64*	0.76**	0.14	0.23
ETP	0.73**	0.44	0.58*	0.02
AWR	0.06	0.35	0.03	0.41
VPD	0.81**	0.47	0.33	0.19

** P<0.01 (0.6411)

* P<0.05 (0.5139)

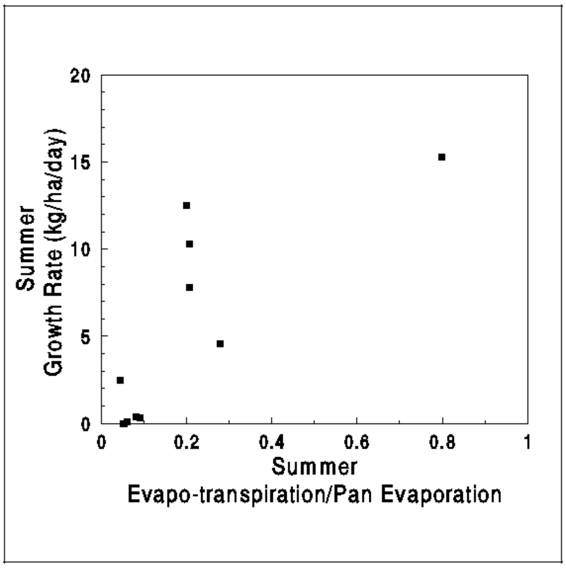
3.4 Discussion

3.4.1 Pasture yield

The range of peak annual dry matter yields of 193-1678 kg/ha approximated those reported elsewhere for semi-arid environments. Following abundant summer rain, Ebersohn (1970) recorded air dry pasture yields of 1333 kg/ha from cleared Mulga pastures and 2222 kg/ha from Mitchell grass pastures in south-west Queensland. Christie (1978) recorded peak yields of 1220 and 1540 kg/ha for Mulga pastures and Buffel grass respectively in western Queensland. A peak yield on Mitchell grass of 1960 kg/ha was reported by Christie (1981) while Hulet (1970) reported a net primary shoot production of 719 kg/ha on a Mitchell grass community near Charleville. Ross (1977b) observed a peak yield of 1230 kg/ha for native pasture in central Australia, and in the United States, Redman (1975) recorded yields in the range 176-3518 kg/ha from semi-arid grassland communities. Sims and Singh (1978) observed yields of 840-3360 kg/ha and Webb *et al*. (1978) yields of 800-3800 kg/ha for similar north American grasslands.

The systematic analysis of the time course of yield indicated that: (1) measurement accuracy was sufficient to detect major trends in pasture yield relative to short term fluctuations; and, (2) that most sites displayed two to three periods of significant growth separated by periods of no growth. However, a common growth pattern could not be derived due to the differences in the timing and magnitude of the changes in yield (Figure 3.6a and 3.6b). Growth rates during these periods varied within and across sites, ranging from 0.7 to 20.4 kg/ha/day. Rates of yield decline also varied, ranging from 0.8 to 32.5 kg/ha/day or 0.2 to 2% of total yield per day. Across all sites, growth pulses matched significant increases in green cover. However, decline in green cover rarely was associated with decline in yield. This indicated that "non-green" or senesced plant material was often a substantial proportion of presentation yield. This result has implications for remote sensing where estimates of yield and ground cover are made using indices of greenness e.g. (NDVI in (Danaher *et al.* 1992) and MSS visible green-visible red in Pickup (1995).

Net growth rate over summer was low when the moisture index was below 0.1 (Table 3.9, Figure 3.8). Six of the eleven site/year combinations had an index of less than 0.1 over summer. At five of these six site/year combinations with an index of less than 0.1, net growth rates of less than 0.4 kg/ha/day were measured. Wongalee was an exception with a net growth rate over summer of 2.5 kg/ha/day in conjunction with a low (0.044) moisture index. The presence of sub-surface moisture at this site indicated rainfall was not the sole source of moisture for growth, possibly explaining the yield increases measured during periods of perceived low moisture supply.



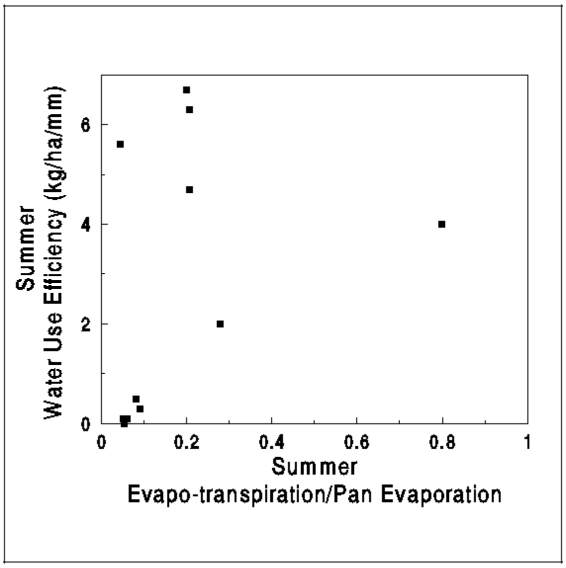


Figure 3.8 The relationship between the moisture index (ratio of evapo-transpiration to pan evaporation) and net growth rate and water use efficiency over summer for nine sites in south-west Queensland from October 1986 to November 1990.

The results indicated that a number of soil variables and vegetative and climatic variables were significantly correlated with annual net growth rate for the sites examined. Combination of these variables improved the prediction of annual net growth rate. This section has identified a number of these factors to be significantly correlated with summer growth. Vapour pressure deficit was also significantly related to summer growth and indicated the importance of this factor in describing growth over this period. For example, rapid growth at Lisnalee occurred during early autumn 1990, a period of relatively low VPD (VPD = 19.5 Table 3.9) compared to peak summer values of 35 hPa. A lack of correlation between net growth rate and total soil nitrogen, total soil phosphorus and soil organic carbon may be biologically significant or a chance result of the distribution of these values across the sites examined.

This indicates that limited insight was gained into the productivity of pastures from individual year data as indicated in the review of literature. The effects of climate, soils and species on pasture growth rates need to be separated. For example, in this study, annual net growth rate was significantly correlated with several parameters characteristic to each site (Table 3.7), with the major effects in summer (Table 3.10). A possible approach for comparison of sites would be to use water use efficiencies to remove the major source of year to year variability due to rainfall.

3.4.2 Water use efficiency

The range of water use efficiencies (WUE) calculated approximate those reported elsewhere for semi-arid environments. The term approximate is used, as considerable confusion arises as to exactly how these values were defined and calculated. Noy-Meir (1973) proposed a range of 5-20 kg/ha/mm of precipitation, Ripley (1992) reported a mean world grassland value of 12 kg/ha/mm of water used; and Webb *et al*. (1978) indicated 1-3 kg/ha/mm of transpired water for hot desert systems; and Sala *et al*. (1988) reported 6 kg/ha/mm of precipitation for the central grasslands of the United States.

In this discussion, water use efficiency is defined as the ratio of above ground dry matter production (kg/ha) to water used (soil evaporation + transpiration) (mm). This chapter has calculated water use efficiencies for a number of pasture types in south-west Queensland. This is distinct to the transpiration efficiency which is the ratio of above ground dry matter production to water transpired through plants (mm). Calculating the transpiration efficiency requires separating soil evaporation and transpiration empirically in the absence of large equipment such as lysimeters.

At each site where C4 species predominated, summer water use efficiencies were greater than both the annual and winter values. This corresponded with rapid summer growth and attainment of a peak yield towards the end of the first summer (13 to 17 weeks since initial mowing back). This reflects the temperature response of these species. An exception was the first summer at Airlie, when rainfall was low.

At sites dominated by C3 species (Charleville site, Maxvale, Turn Turn, and Wittenburra), winter water use efficiencies were generally greater than summer and annual values. This corresponded with significant yield increases occurring later during the year, and attainment of the peak yield towards the end of winter (47 to 54 weeks since initial mowing back).

In western Queensland, Christie (1978) measured a "mean" summer water use efficiency of 3.9 kg/ha/mm of "stored" moisture for a native Mulga pasture, and 6.9 kg/ha/mm for a Buffel grass pasture. Christie (1981) later reported a "mean" summer water use efficiency of 2.6 kg/ha/mm for the same native Mulga pasture and 3.8 kg/ha/mm for a Mitchell grass pasture. Summer values recorded in this work were 2.0 kg/ha/mm of stored moisture for native Mulga pasture at the Charleville site, 6.7 kg/ha/mm for Buffel grass at Lisnalee and 4.7 kg/ha/mm for Mitchell grass at Biddenham.

Differences in water use efficiency between studies at similar sites can be due to several factors:

(1) Variation on the definition of the amount of "water used", precipitation, evapo-transpiration, transpired water, or stored moisture. These measures are not usually clearly defined making comparisons difficult.

(2) The growth period and technique for estimating growth are not well defined. It is often unclear whether yields represent seasonal or annual growth, or whether yields are presentation yields or true values of primary production. Table 3.10 highlighted the variation in water use efficiency when comparing different growth periods, for example summer and winter. If water use efficiency is to reflect true net primary production, estimates of detachment rates need to be made.

(3) Water use efficiencies vary with plant species, soil type and most importantly with vapour pressure deficit (Tanner and Sinclair 1983). These workers showed from both theoretical analysis and field experimentation, that transpiration efficiency (TE) (kg/ha/mm of transpired water) was inversely proportional to daytime vapour pressure deficit (VPD), i.e. TE=K/VPD where K is constant for a given species / nutrient combination. This approach has proved successful in crop modelling (e.g. Hammer and Muchow 1991).

To clarify the differing water use efficiencies of 3.6 kg/ha/mm or 2.6 kg/ha/mm reported by Christie (1978 and 1981 respectively) for Mulga pastures, his results were re-calculated and compared to water use efficiencies measured in this study. The value of 3.6 kg/ha/mm of evapo-transpired water reported by Christie (1978) was confirmed correct. The average daytime VPD for the period (01/12/73 to 21/02/74) was 23.1 hPa. For a similar period (04/12/86 to 03/03/87) in this study, a water use efficiency of 2.1 kg/ha/mm evapo-transpired water was measured at the Charleville site. The average daytime VPD however was higher at 31.5 hPa. The K (i.e. TE * VPD) value for Christie (1978) was 83 compared to 66 in this study. The relative range from 66 to 83 is similar to the range reported by Tanner and Sinclair (1983) for maize, and McKeon *et al*. (1990) for *Heteropogon spp*. pastures, and is within the range of errors in estimating average daytime VPD and approximating TE by using WUE.

A similar difference occurred between Christie's (1981) water use efficiency of 3.8 kg/ha/mm for Mitchell grass pasture measured over 1975/76 and the annual value of 3.4 kg/ha/mm for the Biddenham Mitchell grass site in this trial. After re-calculating Christie's (1981) data, a water use efficiency of 4.2 kg/ha/mm resulted. The average daytime VPD for this period was 17.0 hPa compared to 21.3 hPa for the Biddenham site. The K value of 71 for Christie's (1981) sampling and 72 for the Biddenham site suggested in this case that the different water use efficiencies can be explained in terms of different VPD during the relative sampling periods.

The significant correlation between summer growth and VPD in this experiment in conjunction with the above results, confirm the importance of vapour pressure deficit in understanding water use efficiency and plant growth, as shown by Tanner and Sinclair (1983), McKeon *et al.* (1990), Day *et al.* (1993) and Hammer and Muchow (1991).

Water use efficiencies and net growth rates over summer were also influenced by low moisture indices. Low net growth rates (< 4 kg/ha/day) and low water use efficiencies (< 0.5 kg/ha/mm) were associated with indices less than 0.1. This indicates the importance of the moisture index as one of the factors influencing growth.

3.4.3 Nitrogen uptake and dilution

The peak nitrogen uptake of the Mitchell grass at Biddenham (14 kgN/ha) approximated the 16 kgN/ha reported for Mitchell grass by Christie (1981). However, the range of nitrogen concentrations in this work was wider than that of Christie (1981) (0.59 to 2.57 %N vs. 0.92 to 2.00 %N respectively). Christie (1981) reported a decline in N concentration from 2.00 to 0.92% over the summer growing period. The decline in this work for a similar period (17/12/86 to 18/03/87) was 2.57 to 0.82%. However, N concentrations as low as 0.59% were measured in this work.

Peak nitrogen yield for Mulga pastures in this trial (16 kgN/ha) was below that reported by Christie (1979) for similar species (22 kgN/ha). However, nitrogen concentrations were similar.

Differences between these two pasture communities in terms of nitrogen use exist. The C4 Mitchell grass pasture diluted nitrogen in plant tops to a lower level than the C3 Mulga pastures resulting in an improved efficiency of nitrogen use. Estimates of pasture productivity on a property or regional scale need to accommodate such differences between broad pasture types (C3 vs C4). Christie (1981) suggested that mineral nutrients (including phosphorus limitations) may be more significant than water as an external factor influencing the distribution of pasture types. This study supports that suggestion. Thus for the same amount of nitrogen uptake, C4 grasslands can produce more yield than C3 grasslands. Grasslands with a mix of C3 and C4 species such as in the Mulga lands would exhibit varying patterns of nitrogen use depending on relative species composition.

The efficiency of nitrogen use is also likely to influence forage quality for grazing animals as dietary nitrogen is important component of ruminant nutrition. At the end of the growing season pastures with predominantly C4 species with lower nitrogen concentrations are likely to be of a lower quality than C3 dominated communities with higher nitrogen concentrations.

3.4.4 Conclusion

In this Chapter the collation and analysis of native pasture primary productivity data from sites representative of 8 land systems from south-west Queensland were described. As there was no replication of sites the data can only be interpreted as point-based information. While representing only a small sample of the diversity of land systems found in the region these results provide a basic level of understanding of the productive capacity of the resources in the region. Such an understanding is central to a review of grazing capacity based on ecological principles.

In summary, this section demonstrated that primary production could be measured and related to water use (evapo-transpiration) over short periods of time. The impact of VPD on water use efficiency and subsequent estimates of pasture growth was highlighted. The effects of tree basal area, total soil nitrogen and phosphorus, soil texture, a moisture index and species composition (C3 vs C4) on pasture productivity and nitrogen utilisation were also indicated. Regression analysis using simple multiplicative indices of these factors explained up to 97% of the variation in the data for the time period and sites under observation. However, the effect of topography was not examined as relatively level sites were selected to minimise the effects of rainfall run-on and run-off. A method for reviewing grazing capacities on a regional scale requires extrapolation of this point-based production information temporally and spatially. The spatial component would need to include climatic and topographical variability that exists at a regional scale. To achieve this Lauenroth *et al*. (1986) and Redman (1992) suggested that simulation modeling was the most promising procedure to estimate and extrapolate above-ground net primary production due to the complexity of interrelationships. Such an approach using the above data is described in Chapter 4.