Chapter 3

Site descriptions, general materials and methods

3.1 Site descriptions

Three predominantly native pasture sites on which a grazing cell had recently been established were selected on commercial properties situated within the Northern Tablelands region of NSW, Australia. A summary of site descriptions is presented in Table 3.1. At each property a section was permanently fenced and grazed throughout the year with the same class of livestock as that rotating in the cell. The continuously grazed and cell grazed paddocks had in each instance previously belonged to a single larger paddock. Stocking rates varied with season but were always maintained at the same level in both the cell grazed and continuously grazed paddocks, with the exception of one site as detailed in section 3.1.2.

Table 3.1 Description of the property sites on which the study was conducted.

	Strathroy	**Lana**	**Green Hills**
Lat/Long	30°23'S 151°16'E	30°37'S 151°15'E	30°15'S 151°48'E
Height ASL (m)	750	850	1350
Av. rainfall (mm)	730	780	870
Parent material	fine granite	coarse granite	basalt
Soil pH (H_20)	5.6	5.4	5.9
Bray P (mg/kg)	7.3	6.0	8.2
Nitrate N (mg/kg)	3.7	15.5	6.8
Organic C (%)	1.6	1.8	3.1

3.1.1 *Strathroy*

A 730 ha cell comprising 28 paddocks was established at Strathroy in February 1994. Measurements were made within a 28 ha paddock which was grazed as part of the normal cell rotation and an adjacent paddock which was further subdivided into two 15 ha paddocks (Fig. 3.1). One of these was the "control" paddock which was permanently fenced and continuously stocked at the same rate and with the same type and class of stock as was in the cell. Stock were introduced to this paddock in April 1994. The remaining 15 ha was included in the rotation, giving a further treatment which was double the normal stock density. This treatment will be referred to as the high density cell grazed paddock (HD cell grazed) from this point. By grazing the 15 ha HD cell grazed paddock for half the time that the 28 ha paddock was grazed, the stocking rates were effectively the same. The average stocking rate from April 1994 to June 1996 was 6.2 DSE/ha in the cell grazed, HD cell grazed and continuously grazed paddocks.

The site had a history of regular superphosphate application up to 1989. Subterranean clover (*Trifolium subterraneum*) had been aerially spread during the 1960s. At the time of commencement of monitoring, the vegetation was dominated by the warm season native perennial grasses *Eragrostis leptostachya*, *Sporobolus creber* and *Aristida ramosa*. The environment and topography of the site on Strathroy is shown in Plate 3.1.

Plate 3.1 The Strathroy site.

STRATHROY

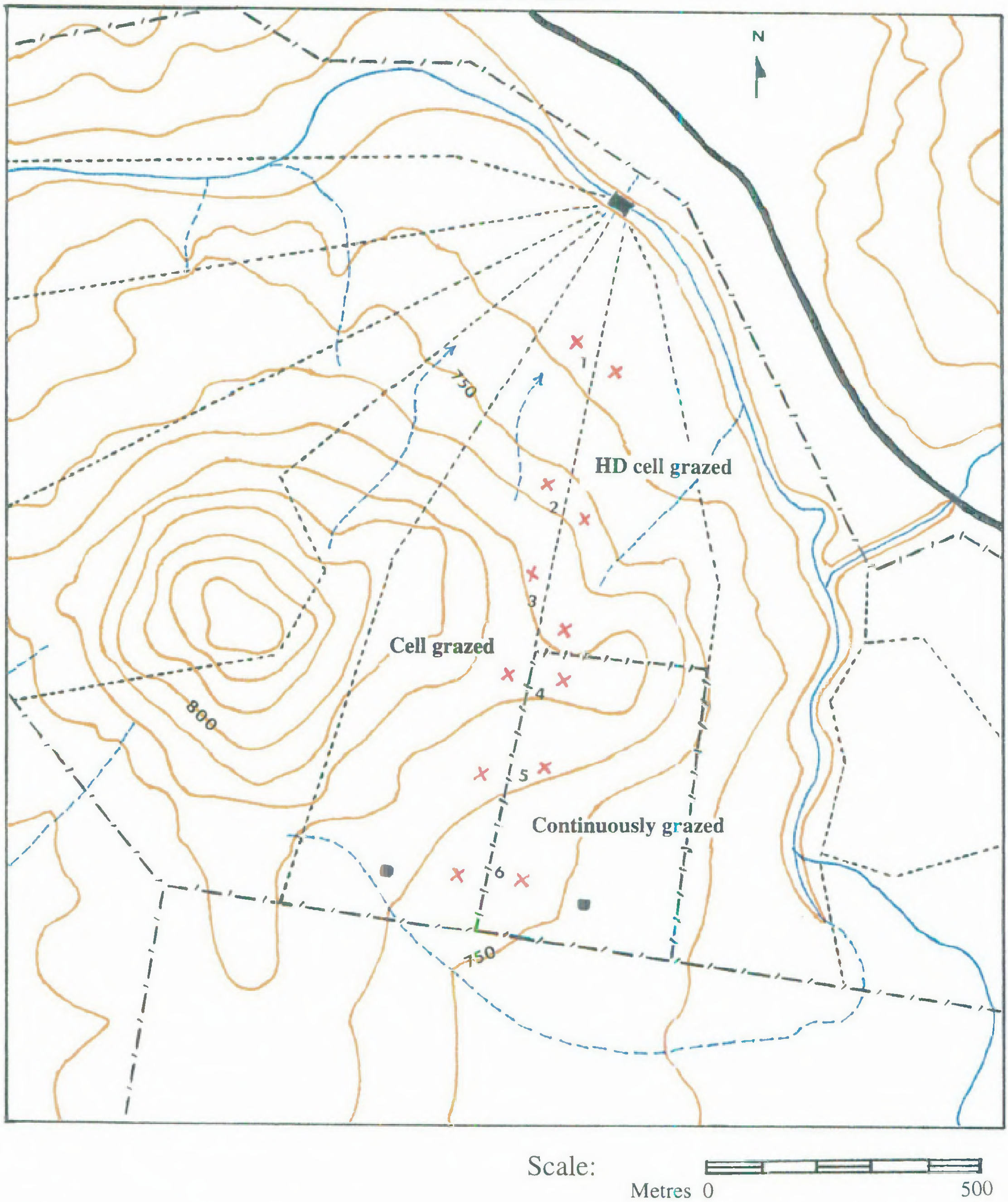

Fig. 3.1 Contour map of the Strathroy site showing the position of the experimental plots.

Total cell area:	730 ha
Number of paddocks:	28
Cell grazed paddock area:	28 ha
Continuously grazed area:	15 ha
HD cell grazed paddock area:	15 ha

Legend:

——	10 m contour line
—/—/	Permanent fence
......	Cell fencing
——	Permanent watercourse
- - - -	Drainage line
■	Water point
▬	Road
×	Experimental plot

3.1.2 *Lana*

Monitoring of the effects of cell grazing on *Aristida ramosa* and *Stipa scabra* was initiated at three sites on Lana in June 1993. The collection of additional data at one of these sites began in December 1994 in a 16 ha paddock within a grazing cell which comprised 33 paddocks (Fig. 3.2). The adjacent 68 ha control paddock was stocked in accordance with the type of grazing management which operated prior to the introduction of cell grazing on this property. The stocking rate from January 1994 to June 1996 averaged 6.0 and 3.1 DSE/ha in the cell grazed and continuously grazed paddocks respectively. At this site the landholder felt that it was not possible to maintain the same stocking rate under continuous grazing as in the cell.

The Lana site had been sown once to introduced species in the 1960s and was annually topdressed with superphosphate until 1989. At the commencement of monitoring at this site in June 1993 the sown species had completely disappeared and the vegetation consisted primarily of the native perennial grasses *Eragrostis leptostachya, Sporobolus creber*, *Elymus scaber, Danthonia racemosa, Stipa scabra* and *Microlaena stipoides*. The environment and topography of the Lana site are shown in Plate 3.2.

Plate 3.2 The Lana site.

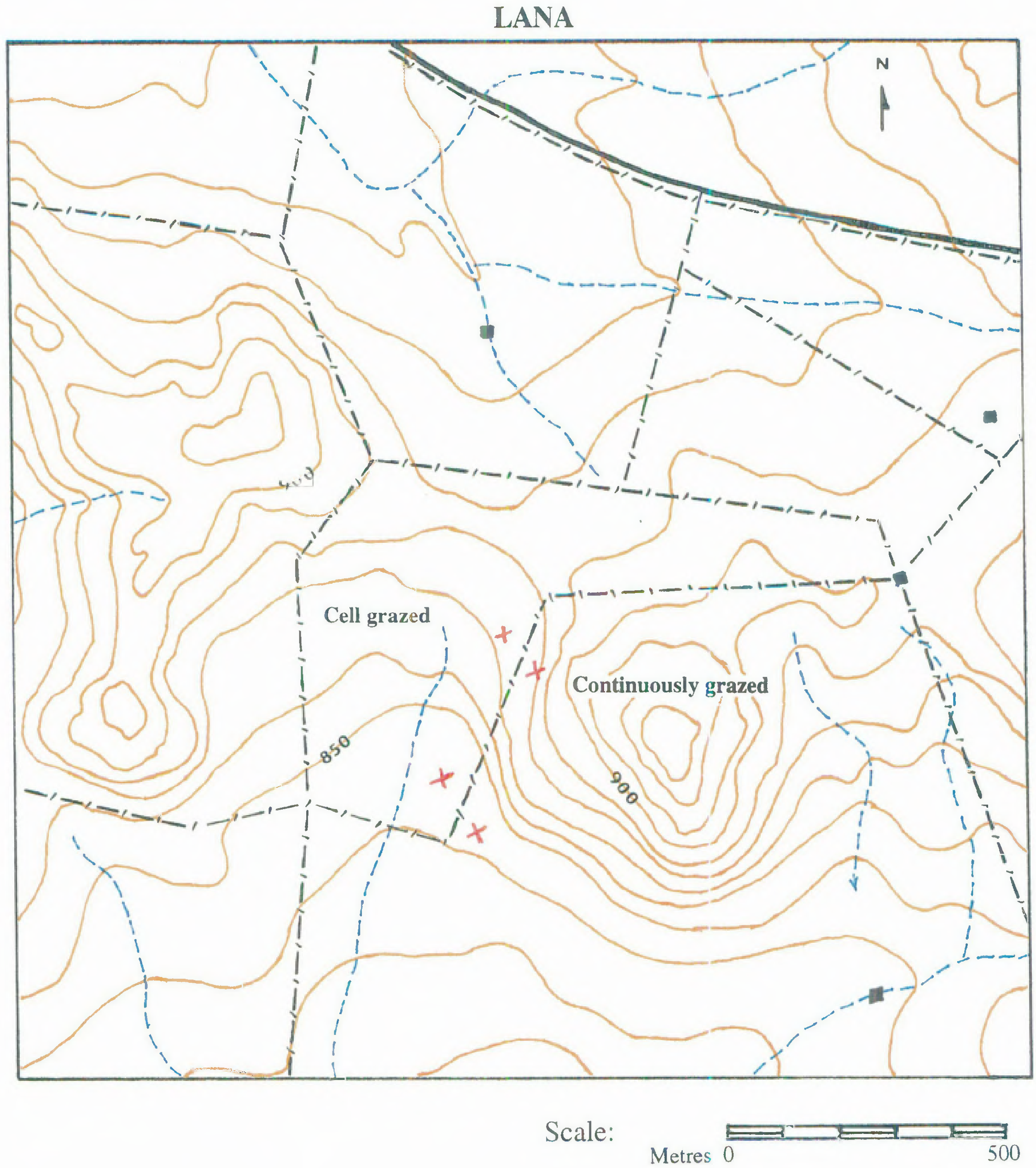

Fig. 3.2 Contour map of the Lana site showing the position of the experimental plots.

Total cell area:	460 ha
Number of paddocks:	33
Cell grazed paddock area:	16 ha
Continuously grazed area:	68 ha

Legend:

- 10 m contour line
- Semi permanent fence
- Water point
- Drainage line
- Road
- Experimental plot

3.1.3 *Green Hills*

A 243 ha grazing cell comprising 26 paddocks was established at the Green Hills site in September 1994. Baseline measurements were made at the same time as the fences were constructed. Monitoring was conducted on a 9 ha cell paddock and an adjacent continuously grazed paddock of 3.5 ha (Fig. 3.3). As for the Strathroy site the control paddock was continuously stocked with the same class and type of stock as in the cell. The average stocking rate from September 1994 to June 1996 was 6.9 DSE/ha in both the cell grazed and continuously grazed paddocks.

The site monitored at Green Hills had been cleared of trees and was last cultivated and sown with a mix of introduced species in 1965. Annual superphosphate application was discontinued in 1989. Of the species sown, only *Phalaris aquatica* remained to contribute to the pasture on offer at the commencement of this study. The dominant species with respect to biomass was the warm season native grass *Bothriochloa macra*. The environment and topography of the two paddocks which were monitored at the Green Hills site are shown in Plate 3.3.

Plate 3.3 The Green Hills site.

DSE days/ha/month over the experimental period on the monitored paddocks on each property are shown in Fig. 3.4. Rainfall for the experimental period at each site and long term averages are shown in Fig. 3.5.

GREEN HILLS

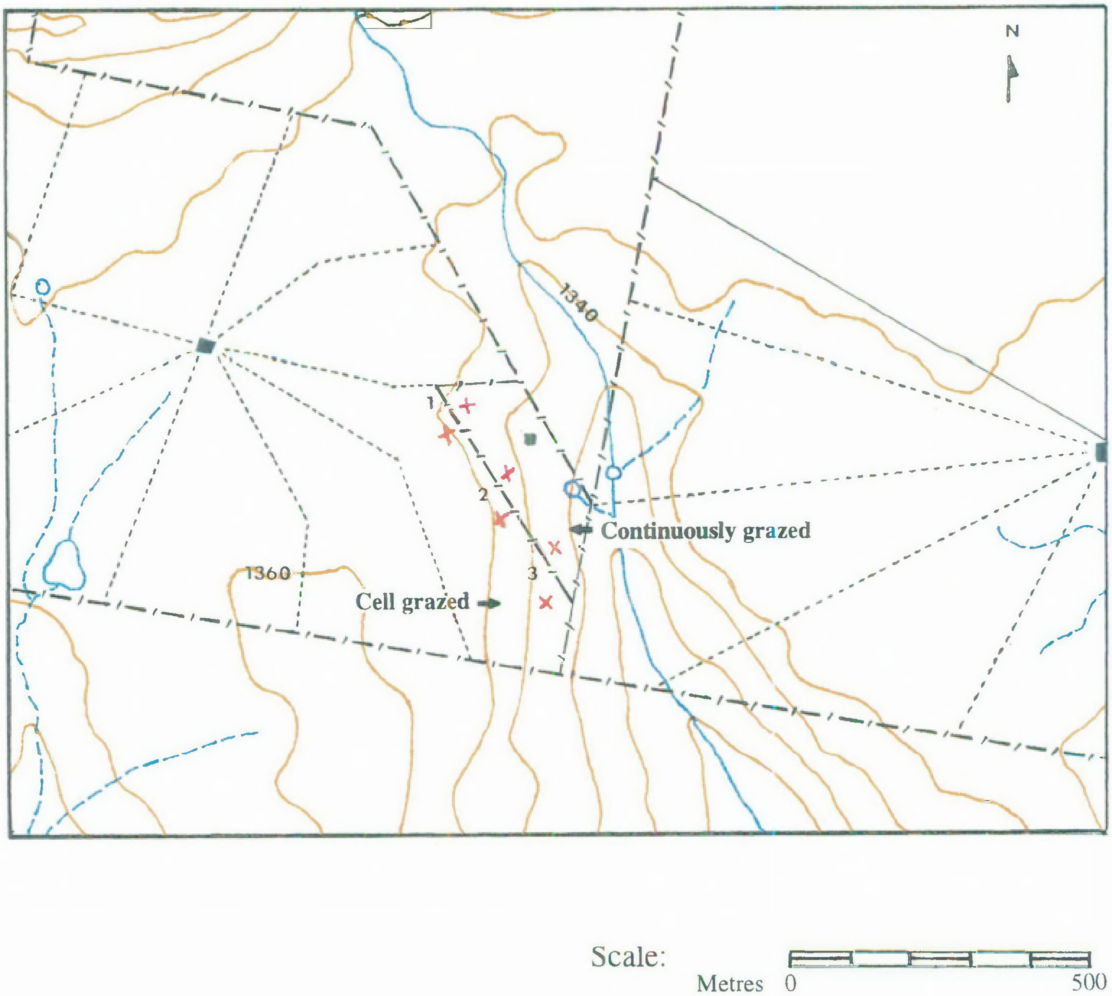

Fig. 3.3 Contour map of the Green Hills site showing the position of the experimental plots.

Total cell area:	243 ha
Number of paddocks:	26
Cell grazed paddock area:	9 ha
Continuously grazed area:	3.5 ha

Legend:

———	10 m contour line
—/—/	Permanent fence
- - - - -	Cell fence
■	Water point
- - - -	Drainage line
×	Experimental plot

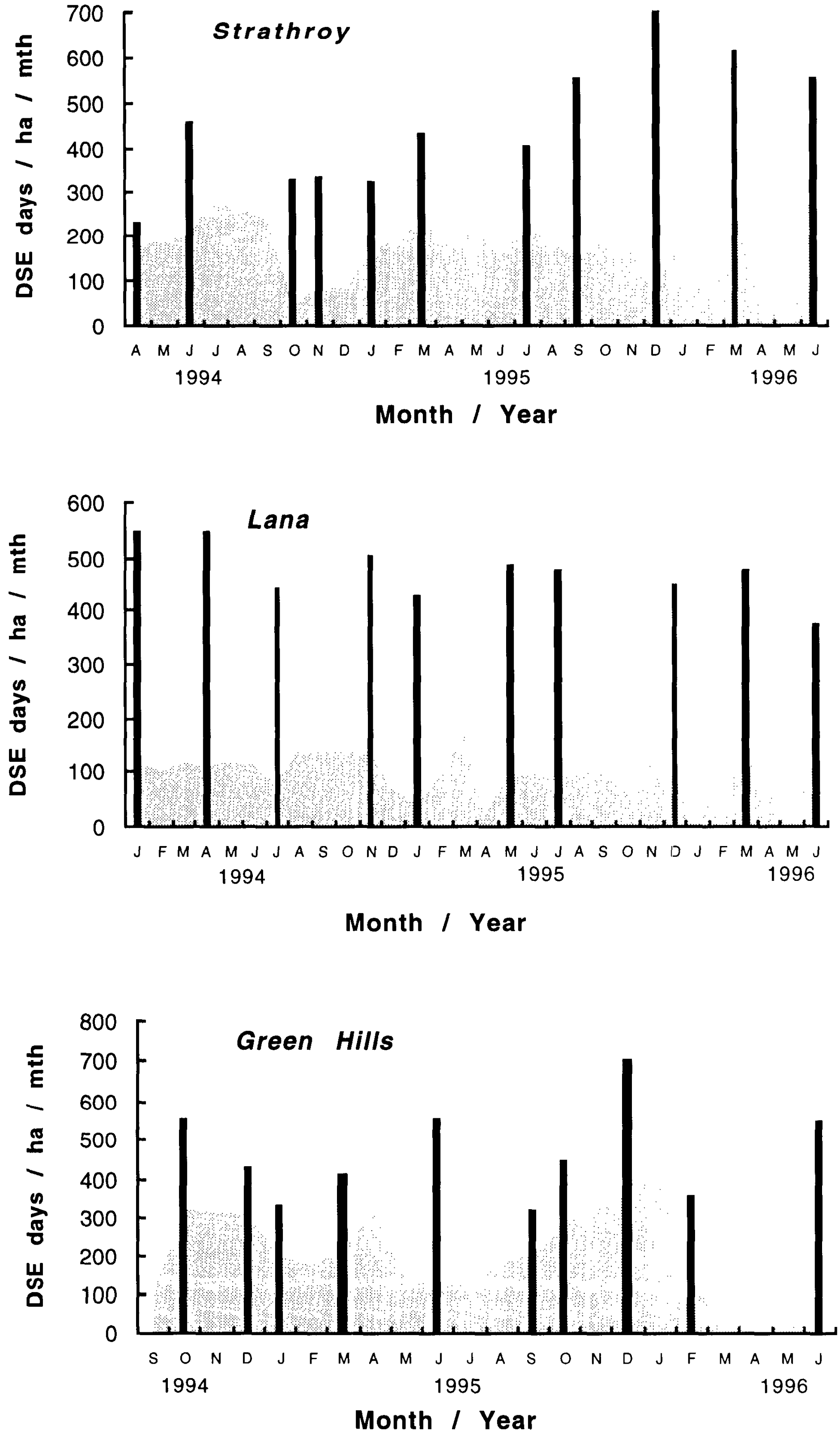

Fig. 3.4 DSE days/ha/month in cell grazed (solid bars) and continuously grazed (shaded area) paddocks from the initiation of monitoring at each site to the end of June 1996.

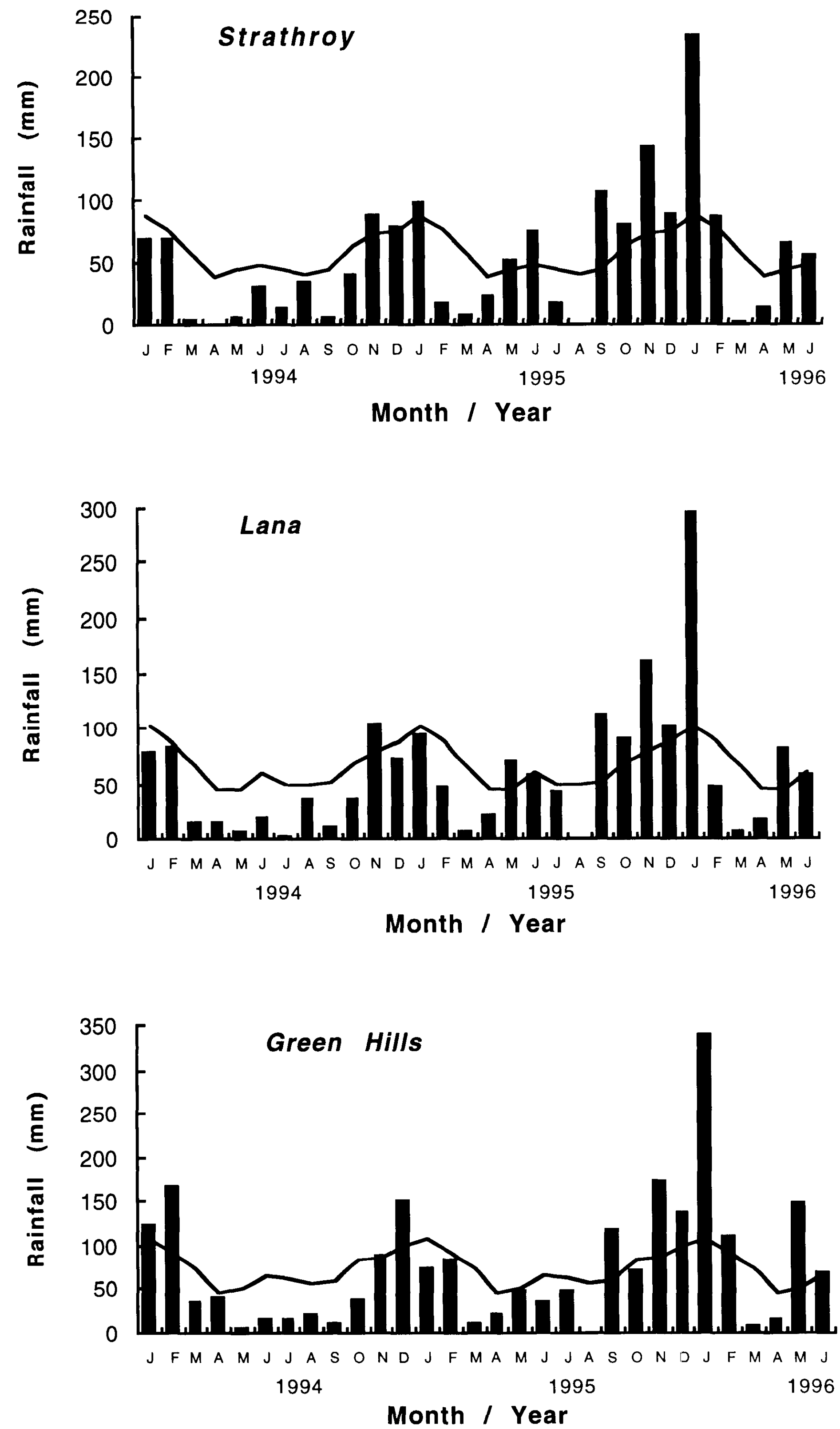

Fig. 3.5 Total monthly rainfall recorded at each site (solid bars) and long term average district monthly rainfall (line).

3.2 Sampling plots

To evaluate the effects of cell grazing and continuous grazing on various aspects of the vegetation and soil characteristics, three paired replicate measurement plots were established along a stratified topographical gradient at each site. The paired plots were carefully chosen to ensure similarity in aspect, position on the contour, soil texture and chemical and botanical composition. By using adjacent paired plots which were originally within one paddock changes which occur in the treatment areas may be linked more confidently to grazing management effects than to environmental variation (Diamond 1986).

In each of these paired plots fixed point transects were established and four different non-destructive sampling methods were used to assess the changes in the vegetation. While ecosystem health is not a physical characteristic that can be easily measured, multiple criteria of vegetation assessment give an indication of the health of grazed land (NRC 1994). The persistence of perennial grasses, basal diameters of indicator species, percentage ground-cover and the components of cover, diversity of species and the contribution of these species to the biomass available for livestock consumption are all parameters which can be used to assess the condition of pastures.

The vegetation parameters measured were:-

i) Basal diameter of the four dominant perennial grasses at each site
ii) Plant basal cover
iii) Relative frequency of species recorded in the pasture
iv) Percentage contribution of species to total dry weight

The soil parameters measured were:-

i) Unsaturated hydraulic conductivity
ii) Soil strength
iii) Bulk density
iv) Gravimetric moisture content
v) Air-filled porosity

Soil characteristics were measured at the beginning of the experiment within the paired measurement plots. Initially the intention was to collect these data annually however, the excessively wet conditions during the summer of 1995 precluded the collection of soil measurements at that time.

Soil cores were also collected from within the experimental areas to determine the initial composition of the seed bank at the sites on Strathroy and Green Hills, as detailed in Chapter 4.

3.3 Experimental design and statistical analyses

The experiment took the form of a Before After Control Impact (BACI) design as described by Green (1979;1993). The environmental impact of cell grazing on several aspects of the vegetation was compared to a continuously grazed control. The "before" samples were collected prior to cell grazing being undertaken on each of the properties and the "after" samples were collected at regular intervals after cell grazing had been initiated. In this type of environmental impact study, sampling is replicated in time (Stewart-Oaten *et al.* 1986; Green 1993). Repeated measurements of representative sub-samples of larger populations within the Control and Impact treatments form the basis of the statistical analysis of changes in the vegetation over time.

All statistical analyses were performed using programs within SAS (1990) unless otherwise stated. The models used for each analyses are described in detail in the relevant sections of subsequent chapters. Reference to significant difference throughout this thesis implies significance at the 5% probability level or better.

3.4 Botanical nomenclature

Botanical nomenclature follows Harden (1991; 1992; 1993; 1994).

3.5 Terminology

The following terms have been used with the meanings listed below.

Sites: the paired paddocks within which the monitored plots were located.

Plots: the areas within paddocks from which data were collected.

Treatments: the three treatments were continuous grazing (control), high intensity cell grazing and cell grazing. The high intensity cell grazed treatment was imposed only at the Strathroy site.

Chapter 4

The soil seed bank

4.1 Introduction

The population of viable seeds in the soil seed bank represents a history of the past and present vegetation (Templeton and Levin 1979) and gives an indication of potential recovery or regenerative capacity following large-scale disturbance such as fire or overgrazing, or periods of stress such as drought (Coffin and Lauenroth 1989). The soil seed bank also provides the source for the episodic turnover of plant species in response to environmental fluctuations and is an integral component of vegetation dynamics (Roberts 1981).

The vegetation at a given site reflects ongoing adjustments to the combinations of stress and disturbance experienced (Grime 1977). The vegetation present, the composition of the seed bank and the possible importation of new seed all contribute to the structure of the future vegetation in response to environmental influences. Seasonal climatic influences such as drought, timing and level of disturbance, soil surface conditions and the presence of safe sites, affect the germination and establishment of seedlings (Harper *et al.* 1965).

The majority of research on seed banks of grazed pastures and grasslands has originated from the United Kingdom and the United States. McIvor (1987) and McIvor and Gardener (1991; 1994) undertook a comprehensive analysis of grassland seed banks in north-eastern Queensland. Otherwise, there is very little data available on seed banks in grassland communities in the high rainfall zone of eastern Australia.

In grazed pastures the most important aspects of soil seed bank dynamics are (i) the composition (ii) the relative density of viable seed (iii) the longevity of seed and (iv) the germination requirements of the species present. The aims of this study were to

(a) determine and characterise the abundance and relative contribution of species to the readily germinable soil seed bank of two grazed pasture sites

(b) determine the relationship between the composition of the seed bank and the extant vegetation

(c) assess the potential for change in botanical composition at each site.

4.2 Methods

4.2.1 *Extant vegetation*

The initial determination of the existing vegetation was made within six weeks of collection of soil samples for the seed bank evaluation, and again 14 months later. The plant basal cover was determined using 64 x 1 m^2 point quadrat measurements at the Strathroy site and 32 at the Green Hills site. The quadrat had 100 points placed 10 cm apart in a square grid design. Species composition was determined using the relative frequency of all species present in 240 quadrats (40 x 40 cm) at the Strathroy site and 120 at the Green Hills site. Total herbage yield and species contribution to dry weight were determined using the dry-weight-rank (Botanal) technique (Haydock and Shaw 1975).

4.2.2 *Soil sampling*

Areas for collection of the soil cores were selected from within plots established to monitor changes in the vegetation, adjacent to permanently marked transects. On 7 August 1994 at the Strathroy site and on 21 August 1994 at the Green Hills site, four replicate samples of 10 soil cores (4 x 4 x 5 cm) were collected at random from each plot. At the time of sampling each core was sectioned to provide a sample from the top 2.5 cm and a sample from 2.5 - 5 cm depth. The 10 cores from each level were bulked giving a soil volume of 400 cm^3 per sample. Each of the samples represented a soil surface area of 160 cm^2. The sampling time (late winter) was chosen to ensure that most species at each site had set seed which had subsequently experienced a degree of cold chilling. Following collection the bulked samples were thoroughly mixed, air dried for two weeks, then sieved through a 5 mm screen to remove excess organic material.

4.2.3 *Seed germination*

Each sample was evenly spread to a depth <10 mm over a 2 cm bed of pre-washed river sand in seedling trays 16 x 26 cm. To monitor the level of extraneous seed contamination, 8 control trays containing only sand were included.

The trays of soil core material were placed randomly in an unheated glasshouse to simulate natural conditions of photoperiod and temperature over the year (Plate 4.1). Commencing 5 September 1994, 19 December 1994, 3 April 1995 and 23 June 1995 the trays were maintained in a moist condition for a period of 4 weeks. The timing of each of the watering periods was selected to coincide with the seasons spring, summer, autumn and winter respectively. Each emergent seedling was counted and identified to estimate the density and composition of the germinable seed bank. Those that could not be identified at the time of removal were transplanted and grown on to flowering (Plate 4.2).

Seed from 26 grass species which occurred on the two sites was collected in the summer preceding the seed bank study, and sown in pots. The seedlings were used to assist in the identification of the grasses emerging from the soil cores.

Species within some genera, particularly *Juncus*, *Cyperus*, *Trifolium* and *Eragrostis* could not be positively distinguished at the seedling stage. The large number of seedlings of these taxa emerging from the seed bank made positive identification of each seedling impractical and they were therefore assigned to their genus only.

4.2.4 *Statistical analysis*

Analysis of variance was used to identify significant differences in the number of seedlings to emerge from soil cores collected from each plot at each site. The data were log transformed to normalise the distribution. Pearson's correlation coefficient was used to express similarity between the composition of the seed bank and the extant vegetation and the relationship between the seed bank and the composition of the dry matter available.

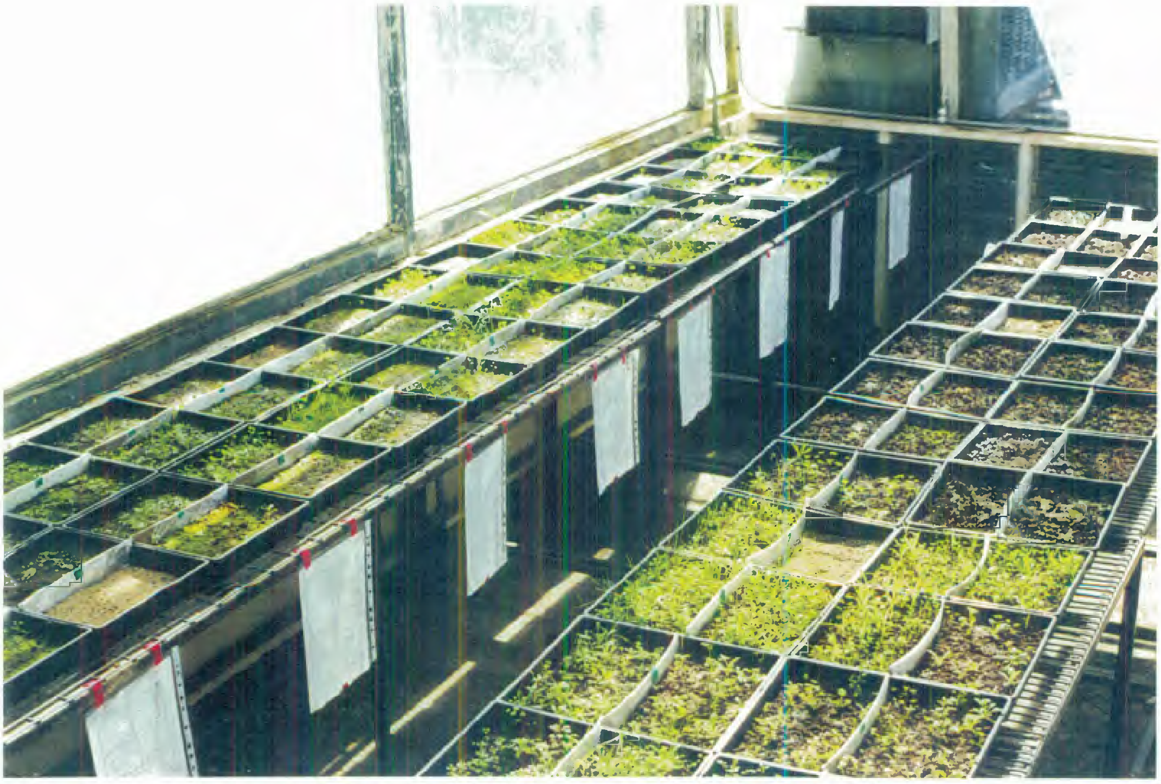

Plate 4.1 Arrangement of trays in the glasshouse.

Plate 4.2 Seedlings at the stage of growth where they were removed, identified and counted.

4.3 Results

4.3.1 *Extant vegetation*

Strathroy

At the time of collection of the soil cores the mean level of plant basal cover was 13%. The combined canopy and litter cover was 93% which meant little bare ground was evident. The species which dominated the area in terms of contribution to dry matter were the native perennial grasses *Eragrostis leptostachya*, *Eulalia aurea*, *Sporobolus creber*, *Aristida ramosa* and *Stipa scabra*. The average dry weight of the herbage on offer was 3,130 kg/ha as estimated using dry weight rank technique (BOTANAL) (Chapter 6).

Green Hills

Plant basal cover was 22% and the total ground cover 97%. The dominant components of the pasture at the time of collection of soil samples were the perennial warm season native grass *Bothriochloa macra* and the introduced species *Phalaris aquatica*. The mean dry weight of pasture was 2,742 kg/ha as estimated using dry weight rank technique (BOTANAL) (Chapter 6).

4.3.2 *Total Germination*

The total seedling emergence was 45,612 and 17,445 from the Strathroy and Green Hills sites respectively (Table 4.1). This equates to a germinable seed number of 59,360/m^2 in the seed bank from the Strathroy site and 45,430/m^2 from the Green Hills site. There were significant between-plot differences in seedling recruitment from soil cores collected at both sites, indicating a large degree of spatial variation. The number of seedlings emerging from soil cores from the Strathroy site ranged from 23,750/m^2 to 115,312/m^2 and for the Green Hills site the numbers varied from 25,938/m^2 to 80,563/m^2.

For both sites the majority of seedlings (77.8% for Strathroy and 80.3% for Green Hills) emerged from the top 2.5 cm layer of soil (Table 4.1). The 2.5 - 5 cm depth level of soil from the Strathroy site was dominated by *Juncus* and *Trifolium* species. For the Green Hills site no one species dominated the lower 2.5 - 5 cm level of soil, probably due to the self-mulching nature of the soil at this site.

Table 4.1 Number and type of seedlings to emerge from the soil seed bank at each site.

	STRATHROY	GREEN HILLS
Total surface area sampled (cm^2)	7,680	3,840
Total surface area per sample (cm^2)	160	160
Volume of soil per 5 cm sample (cm^3)	800	800
Total number of seedlings emerged	45,612	17,445
Number of seedlings /m^2	59,390	45,430
sd	28,000	13,840
Mean number of seedlings per sample	950	727
sd	448	221
Seedlings emerged from 0 - 2.5 cm soil layer	77.2%	80.3%
Seedlings emerged from 2.5 - 5 cm soil layer	22.8%	19.7%
Perennial grasses /m^2	15,620	7,089
Annual grasses /m^2	1,163	7,409
Legumes /m^2	10,461	3,844
Forbs /m^2	13,178	26,227
Other monocots /m^2	18,957	862
Shrubs /m^2	3	0
Trees /m^2	9	0
No. of species recorded in seed bank	106	67
No. of species recorded in vegetation (Aug '94)	48	33
No. of species recorded in vegetation (Oct '95)	96	51

The highest proportion of seedling recruitment was observed after the first period of wetting in September 1994 (Fig. 4.1). The seasonal pattern of seedling emergence was very similar in cores collected from both sites. By the final wetting period, which was conducted during the winter months, relatively few seedlings emerged, 2% of the total for the Strathroy site and 5% for the Green Hills. It was assumed that the majority of viable seeds had germinated by this time.

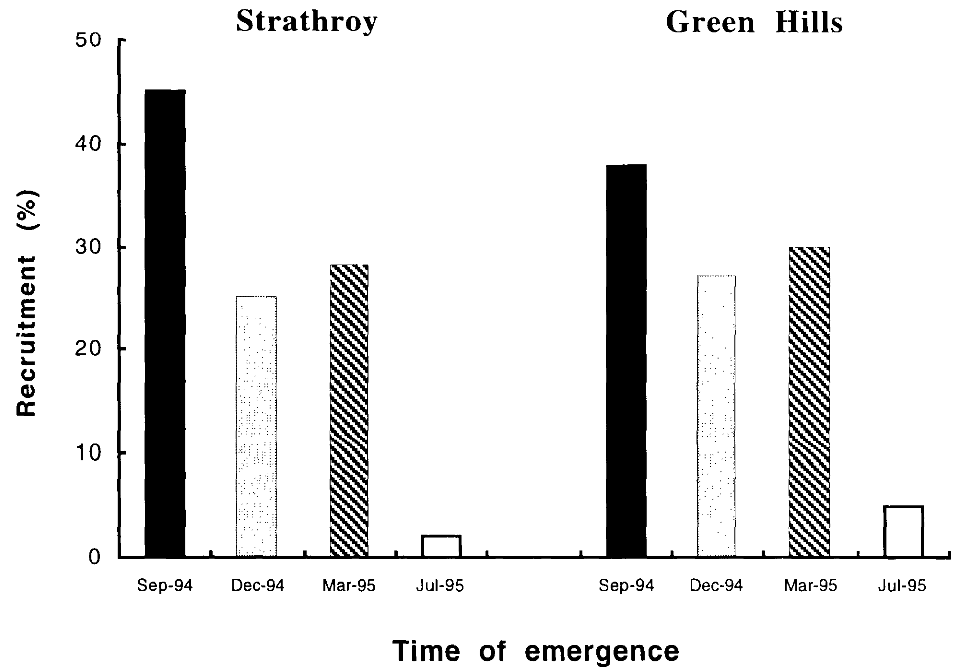

Fig. 4.1 Seedling recruitment as a percentage of the total germinable seed bank in soil cores collected from each site during each period of wetting.

The composition of the seed bank at the two sites was distinctly different in terms of plant growth forms (Table 4.1). At the Strathroy site, perennial grasses contributed 26% of the total germinable seed bank (Fig. 4.2), much greater than the proportion of annual grasses (2%). Two species, *S. creber* and *E. leptostachya* dominated the perennial grass component of the seed bank, contributing 10% and 7% of the total respectively (Table 4.2). The legume component (18%) of the seed bank at this site was dominated by naturalised annual species - *Trifolium glomeratum*, *T. campestre*, *T. dubium* and *T. cernuum.* Other forbs, primarily annual and biennial species, constituted 22% of the total seedlings (Fig. 4.2). The largest contributors (32%) to the seed bank at the Strathroy site were sedges and rushes, the majority of which were from the genus *Juncus* (Fig. 4.2).

Perennial grasses comprised 16% of the total seedling recruitment from the Green Hills seed bank, equivalent to the proportion of annual grasses (Fig. 4.3). Seedlings of *Juncus* were a minor component at this site. The germinable seed bank at the Green Hills site was strongly dominated by annual forbs (Fig. 4.3) which contributed 58% of the total number of seedlings. The same species of annual legumes as recorded at Strathroy, with the exception of *T. cernuum*, dominated the legume component at Green Hills. The introduced species *Trifolium repens* contributed only 2% of the total legumes to emerge.

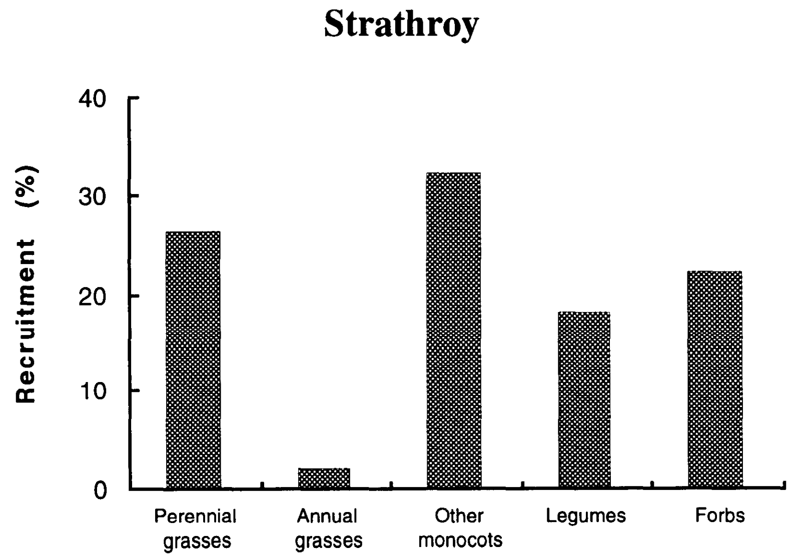

Fig. 4.2 Percentage contribution of each plant type to the total germinable seed bank at the Strathroy site.

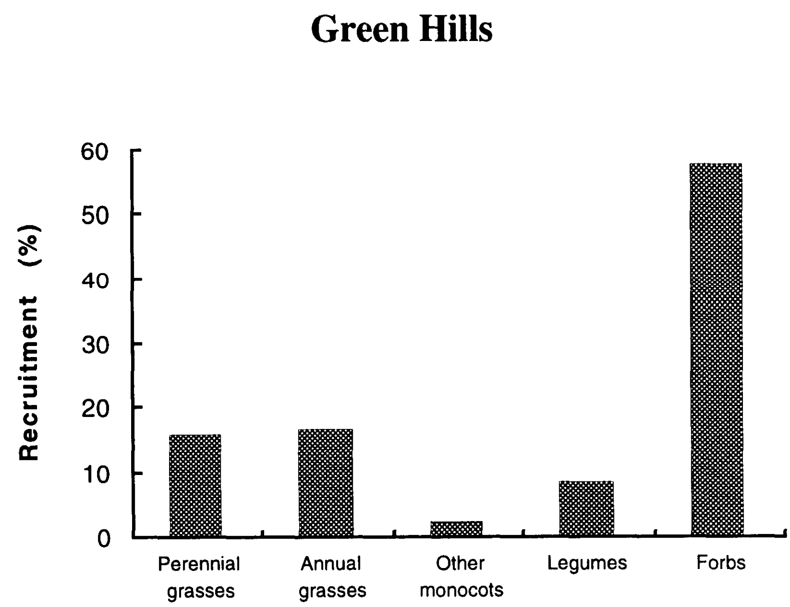

Fig. 4.3 Percentage contribution of each plant type to the total germinable seed bank at the Green Hills site.

While the species richness at the Strathroy site was relatively high, with 106 species recorded (Table 4.1), relatively few species contributed to the major portion of the seed bank. Those species listed within Table 4.2 constituted 83% of the total recruitment from soil cores collected from this site. Table 4.3 lists the species which make the major contribution to the seed bank at the Green Hills site. These species represented 75% of the total emerged seedlings.

Table 4.2 The most abundant taxa to recruit from the seed bank at the Strathroy site.

Species	Percentage of total seed bank	Seedlings /m^2
Juncus spp.	30.7	18245
Trifolium spp.	15.6	10031
Sporobolus creber	9.7	5796
Eragrostis leptostachya	6.8	4073
Chenopodium pumilio	6.7	3983
Verbascum thapsus	3.4	2010
Crassula spp.	3.2	1872
Other *Eragrostis* spp.	3.1	1852
Eleusine tristachya	2.8	1655
Portulaca oleracea	2.1	1257

Table 4.3 The most abundant taxa to recruit from the seed bank at the Green Hills site.

Species	Percentage of total seed bank	Seedlings /m^2
Paronychia brasiliana	17.3	7862
Crassula seiberiana	11.0	4977
Gnaphalium spp.	8.9	4055
Chenopodium pumilio	8.0	3632
Trifolium spp.	7.3	3336
Digitaria sanguinalis	7.2	3258
Vulpia myuros	6.4	2921
Poa pratensis	4.7	2138
Eragrostis spp.	2.9	1333
Eleusine tristachya	2.7	1224

Perennial grasses were well represented in the seed bank from the Strathroy site (Table 4.4). The dominant grasses to recruit were *S. creber, E. leptostachya,* other *Eragrostis* spp. and *E. tristachya*. With the possible exceptions of *Paspalum dilatatum* and *Tragus australianus,* all other perennial grasses were present in sufficient numbers for regeneration purposes given favourable conditions for germination and establishment.

Table 4.4 Recruitment of annual and perennial grass seedlings from soil cores collected from the Strathroy site.

ANNUALS	Seedlings/m^2	PERENNIALS	Seedlings/m^2
Bromus racemosus	366	*Sporobolus creber*	5796
Aira cupaniana	247	*Eragrostis leptostachya*	4072
Vulpia myuros	225	Other *Eragrostis* spp.	1852
Briza minor	153	*Eleusine tristachya*	1665
Lolium rigidum	151	*Stipa scabra*	445
Setaria pumila	7	*Digitaria brownii*	368
Hordeum leporinum	3	*Panicum effusum*	354
		Aristida ramosa	328
		Chloris truncata	287
		Microlaena stipoides	169
		Eulalia aurea	111
		Danthonia spp.	90
		Bothriochloa macra	77
		Tragus australianus	13
		Paspalum dilatatum	1

In contrast to the Strathroy site, the annual species *Digitaria sanguinalis* and *Vulpia bromoides* were the main grasses to recruit from the seed bank from the Green Hills site (Table 4.5). The total number of perennial and annual grasses to emerge from the soil cores were similar at this site. Again, the representation of the perennial grasses would suggest sufficient numbers of germinable seed were present at the time of collection of the soil cores to enable satisfactory regeneration given favourable conditions.

A total of 23 seedlings emerged from the control trays over the period of the experiment. This number was considered inconsequential with respect to the total number of seedlings to recruit from the soil cores so no adjustment to final emergence numbers was made.

Table 4.5 Recruitment of annual and perennial grass seedlings from soil cores collected from the Green Hills site.

ANNUALS	Seedlings/m^2	PERENNIALS	Seedlings/m^2
Digitaria sanguinalis	3258	*Poa pratensis*	2138
Vulpia bromoides	2921	*Eleusine tristachya*	1224
Bromus spp.	461	*Eragrostis* 'red'	976
Eragrostis pilosa	364	*Sporobolus creber*	820
Eragrostis trachycarpa	357	*Panicum effusum*	445
Digitaria ternata	268	*Bothriochloa macra*	414
Panicum gilvum	133	*Chloris truncata*	349
Poa annua	10	*Poa sieberiana*	128
		Sorghum leiocladum	125
		Danthonia spp.	76
		Phalaris aquatica	23
		Elymus scaber	18

4.3.3 *Relationship between the seed bank composition and the extant vegetation*

The composition of the seed bank and the extant vegetation at the time of collection of the soil cores was more closely correlated at the Strathroy site than at Green Hills, although neither exhibited a strong relationship. The correlation between the frequency of species present in the seed bank and the vegetation was 0.45 for Strathroy and 0.31 for Green Hills (Table 4.6). The relationship between the composition of the seed bank and the available dry matter was weaker, 0.26 and 0.11 for the Strathroy and Green Hills sites respectively.

Three perennial grass species recorded in the extant vegetation at the Strathroy site were not recorded in the seed bank - *Elymus scaber*, *Echinopogon ovatus* and *Cynodon dactylon*. Conversely, the annual grasses *Briza minor* and *Aira cupaniana* were well represented in the seed bank but were not present in the extant vegetation. *Tragus australianus* was the only perennial grass recorded in the seed bank which was not present in the vegetation at the experimental site, although a few plants were observed elsewhere within the paddock.

At the Green Hills site all perennial grasses in the initial vegetation survey were recorded in the seed bank. *Vulpia myuros* and *Bromus racemosus* were the only annual grasses present in the vegetation at the time the soil cores were collected. The most abundant annual grass to recruit from the seed bank was *Digitaria sanguinalis* (Table 4.5). This summer active species was absent from the extant vegetation in late winter 1994.

Table 4.6 Pearson's correlation coefficient for the relationship between the composition of the seed bank and the extant vegetation at the Strathroy and Green Hills sites at the time of collection of soil cores (August 1994).

	Correlation coefficient			
	Grasses	Forbs	Legumes	Total
Strathroy				
Frequency of species in the extant vegetation *vs* frequency in seed bank trays	0.41	0.34	0.51	0.45
Species contribution to pasture dry weight *vs* frequency in seed bank trays	0.28	0.27	0.25	0.26
Green Hills				
Frequency of species in the extant vegetation *vs* frequency in seed bank trays	0.29	0.31	0.40	0.31
Species contribution to pasture dry weight *vs* frequency in seed bank trays	0.12	0	0	0.11

Table 4.7 Pearson's correlation coefficient for the relationship between the composition of the seed bank and the vegetation at the Strathroy and Green Hills sites fourteen months after collection of soil cores (October 1995).

	Correlation coefficient			
	Grasses	Forbs	Legumes	Total
Strathroy				
Frequency of species in the extant vegetation *vs* frequency in seed bank trays	0.37	0.61	0.62	0.53
Species contribution to pasture dry weight *vs* frequency in seed bank trays	0.03	0.36	0.52	0.22
Green Hills				
Frequency of species in the extant vegetation *vs* frequency in seed bank trays	0.27	0.51	0.52	0.41
Species contribution to pasture dry weight *vs* frequency in seed bank trays	0.12	0.09	0.11	0.12

The relationship between the recruitment from the seed bank and the vegetation 14 months after the collection of soil cores was generally stronger, although it remained statistically non significant (Table 4.7). The improved seasonal conditions prior to the second vegetation sampling resulted in the emergence of a large number of annuals and an increase in species richness. There was a marked improvement in the correlation between the composition of the seed bank and the forbs and legumes present at both sites (Table 4.7). In contrast, both the proportion of grasses in the vegetation and their relative contribution to dry weight exhibited a reduced correlation with the composition of the seed bank at the Strathroy site at the second time of sampling.

4.4 Discussion

Germinable seed bank

The various methods of sampling and the number of samples required to obtain a true representation of the seed bank have been the subject of a large proportion of the seed bank literature (e.g. Roberts 1981; Gross 1990; de Villiers *et al.* 1994). While each method has limitations it is widely accepted that the emergence method is the most reliable in terms of identifying the readily germinable seed bank.

The density of the germinable seed bank at both sites in the study reported here far exceeded most previously reported values for Australian (McIvor and Gardener 1994), South African (de Villiers *et al.* 1994), British (Thompson and Grime 1979; Rice 1989) and North American (Coffin and Lauenroth 1989; Kinucan and Smeins 1992) grasslands. This may have been due to the timing of collection which was after seed fall. Collection of soil cores after the natural winter chilling period and followed by a period of drying is also regarded as beneficial for breaking dormancy and thus promoting germination (Feast and Roberts 1973).

Typically, grasslands dominated by perennial species possess small seed banks and perennial grasses are poorly represented (Major and Pyott 1966; McIvor and Gardener 1994). Both grazed pasture sites described here had relatively large seed banks (Table 4.1). Perennial grasses comprised 26% and 16% of the total germinable seed bank at the Strathroy and Green Hills sites, respectively. Although small-seeded species constituted a large proportion of the perennial grass component at both sites it was significant that with few exceptions, all perennial grasses recorded in the vegetation were detected in the seed bank.

The difference between the two sites in the proportion of perennial grasses in the seed bank may be explained by their respective land-use histories. The site at Strathroy had never been subjected to any form of broadacre soil disturbance, whereas prior to 1965 the Green Hills site had been cultivated for the purpose of pasture replacement on a number of occasions. Although the long term effects of cultivation on seed bank composition are unclear, in the short term frequent cultivation results in the dominance of the seed bank by annual species (Roberts and Feast 1972; Dessaint *et al.* 1991). Unless the seeding of annual species is prevented it is reasonable to expect that their dominance of the seed bank would continue.

The predominant species occurring in the seed bank contributed 83% and 75% of the total seedling recruitment from soil cores collected at the Strathroy and Green Hills sites, respectively. The dominance of a relatively small number of species in the seed bank is not uncommon. Similar results have been reported by Parker and Leck (1985) and Poiani and Johnson (1988).

A large degree of spatial variation in the number of seedlings to emerge was evident both within and between the plots sampled at each site. The most probable reason for these differences may be the clumping nature of many seeds during dispersal (Thompson 1986). Those plots where small seeded species (e.g. *Juncus* spp.) were abundant recorded the highest seed bank numbers. Similar results have been reported by Thompson and Grime (1979) and Gross (1990). Coffin and Lauenroth (1989) suggested that temporal variation had a greater influence on seed bank dynamics than spatial variability. The seasonal variation documented by a number of authors (Schneider and Sharitz 1986; Coffin and Lauenroth 1989; Jimenez and Armesto 1992; McIvor and Gardener 1994) is an indication of the transient nature of grassland seed banks and is as much a function of the species present in the vegetation as of environmental influences (Thompson and Grime 1979). An analysis of temporal variation in the seed bank was beyond the scope of this study although the importance of the seasonal variation in seed bank numbers in the functional ecology of grasslands is acknowledged.

The seasonal pattern of seedling recruitment was similar from the soil cores collected at both sites, the majority of seedlings emerging during the initial spring watering (Fig. 4.1). Under natural conditions the time of emergence of native grass seedlings is highly variable and closely related to the availability of soil moisture (Harradine and Whalley 1980). Maze *et al.* (1993) found that native species have a higher water potential requirement for germination than introduced species. The lower proportion of seedlings emerging during the autumn wetting period was probably related to the depletion of numbers of germinable seeds by that time.

Perennial grasses were well represented in the seed bank from the Strathroy site (Table 4.4). The dominant species *S. creber, E. leptostachya,* other *Eragrostis* spp. and *E. tristachya* are all small-seeded species and have high seed production. All are considered to be good colonising species but only *E. leptostachya* is regarded as a highly desirable pasture species for animal production. Other species considered highly desirable such as *Microlaena stipoides* and *Danthonia* spp. occurred in relatively lower numbers in the seed bank (Table 4.4).

The annual species *D. sanguinalis* and *V. bromoides* were the main grasses to recruit from the seed bank from the Green Hills site (Table 4.5). These annuals and the short lived perennials *P. pratensis* and *E. tristachya* are effective colonising species. While *P. pratensis* is a desirable species in terms of its nutritional value it contributed little to the dry matter on offer at this site. The more desirable species in terms of dry matter production, *P. aquatica* and *E. scaber* were poorly represented relative to other species (Table 4.5).

While collectively grasses comprised similar percentages of the seed banks at both sites, perennial species were more prevalent at the Strathroy site. Differences in the recruitment of perennial species common to both sites appeared to be related to differences in their relative abundance in the extant vegetation (see Chapter 6).

Relationship between the seed bank composition and the extant vegetation

For both sites, the number of species recorded in the seed bank was approximately double that present in the vegetation at the time the soil samples were collected. The poor correlation between the composition of the seed bank and the extant vegetation (Table 4.6) was due to the presence of a large number of seeds of forb species in the soil, which were absent from the extant vegetation. Furthermore, many of the forbs which occurred with high frequency and contributed to a large proportion of the total seed bank, contributed very little to pasture biomass, hence the low correlation between the seed bank and pasture dry weight at the time of sampling (Table 4.6).

The correlation between the composition of the seed bank and the extant vegetation at both the Strathroy and Green Hills sites was comparable to other reported correlation values for grasslands (Coffin and Lauenroth 1989; Kinucan and Smeins 1992). Typically, the dominant seed bank species have very small seeds, many of which are annual and remain viable in the soil for long periods of time (Harper 1977).

The correlation between the seed bank and the extant vegetation strengthened at both sites following an improvement in seasonal conditions in spring 1995, after almost two years of below-average rainfall. Annual species, particularly forbs, responded quickly at the expense of the perennial grasses, and these changes were reflected in the correlations between the seed bank composition and the vegetation (Table 4.7).

Potential for change in botanical composition

The regenerative capacity of a site and the relative success of each species is dependent on a complex of interactions: the quality and quantity of the previous years seed production, the transience of the existing seed bank, the timing and severity of disturbances such as grazing, seed predation and the presence or absence of specific requirements for germination and establishment (Bertiller 1992). The conditions following germination will strongly influence the composition of grasslands in the subsequent growth season, and hence the structure and composition of vegetation in subsequent years. In order to maintain the stability of grasslands a diversity of age classes within a population is equally as important as species diversity.

The occurrence of 80% of the germinable seed bank at both sites within the top 2.5 cm of soil has important implications for the management of these grasslands. The majority of seedlings which emerge from this depth are from very small seeds. As a general rule these small-seeded species have a high light requirement to stimulate germination and are long lived in the soil (Thompson and Grime 1979).

Three mechanisms may interact to affect the germination of forbs from below a layer of litter on the surface of the soil (Bosy and Reader 1995). Litter may alter the light, temperature and moisture conditions, eliminating the environmental cues which may stimulate germination. It may also act as a mechanical barrier to the emergence of seedlings, or chemicals leaching from the litter may inhibit germination. Any of these factors alone or in combination may adversely influence the germination of forb species although the effects are species dependent (Bosy and Reader 1995).

Gross (1984) reported that the emergence of small seeded annual forbs was reduced significantly under litter, while their relative growth rate was double that of grasses (which have relatively larger seeds) when emerging from bare soil. In contrast, the growth of grass seedlings was enhanced when emerging from beneath a layer of litter in comparison with emergence from bare soil (Gross 1984).

The amount and type of groundcover will therefore have an important influence on the dynamics of the vegetation at both sites studied, high levels of groundcover favouring perennial grasses and low levels of groundcover favouring annual grasses, rushes, sedges and forbs.

The high densities of *Juncus* seedlings which emerged from soil cores collected at the Strathroy site and the high proportion of annual forbs in the seed bank at the Green Hills site indicated that the stability of these grasslands could be jeopardised if inappropriate management practices were implemented. Any practice which reduced the vigour of perennial grasses or reduced the litter layer covering these soils could threaten the stability of these grasslands. Although annual species provide floral diversity, if one or more became dominant contributors to the vegetative biomass of a site in the long term, the environment would become increasingly fragile. Competition from annual species is one of the main factors limiting the establishment of perennial grasses (Harradine and Whalley 1980) which are relatively slower to establish than annuals (Grime 1977).

The composition of the seed bank at both sites indicated that there would be little scope for changing the suite of perennial grasses present in these grasslands. No perennial grasses other than those in the vegetation were found in the seed bank, and those in the vegetation were present in sufficient numbers for regeneration purposes. The greatest potential for change in the perennial grass component would be in the use of grazing management to achieve a more even spatial distribution of species and a greater relative contribution to pasture biomass.

The presence of a viable soil bank of perennial grass seed is important both for regeneration and for providing a diversity of age classes within grasslands (Schneider and Sharitz 1986). However, given the relatively short period that most perennial grass seeds remain viable in soils, the maintenance of plant vigour and vegetative regeneration through the production of new tillers is also extremely important (McIvor and Gardener 1994).

Although the conditions required for grass seed germination occur relatively frequently on the Northern Tablelands, the specific conditions necessary for establishment of perennial grass seedlings are far more sporadic and largely unknown. The environment is highly variable and periods of drought are common. The vegetative persistence of perennial grasses is therefore critical for the integrity of grasslands, providing groundcover and soil stability in below-average rainfall years.

The potential for change in the botanical composition of the two sites reported here will be dependent on the extent of any future disturbance to the vegetation particularly by grazing, in combination with environmental variation. The frequency and intensity of defoliation affects both the level and type of groundcover (Earl and Jones 1996), the growth and seed production of the extant vegetation (Roberts 1965; Hare and Archie 1990), root biomass (Earl 1997) and the competitive relationships between species within the grassland community (Caldwell and Richards 1986). These factors all impact on the quantity and quality of seed incorporated into the soil seed bank and the subsequent opportunities for the expression of the seed bank through germination and establishment.