Chapter 7

Soil characteristics

7.1 Introduction

The soil resource is the foundation for grassland productivity. The influence of herbivores on the plant-soil interaction is perhaps the most important feedback loop which operates in grassland ecosystems (Huntly 1995). Enterprise profitability is directly dependent on soil health, structural stability and the vegetation it supports (Taylor 1989). Ecosystem health is also largely governed by the effective cycling of nutrients within the soil, a process which is dependent on adequate soil structure and aeration (Holt *et al.* 1996; Johnson and Wedin 1997).

The grazing process affects soil conditions indirectly by removal of protective plant cover and directly through hoof pressure on the soil surface (Thurow 1991; Greene *et al.* 1994). The detrimental effects of livestock on compaction and soil structure are well documented. Static pressures of 192 to 400 kPa have been recorded under cattle and 80 kPa from sheep (Kellett 1978; Willatt and Pullar 1983). The pressure applied may increase up to four times as the animal's weight distribution changes with movement (van Haveren 1983). The extent of animal impact is influenced by soil type, soil structure and soil moisture status at the time of grazing, with the probability of damage increasing as soil moisture content increases (Gifford *et al.* 1977; Climo and Richardson 1984). Trampling of the soil surface may result in compaction and/or remoulding of soil aggregates; both processes adversely affect soil structure (Proffitt *et al.* 1995).

Grazing may also have a positive effect on soil processes, accelerating plant-soil interactions at all levels (McNaughton 1986; McNaughton *et al.* 1989). Of the plant material consumed by livestock, 60 - 95% of the nutrients are returned to the soil as either faeces or urine (Williams and Haynes 1992). Livestock may, through the action of trampling standing material into the ground, increase the accessibility of organic matter to soil invertebrates and microbes, and enhance the rate of nutrient and carbon cycling (Naeth *et al.* 1991a). Furthermore, the grazing of plant tops increases the turnover of root material and accelerates the leakage of labile organic constituents into the soil (Richter *et al.* 1990; Singh *et al.* 1991).

Soil physical parameters such as unsaturated hydraulic conductivity, soil strength, bulk density and total porosity have been shown to be effective indicators of hydrologic condition and ecosystem health (Thurow *et al.* 1986). These parameters were monitored to compare the effects of high densities of grazing livestock for short periods of time as occurs under cell grazing, with the effects of long-term low density grazing as occurs under continuous grazing. Soil chemical composition at the beginning and end of the experimental period was also recorded.

7.2 Methods

7.2.1 *Experimental sites*

At the Strathroy and Green Hills sites three permanent 25 m transects were established within each of the two grazing treatments. The transects were located adjacent to the vegetation monitoring sites. All soil physical measurements were collected along these transects. The location of the paired transects was chosen on the basis of position on the contour. The transect was selected as the experimental unit beacause of the variation in slope at both of these sites. In addition, with the differences in animal distribution experienced under cell grazing and continuous grazing regimes the transect was regarded as the most appropriate experimental unit to detect any changes which occurred in soil properties. Figures 3.1 and 3.3 illustrate the approximate location of the transects at the Strathroy and Green Hills sites, respectively.

Monitoring of soil physical characteristics at two separate sites at Lana was initiated as part of a Landcare project in 1993. A 50 m x 50 m area had been permanently marked in each of the two grazing treatments at each site for this purpose. Botanical composition and soil chemical data were subsequently collected at Site 1 as part of the experimental project detailed in this thesis, whereas only the monitoring of soil physical parameters was continued at Site 2.

Measurements from Strathroy, Green Hills and Lana were taken during December 1994 and December 1996.

7.2.2 *Unsaturated hydraulic conductivity*

Estimates of unsaturated hydraulic conductivity were made using a disc permeameter (Plate 7.1) (Perroux and White 1988). For each measurement a 150 mm area was clipped to ground level to clear the vegetation and the disc permeameters mounted on a 5 mm deep bed of fine river sand to ensure uniform contact with the base of the disc.

On each transect at the Strathroy and Green Hills sites, three replicates of paired measurements of unsaturated hydraulic conductivity were taken. At the Lana sites six replicates of paired measurements were taken from within the permanently marked areas. The paired disc permeameters were placed within 300 mm of each other, and mean values of the paired measurements were used for analyses.

Unsaturated hydraulic conductivity was calculated at tensions of 40, 30, 20 and 10 mm after allowing approximately 30 minutes to achieve a steady state flow at 40 mm tension. These tensions equate to pore sizes of approximately 0.75, 1, 1.5 and 3 mm diameter respectively (Craze and Hamilton 1991).

At all times measurements were taken in order from the highest to the lowest tension to avoid hysteresis. Equations derived from the method of Ankeny *et al.* (1991) were used to calculate unsaturated hydraulic conductivity.

The equations used were:-

$$K_{(\psi_i)} = \frac{Q(\psi_i)}{\pi r^2 + (4r / A_i)}$$

$$A_i = \frac{2\ [Q(\psi_i) - Q(\psi_j)]}{\Delta\psi [Q(\psi_i) - Q(\psi_j)]}$$

Where $K_{(\psi_i)}$ = unsaturated hydraulic conductivity at tension *i*

$Q(\psi_i)$ = steady state flow at tension *i*

A = Ankeny's A for tension *i*

r = 100 mm (radius of the disc)

$\Delta\psi$ = -10 mm

Plate 7.1 The disc permeameters used to determine unsaturated hydraulic conductivity of soils under four tensions.

7.2.3 *Soil strength and moisture content*

The penetration resistance of the soil was measured at 15 mm intervals to 300 mm depth using a Rimik CP20 cone penetrometer, 12.8 mm diameter with a 30° angle cone. Along each transect at the Strathroy and Green Hills sites, 36 penetrations were recorded, and at the Lana sites a total of 36 were taken within each grazing treatment at each site. Six recordings were taken from points approximately 300 mm away from each disc permeameter measurement to avoid the influence of associated moisture.

Soil strength may be influenced by soil moisture. At the time of collection of the soil strength data, soil cores (40 mm diameter) were collected to a depth of 300 mm for determination of gravimetric moisture content. The soil cores were divided into 50 mm sections and dried at 100°C for 48 hours to evaluate soil moisture variation with depth.

7.2.4 *Bulk density and total porosity*

Bulk density (ρ_b) was estimated using thin-walled cores (Blake and Hartge 1986) to 40 mm depth and 70 mm diameter. Three replicate measures of bulk density were taken from each transect at Strathroy and Green Hills and six replicates were taken from each 50 x 50 m marked area at Lana. Cores were oven dried at 100°C for 48 hours

Total porosity (P) was calculated from $P = (1 - \rho_b / \rho_s) \times 100$
where ρ_s (particle density of soil) was assumed to be 2.65 g/cm^3.

7.2.5 *Soil chemical analyses*

Soil chemical composition was determined through analyses undertaken by Incitec Analysis Systems. At each site 25 soil cores to 150 mm depth were collected from within each grazing treatment. Cores were collected on 11 June 1994 and 21 June 1996 from Strathroy, 28 August 1994 and 10 September 1996 from Green Hills and 16 December 1994 and 28 November 1996 from the Lana site.

Analyses undertaken and methods used were:-

Organic carbon %	Walkley and Black
pH	1:5 water and 1:5 $CaCl_2$
Nitrate N (mg/kg)	1:5 water analysed in segmented flow analyser
Sulfate S (mg/kg)	KCl-40
Phosphorus (mg/kg)	Bray
Ca, Mg, K and Na (meq/100g)	1:100 0.0125 M $BaCl_2$
Al (meq/100g)	1:10 1M KCl
Electrical conductivity (dS/m)	1:5 soil to water

7.2.6 *Statistical analyses*

Analysis of variance was used to test the significance of differences between unsaturated hydraulic conductivity treatment means after log transformation to normalise the data. Separate analyses were conducted for each tension and year to eliminate year by treatment interactions. Scheffe's test was used to determine minimum significant differences between individual treatment means.

Students t-test was used to compare soil strength treatment means. Data from six depth intervals; 45, 90, 135, 180, 225 and 270 mm, were used for comparison. Bulk density and gravimetric moisture content means were compared with analysis of variance, with the moisture content data from each 50 mm depth interval analysed separately. No statistical analyses were conducted on total porosity data because of the relationship between these data and bulk density. There was no replication of soil samples collected within transect locations which precluded statistical analysis of these data.

7.3 Results

7.3.1 *Unsaturated hydraulic conductivity*

At all sites the unsaturated hydraulic conductivity (infiltration rate) increased significantly between 1994 and 1996. At the Strathroy and Green Hills sites where sampling transects had been established on contour gradients, the differences recorded were greater between transects and years than between treatments. No significant differences were recorded as a result of the grazing management treatments at any soil tension at either of these sites.

Two of the six transects at the Strathroy site exhibited greater relative changes in unsaturated hydraulic conductivity over time. On transect 3 (Fig. 7.1c) unsaturated hydraulic conductivity increased to a greater extent under the high density cell grazing regime than under the regular density cell grazing. Under continuous grazing unsaturated hydraulic conductivity increased relative to the cell grazed treatment on transect 6 (Fig. 7.2c).

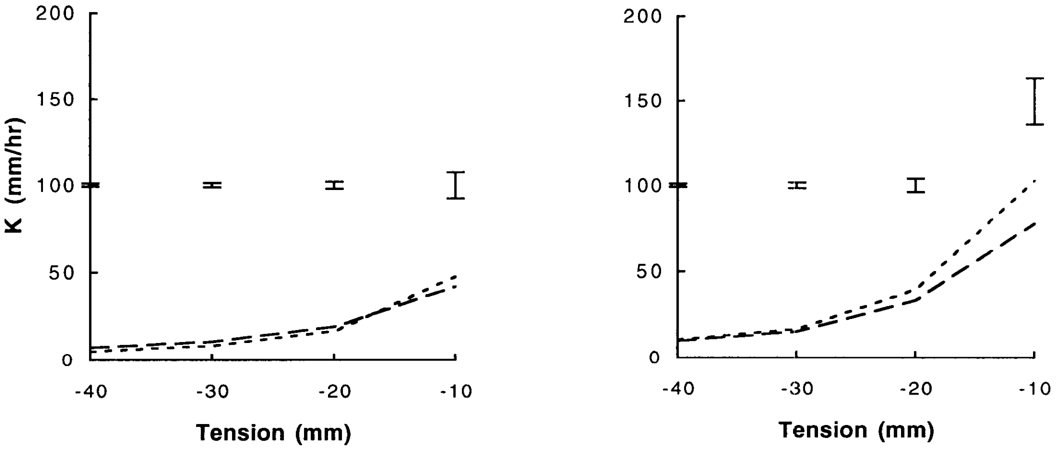
At the Green Hills site unsaturated hydraulic conductivity under cell grazing increased slightly more, relative to the continuously grazed treatment on transects 1 and 2 (Fig. 7.3a and 7.3b). Conversely, on transect 3 (Fig. 7.3c) the data from 1996 showed an equivalent level of decline in unsaturated hydraulic conductivity values under both grazing treatments in comparison to data recorded in 1994.

After 12 months of cell grazing at Site 2 at Lana, the infiltration rate at 10 and 20 mm tension was significantly higher in this treatment than in the continuously grazed area (Fig. 7.4b). At Site 1 there was relatively little difference between the grazing treatments.

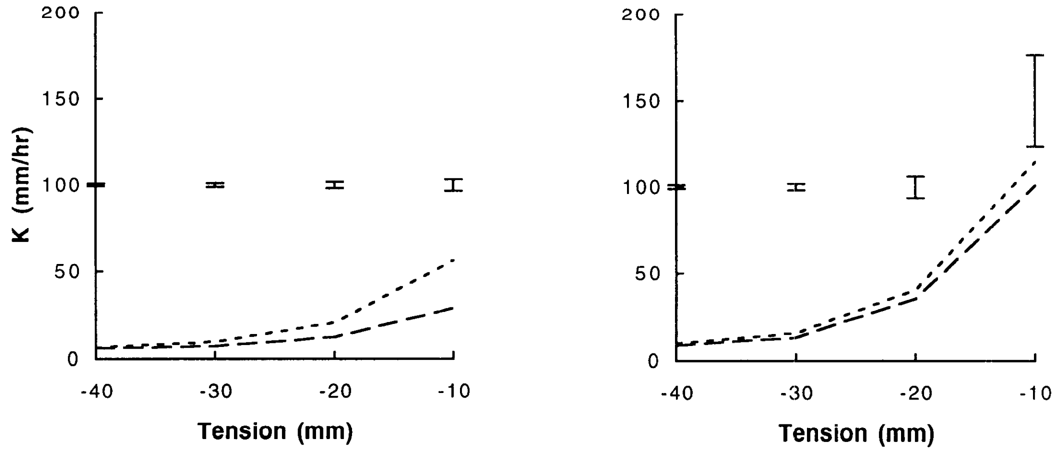
The infiltration rate at 10 mm tension was significantly higher under cell grazing than under the continuous grazing regime at both the Lana sites in 1996 (Fig. 7.4c). No significant differences between treatments were recorded at lower soil tensions.

1994 **1996**

(a) Transect 1



(b) Transect 2



(c) Transect 3

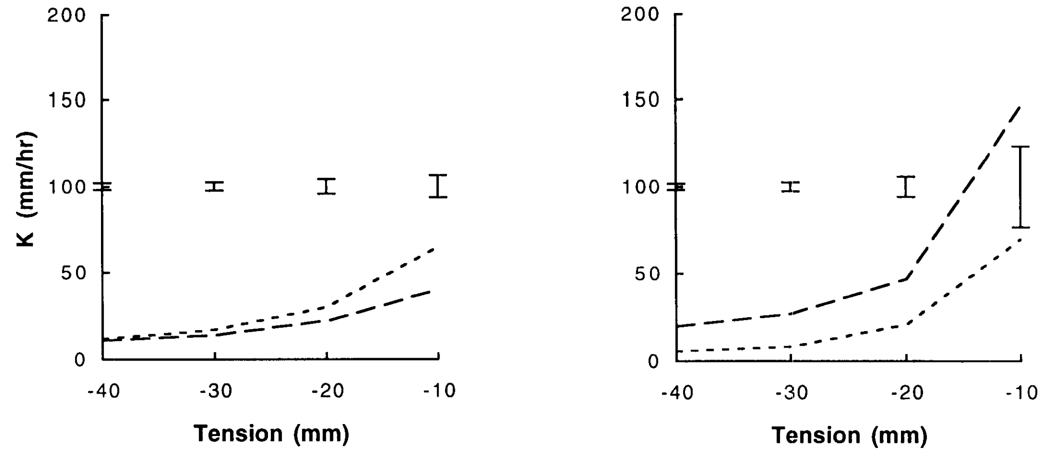
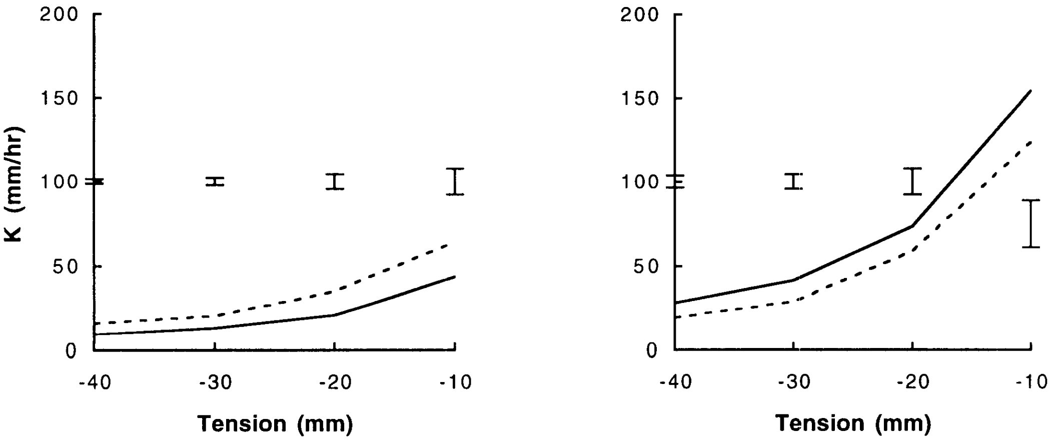


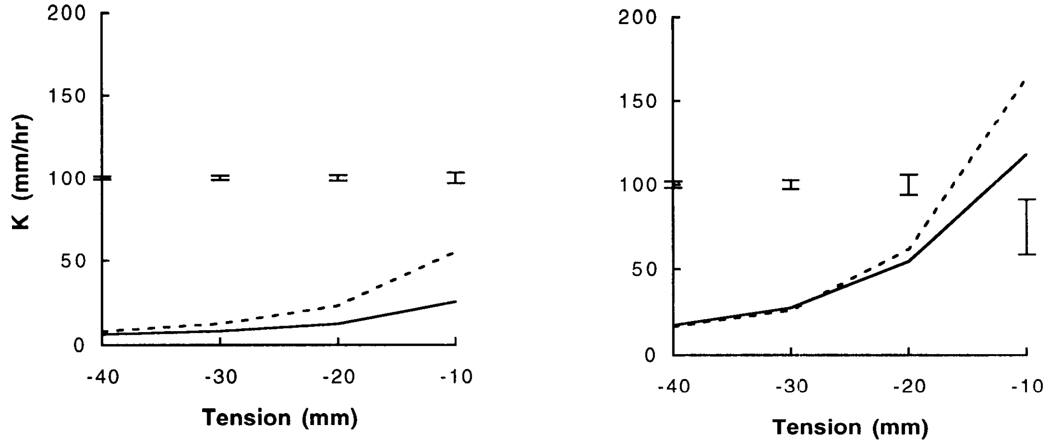
Fig. 7.1 Unsaturated hydraulic conductivity (mm/hr) at the Strathroy site under cell grazing (- - - -) and high density cell grazing (— — —) at (a) Transect 1 (b) Transect 2 and (c) Transect 3 during December 1994 (left) and 1996 (right). Error bars represent one SE.

1994 **1996**

(a) Transect 4



(b) Transect 5



(c) Transect 6

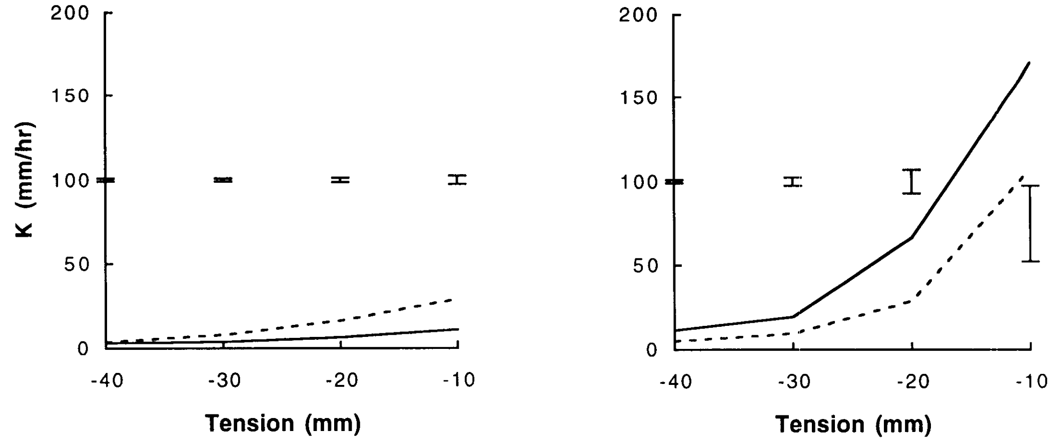
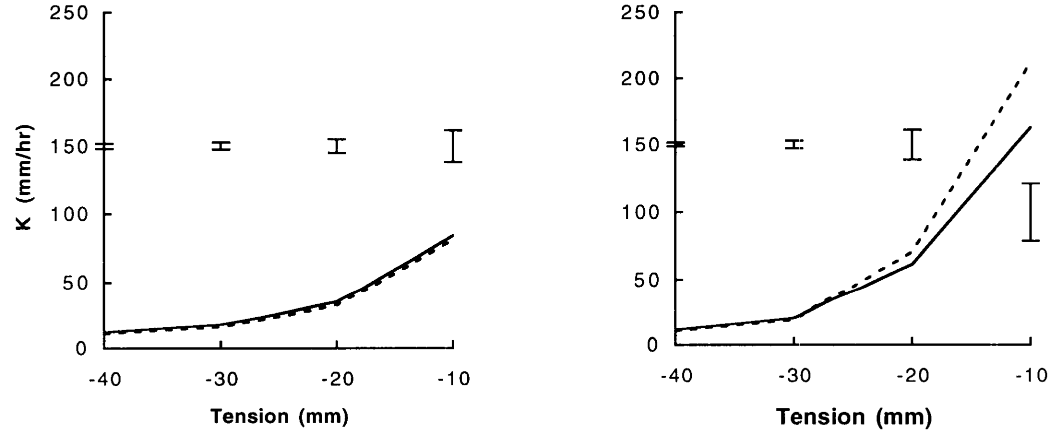


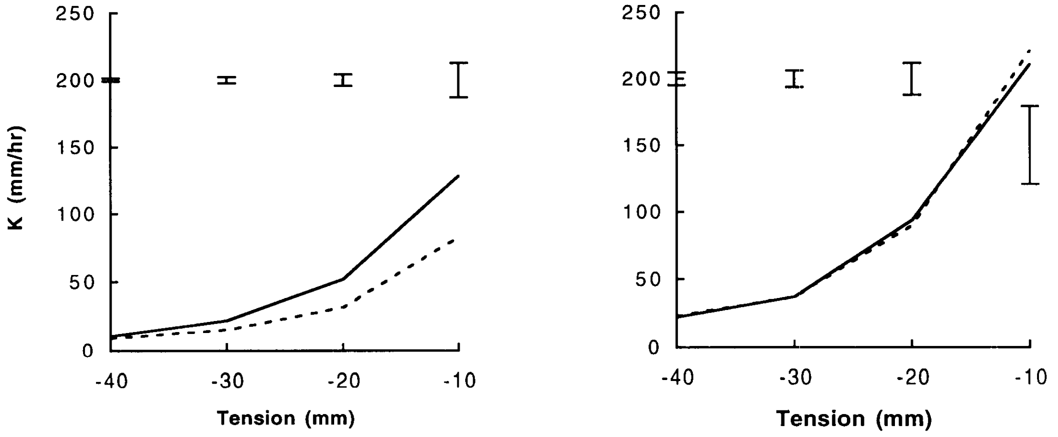
Fig. 7.2 Unsaturated hydraulic conductivity (mm/hr) at the Strathroy site under cell grazing (- - -) and continuous grazing (——) at (a) Transect 4 (b) Transect 5 and (c) Transect 6 during December 1994 (left) and 1996 (right). Error bars represent one SE.

1994 **1996**

(a) Transect 1



(b) Transect 2



(c) Transect 3

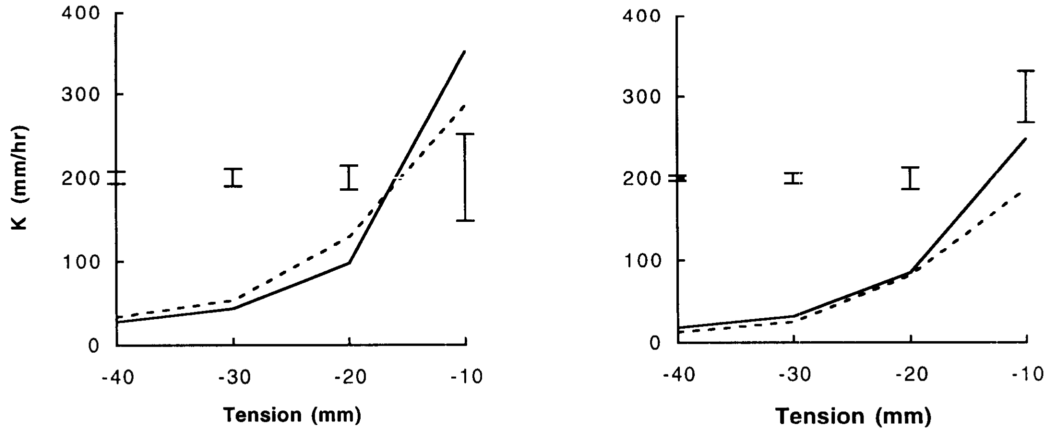
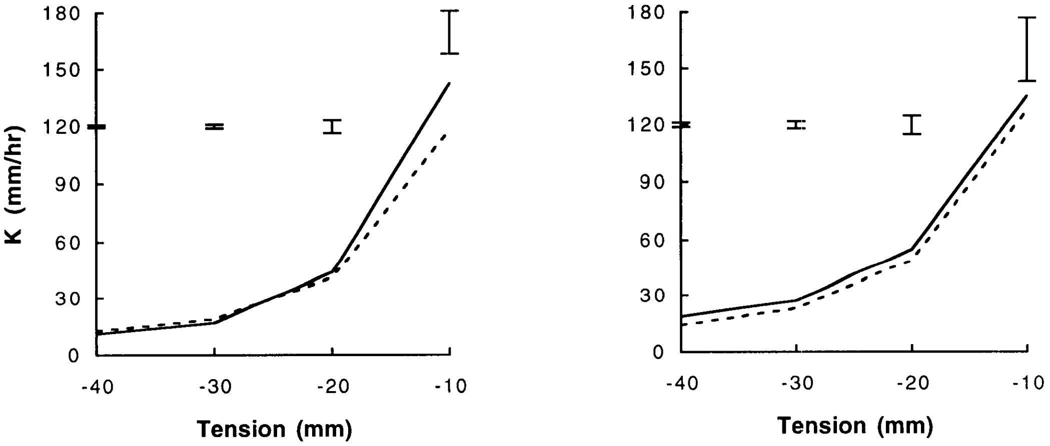


Fig. 7.3 Unsaturated hydraulic conductivity (mm/hr) at the Green Hills site under cell grazing (- - -) and continuous grazing (——) at (a) Transect 1 (b) Transect 2 and (c) Transect 3 during December 1994 (left) and 1996 (right). Error bars represent one SE.

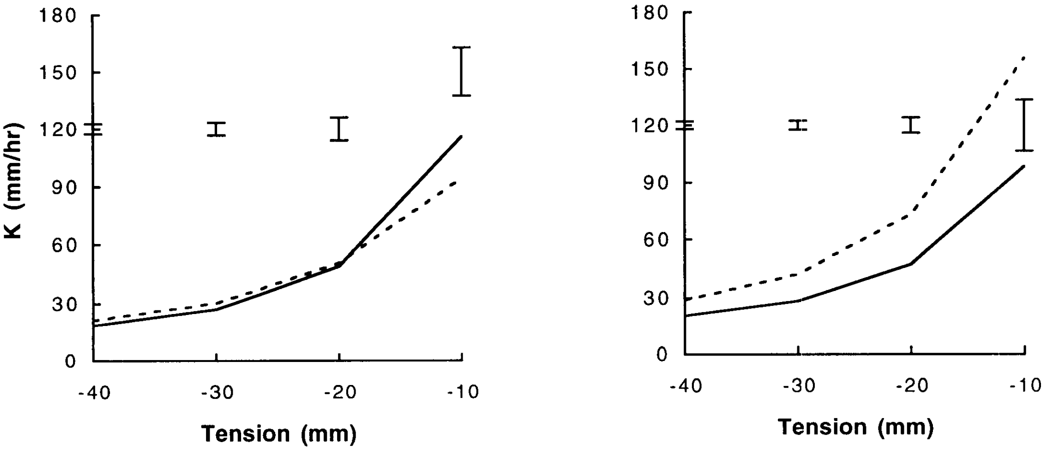
Note: scale of the y axis is different for Transect 3.

Site 1 **Site 2**

(a) Dec 1993



(b) Dec 1994



(c) Dec 1996

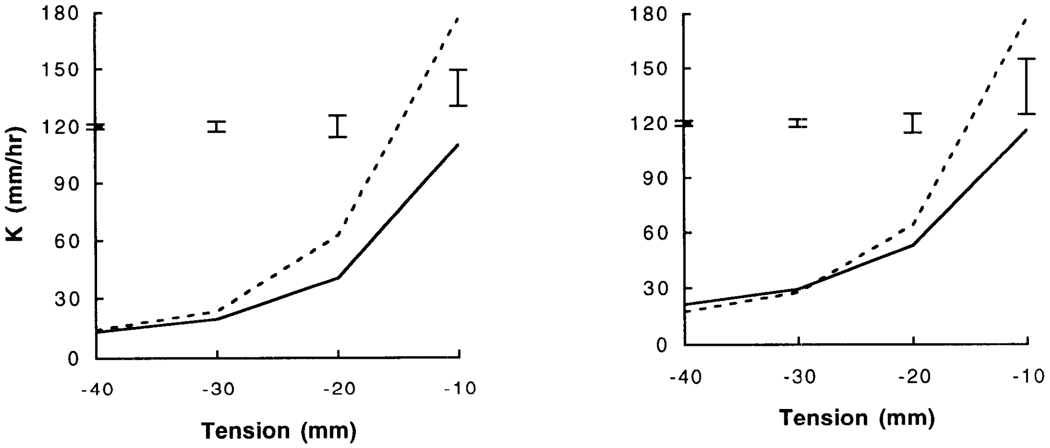


Fig. 7.4 Unsaturated hydraulic conductivity (mm/hr) at Site 1 (left) and Site 2 (right) on Lana under cell grazing (- - -) and continuous grazing (——) during (a) December 1993 (b) 1994 and (c) 1996. Error bars represent one SE.

Note: 1993 data collected by and reprinted with permission from K. Greenwood.

7.3.2 *Soil strength and moisture content*

At the time of collection of the baseline data at the Strathroy site in December 1994, a number of significant differences in soil strength were detected between the areas allocated to each grazing treatment (Fig. 7.5, Fig. 7.6). At the 1996 measurements on transects 1 and 2 there were fewer differences of significance between the regular density cell grazed and high density cell grazed treatment. On transect 1 the pattern of soil strength did not change markedly over time (Fig. 7.5a) however, on transect 2 under regular density cell grazing soil strength decreased to 90 mm depth relative to the HD cell grazed treatment (Fig. 7.5b). From 135 mm to 240 mm depth soil strength decreased to a greater extent under the HD cell grazed regime, though these changes were not statistically significant. At the initial measurement in 1994 soil strength at transect 3 was significantly higher within the regular density cell grazed area than in the HD cell grazed treatment (Fig. 7.5c). This situation was reversed by December 1996 where soil strength decreased significantly at all depth intervals under regular density cell grazing relative to HD cell grazing.

Similarly, at the initial measurement on transect 4 at the Strathroy site, soil strength was significantly higher in the designated cell grazed area than in the designated continuously grazed paddock (Fig. 7.6a). After the grazing treatments had been imposed for 2 years this result was reversed and under cell grazing soil strength was significantly less than under continuous grazing at all depths greater than 45 mm (Fig. 7.6a). At the 1996 measurement on transect 5, soil strength was lower in both treatments. It declined to a relatively greater extent under the continuously grazed regime and was significantly less than the comparable cell grazed transect at all depth intervals except 180 mm (Fig. 7.6b). No differences in soil strength were detected between the areas allocated to each grazing treatment on transect 6 at the initial measurement in December 1994. After 2 years, soil strength was significantly less at 45 mm and 270 mm depth under continuous grazing (Fig. 7.6c). At intermediate depth intervals soil strength under the cell grazed regime was less than or equal to that in the continuously grazed treatment though the differences were not significant.

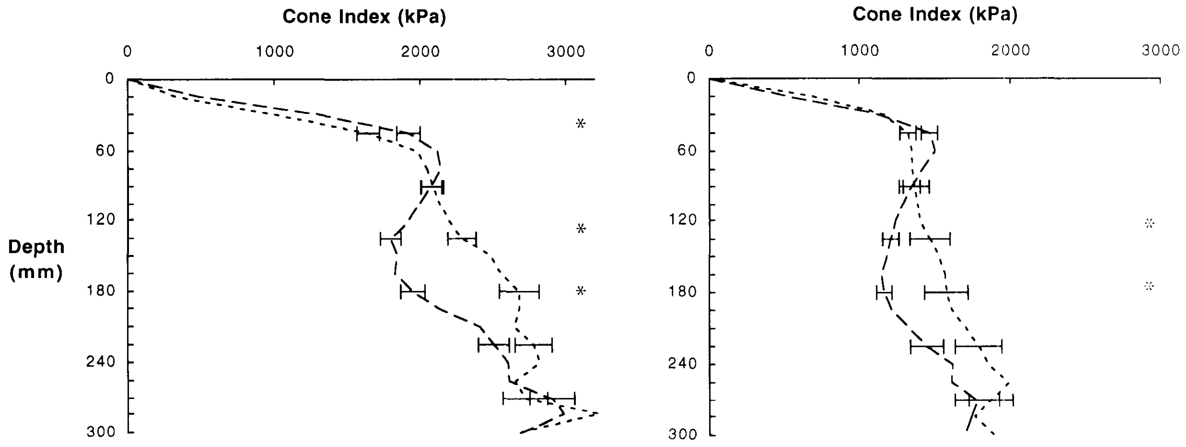
At the Green Hills site relatively few significant grazing treatment effects on soil strength were recorded over time. No change was detected on transect 1 (Fig. 7.7a). On transect 2, at the initial measurement soil strength in the designated cell grazed treatment was significantly higher at 45 and 90 mm depth. By the time of the final measurement in December 1996 soil strength was significantly lower under the cell grazed regime than under continuous grazing at 225 and 270 mm, although it remained higher at 45 mm depth (Fig. 7.7b). Soil strength on transect 3 increased significantly under cell grazing at 45 and 90 mm depth however, at 270 mm depth it had declined under cell grazing relative to the continuously grazed treatment (Fig. 7.7c).

The initial measurement of soil strength at Site 1 at Lana in December 1993 showed no significant differences between treatment areas at any depth interval (Fig. 7.8a). The only change at the 1996 measurement was at 45 mm depth, where under cell grazing soil strength was significantly lower at this depth than under the continuous grazing regime (Fig. 7.8c). Conversely, at Site 2 at Lana soil strength changed markedly over time at all depth intervals. At the 1993 baseline measurement, soil strength was higher in the designated cell grazed area (Fig. 7.8a). By December 1994 soil strength was lower under cell grazing than under continuous grazing although the difference between the treatments was significant only at 45 mm depth (Fig. 7.8b). At the final measurement in 1996 soil strength at Site 2 was significantly lower at all depth intervals tested under cell grazing than under continuous grazing (Fig. 7.8c).

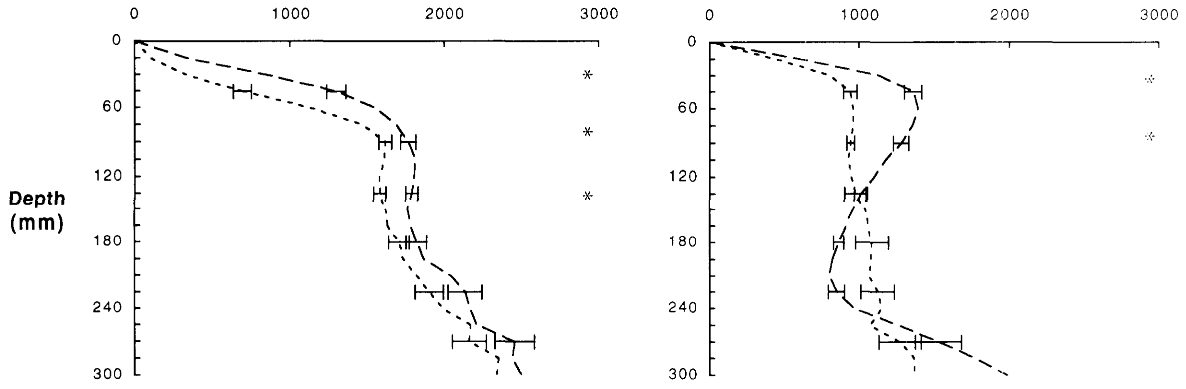
Gravimetric moisture content data showed no significant differences in relation to grazing regime any of the three sites at any time of measurement.

1994 **1996**

(a) Transect 1



(b) Transect 2



(c) Transect 3

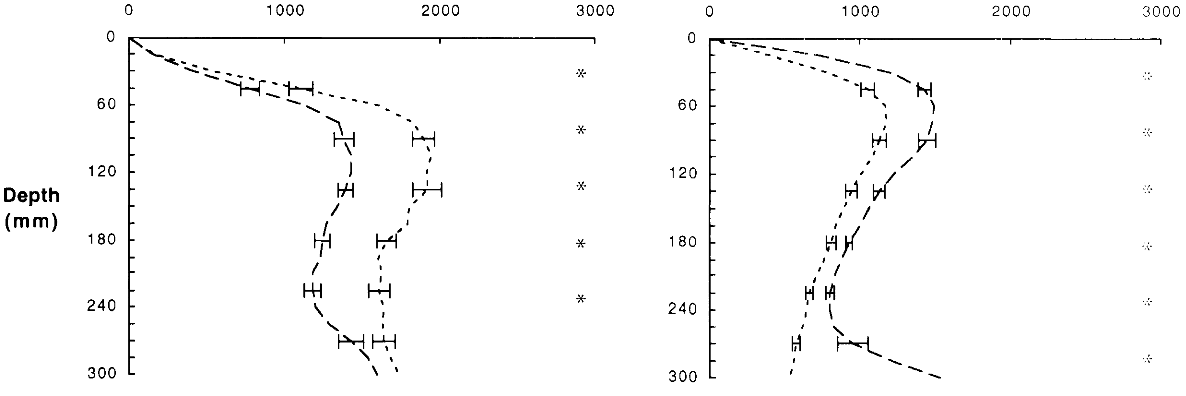
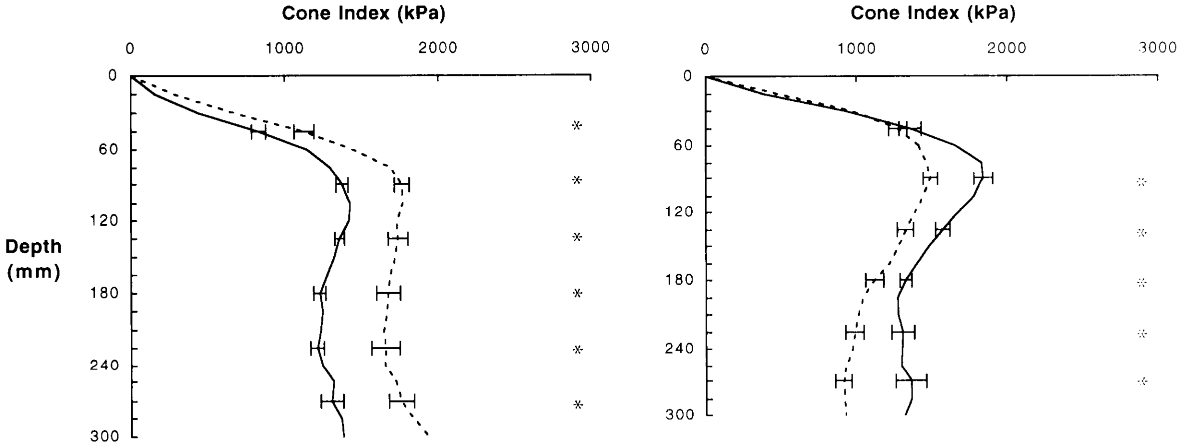


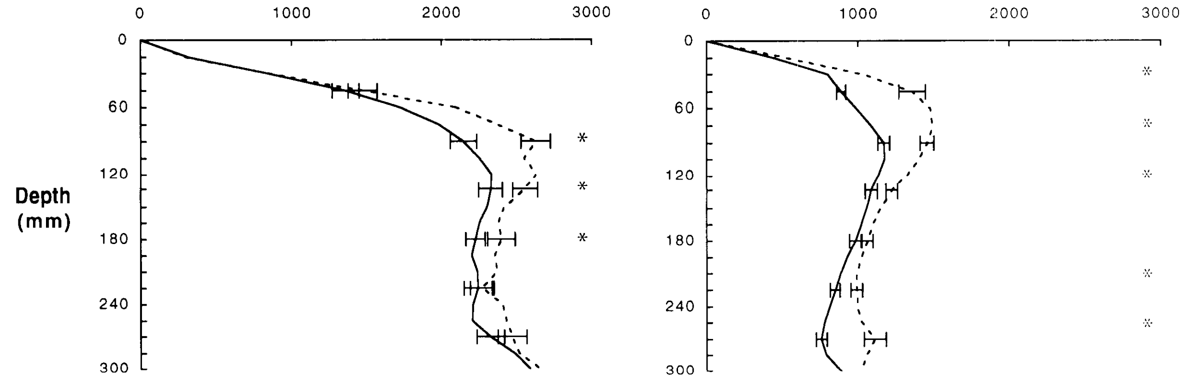
Fig. 7.5 Soil strength (kPa) at the Strathroy site under cell grazing (- - -) and high density cell grazing (— — —) at (a) Transect 1 (b) Transect 2 and (c) Transect 3 in December 1994 (left) and 1996 (right). * Indicates significant difference (P<0.05) between treatments at specified depth interval. Error bars indicate one SE.

1994 **1996**

(a) Transect 4



(b) Transect 5



(c) Transect 6

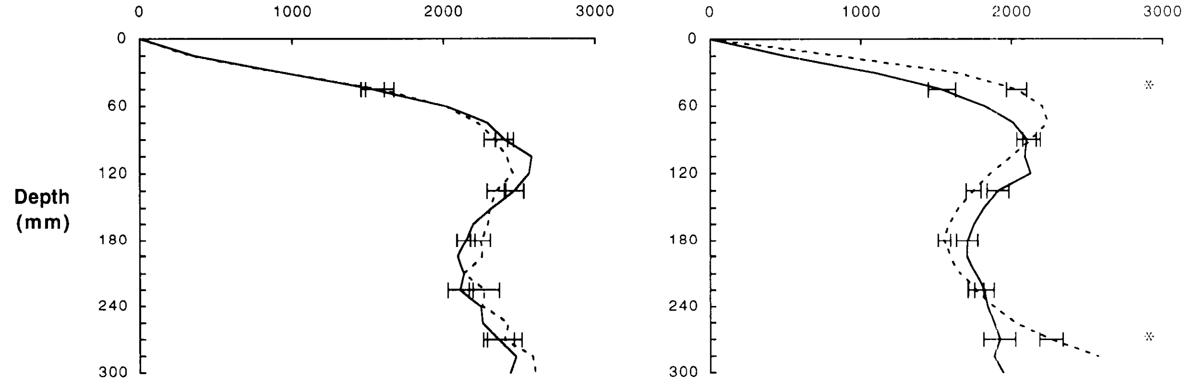
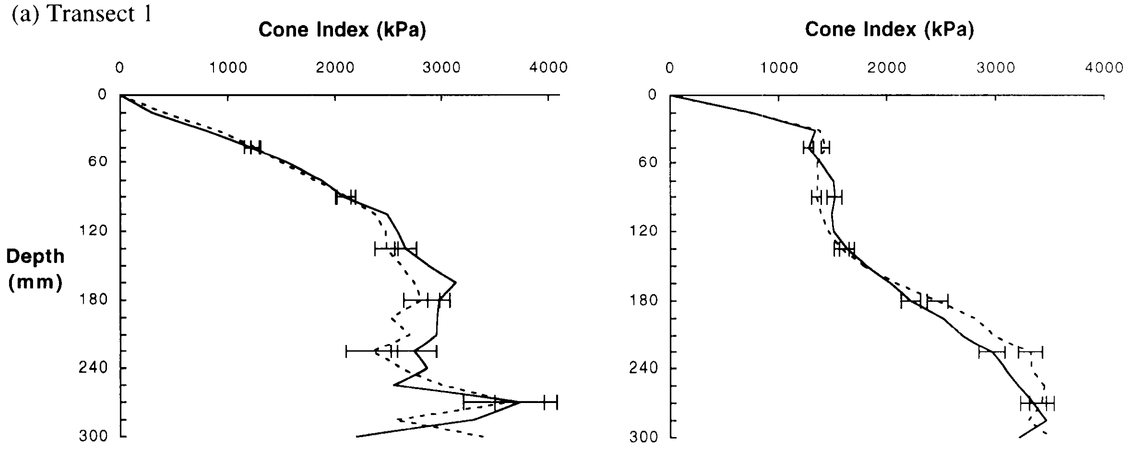


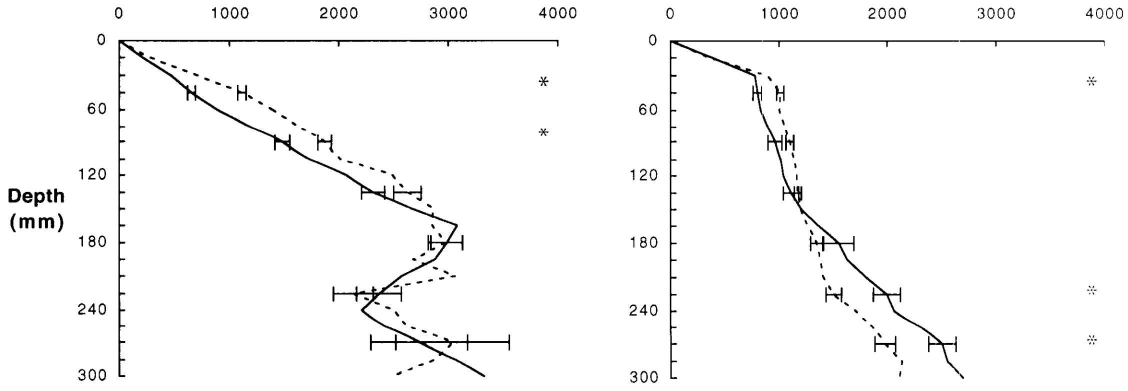
Fig. 7.6 Soil strength (kPa) at the Strathroy site under cell grazing (- - -) and continuous grazing (——) at (a) Transect 4 (b) Transect 5 and (c) Transect 6 in December 1994 (left) and 1996 (right). * Indicates significant difference (P<0.05) between treatments at specified depth interval. Error bars indicate one SE.

1994 **1996**

(a) Transect 1



(b) Transect 2



(c) Transect 3

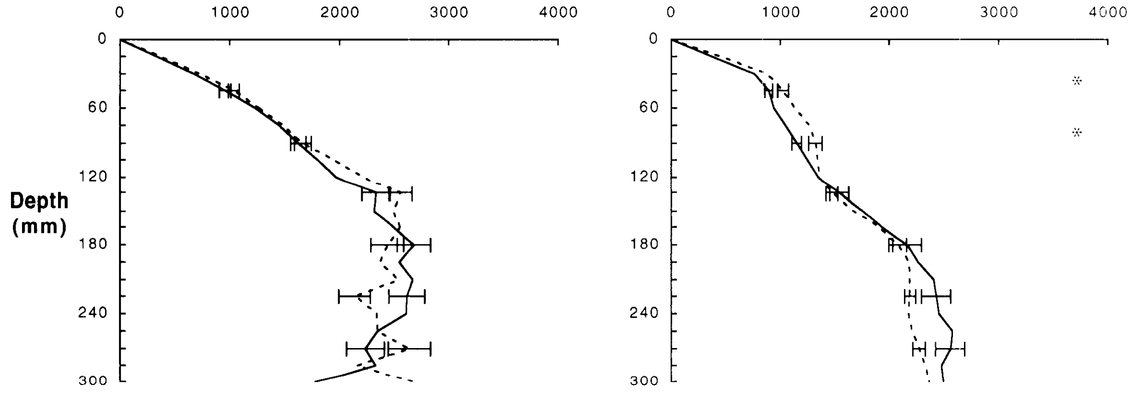
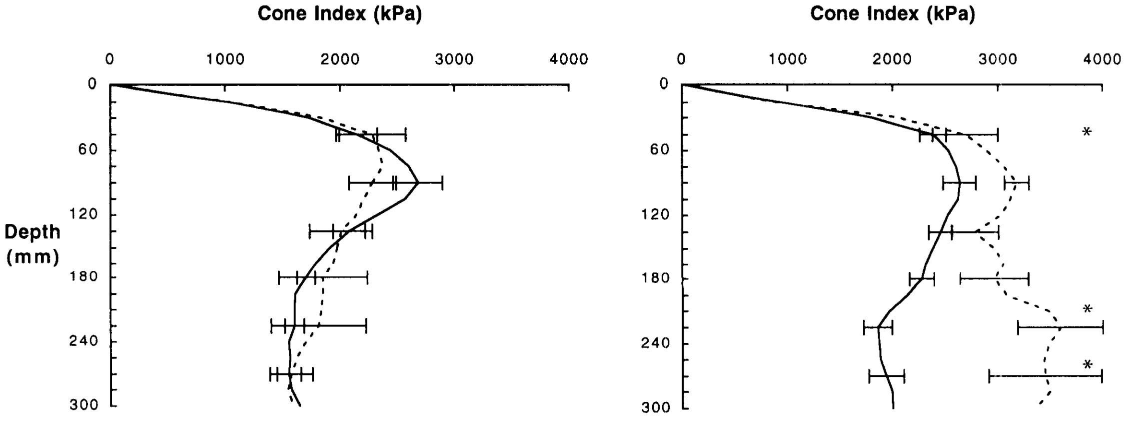


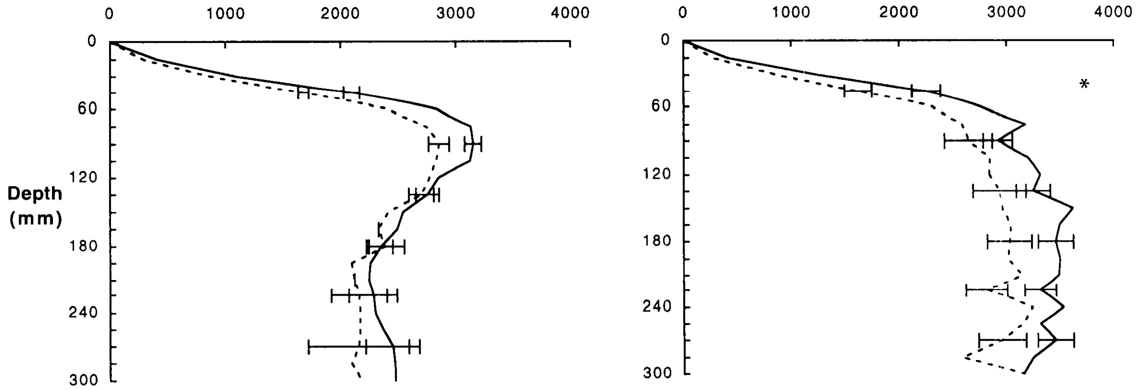
Fig. 7.7 Soil strength (kPa) at the Green Hills site under cell grazing (- - -) and continuous grazing (——) at (a) Transect 1 (b) Transect 2 and (c) Transect 3 in December 1994 (left) and 1996 (right). * Indicates significant difference (P<0.05) between treatments at specified depth interval. Error bars indicate one SE.

Site 1 **Site 2**

(a) Dec 1993



(b) Dec 1994



(c) Dec 1996

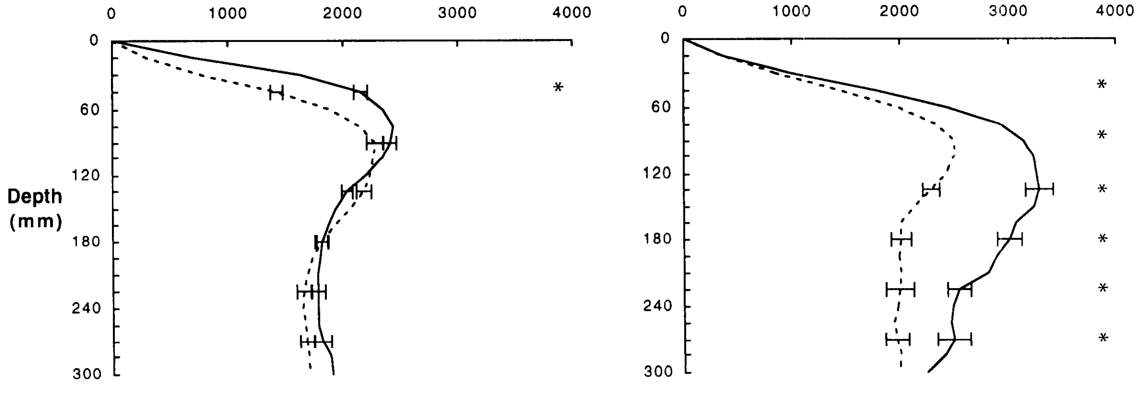


Fig. 7.8 Soil strength (kPa) at Site 1 (left) and Site 2 (right) on Lana under cell grazing (- - -) and continuous grazing (——) during (a) December 1993 (b) 1994 and (c) 1996.
* Indicates significant difference ($P<0.05$) between treatments at specified depth interval. Error bars indicate one SE.

Note: 1993 data collected by and reprinted with permission from K. Greenwood.

7.3.3 *Bulk density and total porosity*

At the initial measurement in December 1994 at the Strathroy site the bulk density on transect 1 was significantly higher than that recorded on the other two transects within the regular density cell grazed and the HD treatment comparison (Table 7.1). The difference between transects was still evident at the 1996 measurement. There were no changes recorded in the paired transects as a result of grazing treatment.

Bulk density at the Strathroy site in the designated cell grazed area tended to be higher than that in the continuously grazed paddock in December 1994, although the differences were not statistically significant (Table 7.2). There were no differences in bulk density among transects. At the December 1996 measurement bulk density had decreased on all transects under cell grazing. Under the continuous grazing regime bulk density remained relatively unchanged on transect 4 and 5 however, on transect 6 it had increased and was significantly higher than that recorded on the comparable cell grazed transect (Table 7.2).

At the Green Hills site there were no significant differences in the bulk density recorded at the initial measurement in December 1994 (Table 7.3). Bulk density tended to be higher on transect 2, and on transects 1 and 3 was higher within the designated continuously grazed area than the comparable cell grazed treatment area. By the 1996 measurement bulk density had increased on transects 1 and 3 in both grazing treatments (Table 7.3). On transect 1 the increase was significantly greater under continuous grazing than under cell grazing. Conversely, on transect 3 bulk density increased more under cell grazing although not significantly so.

At the two Lana sites bulk density was greater at all measurement dates under continuous grazing than under cell grazing (Table 7.4). The differences between the grazing treatments were not statistically significant at either site in December 1993 and 1994. However, by the final measurement in 1996, bulk density on both sites was significantly higher under the continuous grazing regime than under cell grazing.

There were no consistent trends in soil porosity in relation to grazing treatment at any of the sites (Tables 7.5, 7.6, 7.7 and 7.8). At the Green Hills site, where the soil is derived from basaltic parent material, total porosity was higher than from the lighter soil sites (Table 7.7).

Table 7.1 Bulk density of surface 40 mm soil at the Strathroy site under cell grazing and high density (HD) cell grazing.

Transect	**1**		**2**		**3**		
	Cell	HD Cell	Cell	HD Cell	Cell	HD Cell	5% LSD
1994	1.28	1.22	1.14	1.15	1.09	1.17	0.14
1996	1.29	1.24	1.19	1.16	1.10	1.22	0.13

Table 7.2 Bulk density of surface 40 mm soil at the Strathroy site under cell grazing and continuous grazing.

Transect	**4**		**5**		**6**		
	Cell	Continuous	Cell	Continuous	Cell	Continuous	5% LSD
1994	1.26	1.18	1.28	1.14	1.23	1.18	0.14
1996	1.21	1.18	1.21	1.13	1.22	1.44	0.13

Table 7.3 Bulk density of surface 40 mm soil at the Green Hills site under cell grazing and continuous grazing.

Transect	**1**		**2**		**3**		
	Cell	Continuous	Cell	Continuous	Cell	Continuous	5% LSD
1994	0.90	1.06	1.08	1.06	0.84	0.98	0.19
1996	0.97	1.12	1.07	0.98	1.05	0.98	0.12

Table 7.4 Bulk density of surface 40 mm soil at the two Lana sites under cell grazing and continuous grazing.

	Site 1			**Site 2**		
	Cell	Continuous	5% LSD	Cell	Continuous	5% LSD
1993	1.23	1.26	0.16	1.34	1.44	0.21
1994	1.19	1.20	0.09	1.46	1.56	0.14
1996	1.27	1.37	0.08	1.35	1.50	0.11

Table 7.5 Total porosity (%) of surface 40 mm soil at the Strathroy site under cell grazing and high density (HD) cell grazing.

Transect	**1**		**2**		**3**	
	Cell	HD Cell	Cell	HD Cell	Cell	HD Cell
1994	51.70	53.96	56.98	56.60	58.87	55.85
1996	51.32	53.21	55.09	56.23	58.49	53.96

Table 7.6 Total porosity (%) of surface 40 mm soil at the Strathroy site under cell grazing and continuous grazing.

Transect	**4**		**5**		**6**	
	Cell	Continuous	Cell	Continuous	Cell	Continuous
1994	52.45	55.47	51.70	56.98	53.58	55.47
1996	54.34	55.47	54.34	57.35	53.96	45.66

Table 7.7 Total porosity (%) of surface 40 mm soil at the Green Hills site under cell grazing and continuous grazing.

Transect	**1**		**2**		**3**	
	Cell	Continuous	Cell	Continuous	Cell	Continuous
1994	66.04	60.00	59.25	60.00	68.30	63.02
1996	63.40	57.74	59.62	63.02	60.38	63.02

Table 7.8 Total porosity (%) of surface 40 mm soil at the two Lana sites under cell grazing and continuous grazing.

	Site 1		**Site 2**	
	Cell	Continuous	Cell	Continuous
1993	53.58	52.45	49.43	45.66
1994	55.09	54.72	44.90	41.13
1996	52.08	48.30	49.06	43.40

7.3.4 *Soil chemical analysis*

The most marked feature of the soil chemical data was the increase in nitrogen, phosphorus and potassium levels at the stock camp which was created on transect 4 under continuous grazing at Strathroy (Table 7.9). Despite the evidence of nutrient increase at the camp under continuous grazing, there was no indication of a general rundown of the nutrient pool on the other transects. Nitrogen increased on transect 1 where the stock camp was created in the continuously grazed paddock at the Green Hills site (Table 7.10). At this site there was a marked decline in nitrogen on transect 3 under continuous grazing while it had increased slightly at the corresponding transect under cell grazing.

At Site 1 at Lana, the level of soil available phosphorus in the cell grazed treatment increased four-fold from 1994 to 1996, whereas the level under continuous grazing increased 57% (Table 7.11). Calcium and magnesium levels and the cation exchange capacity also increased within both treatments, although the increases in calcium and cation exchange capacity were greater under cell grazing. Nitrogen levels decreased markedly within both treatments at Site 1 at Lana (Table 7.11). Chemical analyses were not undertaken at Site 2.

There was a 20% increase in the level of organic carbon at the Strathroy site in the continuously grazed treatment, compared to a 9.5% increase under cell grazing and a 8% decline under the high density cell grazed regime. At the Green Hills site there was a 9% increase in organic carbon under cell grazing compared to 13% increase under continuous grazing. The greatest treatment differences were at Site 1 at Lana, where organic carbon levels increased 35% between 1994 and 1996 under cell grazing and declined 5% under continuous grazing.

Table 7.9 Changes in soil chemical composition over time at the Strathroy site.

		pH (water)	Organic C (%)	Nitrate N (mg/kg)	Sulfate S (mg/kg)	Bray P (mg/kg)	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	EC dS/m	CEC	Ca : Mg
Transect 1	Cell '94	6.1	1.7	3	3	8	0.3	5.2	0.7	0.08	0.04	6.3	7.4
	Cell '96	5.7	2.1	8	4	10	0.2	3.9	0.7	0.10	0.04	4.9	5.8
	HD Cell '94	5.8	2.6	3	4	11	0.2	6.2	1.2	0.16	0.04	7.8	5.2
	HD Cell '96	5.6	2.2	6	4	7	0.3	5.3	1.0	<0.05	0.04	6.7	5.2
Transect 2	Cell '94	5.6	2.1	4	5	5	0.3	5.1	1.2	<0.05	0.04	6.7	4.2
	Cell '96	5.7	2.2	5	3	5	0.4	4.2	1.1	<0.05	0.04	5.8	3.7
	HD Cell '94	5.6	1.6	3	4	6	0.2	3.3	0.8	<0.05	0.03	4.4	4.1
	HD Cell '96	5.7	1.7	8	4	6	0.4	3.0	0.9	<0.05	0.04	4.4	3.3
Transect 3	Cell '94	5.6	1.5	3	4	7	0.3	2.9	0.6	<0.05	0.03	3.9	4.8
	Cell '96	5.6	1.6	4	4	10	0.2	3.7	0.8	<0.05	0.04	4.9	4.4
	HD Cell '94	5.7	1.5	7	4	9	0.4	2.9	0.6	<0.05	0.04	4.0	4.8
	HD Cell '96	5.6	1.4	6	3	5	0.3	3.3	0.7	<0.05	0.04	4.4	4.8
Transect 4	Cell '94	5.5	1.2	3	4	11	0.3	2.2	0.6	<0.05	0.03	3.2	3.7
	Cell '96	5.3	1.3	6	3	7	0.3	2.1	0.5	<0.05	0.04	3.1	4.3
	Continuous '94	5.6	1.3	4	3	9	0.3	3.0	0.5	<0.05	0.04	3.9	6.0
	Continuous '96	5.6	1.6	24	4	17	0.7	2.8	0.6	<0.05	0.07	4.2	5.1
Transect 5	Cell '94	5.4	1.5	4	4	7	0.2	2.2	0.5	<0.05	0.03	3.0	4.4
	Cell '96	5.5	1.8	11	7	9	0.3	2.7	0.7	<0.05	0.04	3.9	4.1
	Continuous '94	5.5	1.1	2	4	5	0.2	2.1	0.6	<0.05	0.02	3.0	3.5
	Continuous '96	5.5	1.6	7	3	7	0.2	2.5	0.5	<0.05	0.04	3.4	4.9
Transect 6	Cell '94	5.6	2.1	3	5	3	0.3	3.7	1.1	0.06	0.04	5.2	3.4
	Cell '96	5.6	2.1	8	6	6	0.1	2.9	1.0	0.11	0.05	4.3	2.8
	Continuous '94	5.3	1.5	5	4	7	0.2	2.2	0.7	<0.05	0.04	3.2	3.1
	Continuous '96	5.4	1.5	12	4	6	0.2	2.4	0.9	0.07	0.05	3.7	2.7

Table 7.10 Changes in soil chemical composition over time at the Green Hills site.

		pH (water)	Organic C (%)	Nitrate N (mg/kg)	Sulfate S (mg/kg)	Bray P (mg/kg)	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	EC dS/m	CEC	Ca : Mg
Transect 1	Cell '94	5.9	3.4	5	2	6	1.4	11.8	6.8	0.07	0.06	20.1	1.7
	Cell '96	5.8	3.3	4	4	6	0.4	8.4	4.7	<0.05	0.05	13.6	1.8
	Continuous '94	5.8	3.1	10	3	8	1.1	11.2	5.3	<0.05	0.06	17.7	2.1
	Continuous '96	5.7	4.1	16	3	9	1.0	7.2	4.0	<0.05	0.09	12.2	1.8
Transect 2	Cell '94	6.0	3.3	5	4	11	1.1	11.9	5.3	<0.05	0.05	18.4	2.2
	Cell '96	6.0	3.0	7	6	10	0.7	11.0	4.9	0.05	0.06	16.7	2.2
	Continuous '94	5.9	3.1	3	4	7	0.9	10.5	5.0	<0.05	0.04	16.5	2.1
	Continuous '96	5.9	2.9	5	3	8	0.9	8.9	5.2	<0.05	0.05	15.2	1.7
Transect 3	Cell '94	5.9	3.0	6	4	9	0.8	13.6	5.9	0.05	0.05	20.4	2.3
	Cell '96	6.1	4.2	8	4	11	1.2	17.2	8.2	0.17	0.08	26.9	2.1
	Continuous '94	5.8	3.0	12	4	8	0.8	13.2	7.2	0.05	0.06	21.3	1.8
	Continuous '96	6.0	3.4	3	2	6	0.9	11.6	6.4	0.05	0.05	19.0	1.8

Table 7.11 Changes in soil chemical composition over time at Site 1 at Lana.

	pH (water)	Organic C (%)	Nitrate N (mg/kg)	Sulfate S (mg/kg)	Bray P (mg/kg)	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Al (meq/100g)	Na (meq/100g)	EC dS/m	CEC	Ca : Mg	Al Sat %
Cell '94	5.4	1.7	15	1	5	0.3	2.0	0.4	0.13	<0.05	0.05	2.9	5.0	4.5
Cell '96	5.7	2.3	<2	3	22	0.3	2.9	0.6	0.05	<0.05	0.04	3.8	5.0	1.3
Continuous '94	5.4	1.9	16	1	7	0.3	2.0	0.3	0.17	<0.05	0.06	2.8	6.7	6.1
Continuous '96	5.7	1.8	2	3	11	0.3	2.1	0.6	0.08	<0.05	0.04	3.1	3.9	2.6

7.4 Discussion

This study describes what is thought to be the first Australian research on the effects of cell grazing on soil physical properties. Similar studies of grazing systems have compared the effects of high intensity - low frequency grazing or short duration grazing with various levels of continuous grazing (see Chapter 2 for a description of the terminology). McCalla *et al.* (1984) concluded there was no difference in infiltration rates between soils subjected to high intensity - low frequency grazing and moderate continuous grazing. Weltz and Wood (1986) reported differing results from their two study sites and concluded that stocking rate influenced infiltration rate to a greater extent than grazing method. Greenwood (1997) however, found little difference in soil physical properties where pastures had been continuously grazed with sheep under a range of stocking rates for 30 years, indicating that in the long term continuous grazing has detrimental effects on soil physical properties regardless of stocking rate.

Natural processes have been shown to have the capacity to restore soil physical conditions relatively quickly if paddocks are rested (Proffitt *et al.* 1995), although the rate of recovery would depend on the extent of the damage and prevailing environmental conditions. In comparing a range of rotational "grazing systems" Taylor (1989) found 90 days rest was optimal for recovery of the soil. Warren *et al.* (1986b) suggested soil properties were more susceptible to damage when pasture was in the dormant phase over winter due to the inability of the pasture and soil to recover rapidly from grazing. These authors proposed that longer rest periods would be desirable during winter or drought periods as a measure to reduce the effects of grazing at these times. The length of rest appears to be the key to hydrologic stability rather than the density of livestock or the length of the graze period (Warren *et al.* 1986a; Taylor 1989).

The high density of livestock associated with the practice of cell grazing (usually around 200 dse/ha) was found to have no detrimental effects on any of the soil parameters measured at any of the three sites in this study. At the Strathroy and Green Hills sites the changes over time indicated a greater influence of spatial variation along a stratified topographical gradient than a grazing treatment effect. At the two Lana sites, where intensive monitoring was conducted over a longer time frame, significant improvements in unsaturated hydraulic conductivity, bulk density and soil strength were recorded in the cell grazed treatments.

Unsaturated hydraulic conductivity

At Strathroy and Green Hills unsaturated hydraulic conductivity (water infiltration rate) increased significantly in the two years from December 1994 to 1996. The results presented here indicate that grazing method plays a secondary role to seasonal and site-related factors in the short term if stocking rates are similar. At the Strathroy site infiltration rates increased under continuous low density grazing compared to the cell grazed treatment (Fig. 7.2) although they also increased to a similar extent under the high density cell grazed treatment compared to the regular density cell grazing (Fig 7.1). Trampling under high stocking density would not appear to be a primary factor influencing infiltration rate at this site.

Across the three paired transects at the Green Hills site the mean level of unsaturated hydraulic conductivity remained constant at all tensions over time. Infiltration rates increased at transects 1 and 2 and decreased at transect 3 under both grazing treatments, indicating a greater influence of spatial variation than grazing regime. At Site 1 at Lana, also, the pattern of the infiltration curves remained almost identical for the first two years of monitoring. However, at Site 2 at Lana significant improvements at the lower (-20 and -10 mm) tensions were recorded within 12 months relative to continuous grazing. After three years of differential grazing management, an improvement in infiltration rates associated with cell grazing was apparent at both sites.

While there were no differences in biomass production among any of the three sites, significant changes in the level of plant basal cover and botanical composition were recorded (Chapter 6). Increasing the amount of ground cover will provide the soil surface with protection from trampling damage and decrease the impact of raindrops, allowing greater interception rates (Climo and Richardson 1984). Given the changes to the vegetation recorded under cell grazing at all sites it is possible that changes in soil properties similar to those recorded at Lana may also be detected at the Strathroy and Green Hills sites over longer time frames. Changes in soil hydrologic parameters are often subtle and not apparent in the short term (Williams and Chartres 1991).

Temperature and diurnal factors have a large influence on infiltration rates. Jaynes (1990) suggested that temperature fluctuations could be equally important as spatial variation. The influence of barometric pressure has apparently not been considered in the literature. On two separate occasions when monitoring was being undertaken, infiltration ceased with the onset of thunderstorm activity. Measurements from these sites were repeated at later dates. It was beyond the scope of this study to evaluate the influence of air pressure but it appears to be an important factor which should be taken into account in future work of this nature.

Soil strength

A number of studies have shown that the most pronounced changes in soil strength occur in the top 50 mm of the soil (Chappell *et al.* 1971; Greenwood 1997). In this study there were a number of instances where significant changes between grazing treatments were recorded at depths below 50 mm (Figs. 7.5b, 7.5c, 7.6a 7.6b, 7.6c, 7.7b, 7.8a, 7.8c). This may have been due to the ameliorating effect of perennial plant roots, which have the capacity to restore soil physical condition through active growth (Cresswell and Kirkegaard 1995). At the time of the initial measurements, pasture growth may have been limited by soil moisture as the region was approaching drought declaration. The final measures were made after twelve months of adequate rainfall which had stimulated the growth of perennial grasses.

There were two pronounced reversals in soil strength at the Strathroy site which were possibly related to changes in botanical composition. These occurred at transects 3 and 4 where soil strength decreased under cell grazing over time, in comparison with high density and continuous grazing treatments, respectively (Figs. 7.5c, 7.6a). In the cell grazed paddocks an increase in the proportion of the perennial native grass *Microlaena stipoides* was recorded in the vicinity of these transects over time. The increased abundance of this species may have enhanced soil structure relative to that of the other grazing treatments.

Bulk density and soil porosity

Measures of bulk density and total porosity showed that soils at all sites were in relatively good condition (Craze and Hamilton 1991) prior to the commencement of the grazing treatments. There was no indication over the term of the experiment that increased compaction of the top 40 mm of soil had occurred as a result of the high stock densities associated with the cell grazing regimes. If, as Naeth *et al.* (1991b) indicated, the effects of grazing are most apparent close to the surface, then measures of bulk density and total porosity to 40 mm should provide a sound measure of any effects of high density stocking on surface soil structure. At the two Lana sites where cell grazing had been implemented over a longer time period there were indications that the condition of the soil in terms of bulk density and porosity was better under this regime.

Soil chemistry

Soil fertility and ecosystem productivity are a function of the quantity and quality of the organic matter returned to the soil, the rate of decomposition and nutrient release and the inherent characteristics of the parent material (Tripathi and Singh 1992; Robertson *et al.* 1994). These processes are influenced by soil structure, porosity (Hassink *et al.* 1993), temperature, moisture and the density and activity of decomposer organisms (Dormaar *et al.* 1990).

Organic carbon is the primary source of energy for soil microorganisms and invertebrates which are essential for nutrient cycling within the ecosystem. Much of the nutrient capital of the soil is contained within the organic matter and the ratio of inputs and outputs must be balanced or positive to ensure sustainability (Williams and Chartres 1991). Organic matter also has long term positive effects on the physiochemical properties of soils. Beneficial effects emerge through the formation of soil aggregates which influence soil structure, water holding capacity, infiltration rates, aeration, biological activity, nutrient cycling and root penetration (Campbell 1978; Williams and Chartres 1991; Srivastava 1992; Emerson 1995).

The upper limits of soil organic matter levels are determined primarily by climatic factors and their influence on the plant species which the environment can support (Campbell 1978). Rainfall and temperature are the main variables which determine vegetative biomass (Spain *et al.* 1983) but grazing management, through its influence on selective grazing and subsequent botanical composition, will affect the quality and quantity of the organic material within the cycle. Organic carbon levels indicated that the soils at the three sites were in relatively good condition at the commencement of the experiment, averaging 1.6, 1.9 and 3.3% at Strathroy, Lana and Green Hills respectively. Spain *et al.* (1983) in a survey of Australian soils in the 500 -1000 mm rainfall zone found that the majority had organic carbon levels between 0 and 1%. The general increase in organic carbon levels measured over time at all sites is a positive result from an ecosystem health perspective.

The rate of cycling of carbon and other soil nutrients is dependent on the effective functioning of decomposer organisms (Killham 1994). The maintenance of an adequate organic carbon pool, sourced from plant residues in the form of litter, dead root material and root exudates, is essential to this process. Beckwith and Butler (1983) suggested that the time required to re-establish a favourable level of organic matter within ecosystems following a change in management was dependent on the nature and extent of the changes imposed.

At the Lana site, the greater relative increase in the amount of available phosphorus and calcium over time under cell grazing was possibly due to increased rates of nutrient cycling in this treatment. It is hypothesised that the high stock density associated with the cell grazing regime at this site resulted in a greater amount of organic material being returned to the soil and/or increased the fragmentation of organic material and consequently its accessibility to decomposer organisms. Through this process the rates of decomposition and nutrient cycling within the cell grazed treatment may have been accelerated.

The quality of the organic material returned to the soil also has an important influence on the rate of cycling of nutrients. The more desirable botanical composition and greater diversity of perennial grasses evident at Lana (Chapter 6) may have been an important factor influencing both the above and below-ground supply of organic material. Both root and shoot production was shown to be enhanced when plants were rested from frequent defoliation (Chapter 5). Root biomass is a critical source of below-ground organic carbon supply and has a direct and positive influence on microbial biomass and activity (Srivastava and Singh 1991; Sparling 1992).

Up to 95% of nutrients consumed by livestock are returned in excreta and this has important implications for the nutrient status of pastures if animals form stock camps. The increased levels of nitrogen, phosphorus and potassium recorded under continuous grazing on transect 4 on Strathroy and an increase in nitrogen on transect 1 at Green Hills were indicative of the formation of stock camps. Conversely, the use of high stock density under cell grazing tends to result in a more even distribution of dung and urine over a greater area of the paddock.

Conclusion

Greenwood (1997) hypothesised that the effects of grazing on soil physical properties were cumulative and approached an equilibrium over time. Such an equilibrium would be unlikely to have been reached at the three sites monitored, given the relatively short period of time that cell grazing had been operating.

Soil physical properties tended to be influenced more by spatial heterogeneity along the contour at the sites where stratified sampling was undertaken than by grazing treatment. There was evidence of nutrient accumulation on stock camp areas under continuous grazing at two of the sites, even within the short time-frame of this experiment. The transfer of nutrients within paddocks under continuous grazing regimes is likely to be of greater significance in the long term than the small amount of nutrients exported in livestock product (Williams and Haynes 1992).

At the two Lana sites, where cell grazing had been practiced for longer than at the Strathroy or Green Hills sites, the cell grazed treatments showed significant improvements in some soil properties relative to the continuously grazed treatments. It is possible that over a longer time-frame, changes may have also been discernible at the other sites.

Chapter 8

Integrating discussion

Vegetation change is a dynamic process, usually manifested through changes in the relative vigour and abundance of the component parts. It may be influenced by species extinctions, the importation of new species or recruitment from the soil seed bank. All vegetation change is due to one or several causal mechanisms, although the exact nature of these may not be readily apparent. In pasture ecosystems the actions of grazing animals can have a profound effect on the direction of vegetation change.

The quality and stability of grasslands is dependent on the ability of perennial grasses to regenerate new tillers and to recruit from the soil seed bank. While conditions for the germination of grass seed occur frequently on the Northern Tablelands, the conditions necessary for establishment are far more sporadic. The vegetative persistence of perennial grasses is therefore essential for the provision of groundcover and soil stability in below average rainfall years and for the maintenance of the integrity of grasslands.

At both the Strathroy and Green Hills sites all perennial grass species recorded in the extant vegetation were relatively well represented in the seed bank at the time of collection of the soil samples (Chapter 4). They were present in sufficient numbers to enable adequate regeneration if the environmental requirements for germination and establishment were met. However, the seed bank composition indicated that if an extended period of stress or disturbance was experienced, the Strathroy site had the potential to undergo transition to a pasture dominated by rushes, while the Green Hills site had a high potential to undergo transition to a vegetation state dominated by forbs and annual grasses.

The interactions which occur at the plant soil interface provide one of the most influential positive feedback loops in grassland ecosystems (Reitkirk and van der Koppel 1997). The level of plant cover has well-documented effects on soil biological activity, energy flow, rates of water infiltration, and the losses of dissolved and particulate matter including nutrients and organic matter (Tainton and Walker 1993; Prosser and Hairsine 1995). Maintaining high levels of groundcover at all times will also reduce the opportunity for *Juncus* spp. and many annual species to become dominant components of the vegetation.

In the defoliation experiment described in Chapter 5, all species, when defoliated at 2 week intervals, exhibited the following trends in comparison to plants cut at 4 and 8 week intervals:-

- cumulative dry matter production was reduced
- leaf protein content was increased (initially at least)
- plant basal diameter was reduced
- crown weight was reduced
- reproductive tiller production was reduced.

The defoliation experiment was conducted under non-limiting moisture and nutrient conditions and in the absence of inter-plant competition. It would be reasonable to expect that under field conditions the negative response of plants to frequent defoliation under a continuous grazing regime would be amplified.

Under continuous grazing in mixed species swards, the grazing pressure exerted on individual species is likely to vary markedly, as the active selection of the most palatable species is an inherent feature of animal behaviour. While it is accepted that individual plants are rotationally grazed, the frequency of grazing of different species will vary, and in a mixed sward some species will be largely avoided.

The degree of selective grazing exerted on individual species is dependent on a complex of site-related interacting factors, including floristic diversity, grazing intensity, species of grazer, age of sown pasture, age of individual plants, pasture height, moisture content, season of grazing and the growth cycle of each plant species. One of the most important determinants of whether or not an individual plant will be grazed at a particular time, will be the relative palatability of the other plants on offer and their relative proportions in the pasture.

The field experiments described in Chapter 6 demonstrated that the most palatable components of the pastures, *E. leptostachya* at the Strathroy and Lana sites and *P. aquatica* at the Green Hills site, exhibited the greatest response to a change in grazing regime. Under cell grazing, the plant basal diameter, contribution to plant cover and contribution to biomass by these palatable grasses either increased or remained constant while declining significantly under continuous grazing. The rest afforded to these palatable species under the cell grazing regime was hypothesised to be the predominant mechanism through which their increased vigour, increased presence and contribution to pasture biomass were maintained. Presumably, the constant grazing pressure applied to the same species under the continuous grazing regime led to their significant reduction.

Previous defoliation events may influence the selection pressure placed upon preferred species. The pot experiment described in Chapter 5 showed that when defoliated at 2 week intervals regenerating plants produced new shoots of relatively higher protein content than those defoliated less frequently. Under field conditions this would have the effect of attracting attention from grazers and inducing further defoliation. The increased pressure on desirable plants would result in the relatively unpalatable species gaining a competitive and reproductive advantage by becoming even less attractive to livestock over time. Under a cell grazing regime, the more even utilisation of the pasture by high stock densities over a short period (1-3 days) would increase the probability of a greater number of species being grazed and would possibly delay their progression to the reproductive phase.

The seasonal variation in the growth and protein content of key perennial grasses from each site would suggest that when grazed intermittently over the course of the growing season, they may be preferred by livestock at different times (Chapter 5), assuming that protein content is a primary determinant of animal preference. The species tested exhibited a high degree of variation in protein content as a result of different defoliation intervals.

The concentration of protein in the leaf tissue of *P. aquatica*, *E. leptostachya* and *S. scabra* towards the end of the experiment declined markedly in plants cut at 2 week intervals relative to plants which had been cut at either 4 or 8 week intervals. This may be an indication of these species initiating physiological changes as a mechanism of grazing avoidance. These data would suggest that further investigation is warranted into the effects of defoliation interval on the allocation of resources within these grasses.

Under the continuous grazing regime the basal diameters of the desirable species at each site were significantly reduced, while remaining unchanged or increasing under cell grazing (Chapter 6). The basal diameters of plants which were defoliated at 2 week intervals in the pot experiment were also significantly reduced, and basal diameter showed a significant correlation with the cumulative dry matter production of *E. leptostachya*, *P. aquatica*, *S. scabra* and *B. macra* (Chapter 5).

The field data demonstrated a correlation between reduced basal diameters of the desirable perennial grasses and percentage groundcover under continuous grazing in comparison with cell grazing at all sites. In terms of maintaining ecosystem processes within grasslands, the decline in ground cover is highly significant. With the creation of gaps in the canopy the opportunity for the germination of less desirable pasture components (rushes and annual grasses and dicots at the Strathroy and Green Hills sites, respectively) also increases (Chapter 4).

The longer a grassland ecosystem can be left undisturbed to enable the component parts to engage in core functions such as primary and secondary production, energy flow, reproduction and nutrient cycling, the better (Jefferies 1988). Herbivores are essential components of grassland ecosystems but it is difficult to mimic natural plant-herbivore interactions when animals are confined within one paddock for long periods. It is hypothesised that ecosystem processes were enhanced through provision of adequate rest periods under the cell grazing regime.

Defoliation at 2 week intervals was found to reduce root biomass in comparison to the 4 and 8 week defoliation interval in the pot experiment described in Chapter 5. Even when cut at 8 week intervals the root biomass of all species except *E. leptostachya* and *S. scabra* were significantly less than that of those plants which remained uncut. It has been proposed that competition for below-ground resources may be relatively more intense than for above-ground resources (Berendse and Elberse 1990).

The deleterious effects of animal selectivity on the desirable pasture components under continuous grazing under field conditions were probably accentuated by the dry conditions which were experienced at all sites during the initial 12 months of this experiment. During this time rainfall at each of the sites was 60% of the average annual precipitation. Most of the significant changes which occurred in the vegetation at all sites occurred during this period.

In the continuously grazed treatment at each site, the apparent weakening of the preferred species as indicated by the reduction of basal diameter and contribution to groundcover would suggest that the position of these species in the pasture was under threat. Their vulnerability was highlighted by the significant reduction in root biomass recorded in the pot experiment (Chapter 5) when plants were defoliated at 2 week intervals. As the proportion of desirable species in the sward declined the selection pressure placed on these species by grazing animals would increase accordingly, and it is highly probable that plant mortality rates would have increased if the below-average rainfall conditions had continued.

In contrast to the desirable components, the relatively undesirable species, *A. ramosa* at the Strathroy and Lana sites and *P. sieberiana* at the Green Hills site, tended to maintain their status in the sward under continuous grazing, while under the cell grazing regime these less desirable species decreased in basal diameter and contribution to dry weight.

In the defoliation experiment *A. ramosa* did not tolerate any of the treatments imposed, the majority of cut plants dying within two months of the initiation of defoliation. This would suggest *A. ramosa* possesses a very low tolerance to even a small amount of grazing. During the dry period experienced during the initial 12 months of the field experiment the level of total pasture biomass at all sites was relatively low. At the Strathroy site under the high stock density of the cell grazing regime a greater proportion of *A. ramosa* plants experienced some degree of defoliation, whereas under low density continuous stocking this species was almost entirely avoided. In both the regular density and high density cell grazed treatments the basal diameter of *A. ramosa* declined significantly during this period while under continuous grazing it remained unchanged. At the Lana site where its representation in the sward was initially low, *A. ramosa* was avoided by stock under both grazing regimes and consequently little change in the basal diameter was recorded.

In contrast, *P. sieberiana* was relatively productive under all defoliation treatments in the pot trial. At the Green Hills site, grazing of *P. sieberiana* during the dry period resulted in the production of relatively palatable regrowth. *Poa sieberiana* is usually avoided by stock because of its tendency to form large tussocks with green shoots interspersed among senesced tillers which limit access to livestock. By promoting the production of new leaf material and maintaining this species in a vegetative state and limiting the formation of large unpalatable tussocks, the productivity and utilisation of *P. sieberiana* may be dramatically improved. It is hypothesised that the reduction in the basal diameter of *P. sieberiana* in the field was a result of an increase in the competitive ability of neighbouring species such as *P. aquatica* due to the rest periods afforded under cell grazing.

These findings indicate that the effect of cell grazing on the less palatable components of pastures will be determined by their relative abundance, tolerance of grazing, seasonal conditions and the inherent competitive ability of neighbouring plants.

Following the return of favourable rainfall conditions at each of the sites, changes in the basal diameters of indicator species were relatively minor and were not greatly influenced by grazing method. This would indicate that the greatest opportunity to influence botanical composition exists during dry periods. In multi-species swards when conditions are favourable for plant growth and dry matter production exceeds the rate of consumption by livestock, grazing regime is less likely to have a major influence on the composition of perennial pastures. The mortality of established plants following severe defoliation is unlikely since the availability of resources for regrowth will be relatively high and the degree of selectivity will be relatively low due to the active growth of a broader range of species. Resting of pastures at such a time provides an opportunity for perennial plants to regenerate structures which may have been depleted by grazing during below-average rainfall years.

When the rate of animal intake exceeds pasture growth rate the effects of selective grazing will be intensified. Under such conditions it is essential that stocking rate be reduced to match the carrying capacity of the property, in order to conserve desirable species and maintain groundcover. The number of animals which can be maintained on area of land is dependent on the amount of herbage available in relation to the demands of livestock. Given the dynamic nature of grasslands, the carrying capacity should be viewed as a continuous variable in any livestock production system. Forage availability and quality will change seasonally and annually in response to prevailing climatic conditions and the previous grazing history.

At the Lana and Green Hills sites plant density (as indicated by plant basal cover) and species composition were maintained under cell grazing during the drought, presumably due to the application of suitable stocking rates and the provision of adequate rest periods to recover from previous defoliations. The reduction in plant basal cover in all treatments at the Strathroy site at the height of the drought in May 1995 suggested that the stocking rate exceeded the carrying capacity at that time. No form of grazing will compensate for the effects of an extended period of overstocking. However, the deleterious effects were minimised under cell grazing by allowing plants a period of rest between successive defoliations. The desirable species persisted in greater numbers through the drought period under cell grazing whereas under continuous grazing plants were reduced in size and number.

Following relief from the dry conditions at the Strathroy site the contribution of perennial grasses to pasture dry weight was higher under cell grazing than under continuous grazing although pasture biomass in all treatments was dominated by annual species, most notably annual clovers. The productivity of the desirable perennial grasses had increased by the June 1996 measurement under cell grazing while under continuous grazing these species failed to recover and this paddock was dominated by two species, *S. creber* and *A. ramosa.*

The effects of defoliation events over a year or more are cumulative. Perennial grasses must be given time to recover from defoliation if they are to persist in the sward. In order to maintain the size of plant bases each tiller must produce at least 1 daughter tiller per season. Some perennial grass species reportedly have the potential to produce up to 20 daughter tillers per adult tiller per year however, 2-3 may be more common (Becker *et al.* 1997a). The regeneration of new tillers is essential to maintain productivity and ensure the perenniality of grasses.

The quality of herbage is frequently reported to decline as pastures age. The decline in the protein content of tissue over time is a natural process. The regeneration of new leaf material following defoliation extends the period of vegetative growth and maintains the nutritive quality of each plant. If growth conditions or defoliation regime are such that the regeneration and development of new tillers in perennial grasses is interrupted, the quality of herbage may decline. A range of age classes among tillers of a plant may also be important in maintaining the quality of herbage produced. Constant monitoring and the ability to respond rapidly to the needs of grasses in terms of both rest and graze periods, are the keys to effective grassland management.

Native grasses are well adapted to tolerate periods of moisture stress and low nutrient levels. A number of native species tested in the defoliation experiment had greater growth rates than the introduced species *P. aquatica* and all had significantly lower root:shoot ratios. Not only was the root biomass of all native species much lower, but visually, roots appeared much finer. This growth and pattern of resource allocation contrasts with the theories of Grime (1979) and Tilman (1990b), who suggested stress tolerant species have low growth rates and allocate proportionally more carbon to root systems. When defoliated at 8 week intervals above-ground production of the desirable native species exceeded that of *P. aquatica*. This suggests that when management is sympathetic to the requirements of these native species and adequate periods of rest are provided, productivity gains may be significant.

For too long maximum animal production has been the sole focus in agricultural systems and the cost has been degradation of the landscape. Stability of production is a more important goal and is only achievable through improved understanding and controlled utilisation of natural resources, of which native grasses are a vital component. While appropriate grazing practices are important at all times, they are critical during periods of drought, when rapid and permanent damage can be inflicted on both pastures and soils.

Significant improvements in soil parameters were recorded at the two Lana sites which had been under cell grazing for a longer period of time than Strathroy and Green Hills.. It is proposed that one of the mechanisms through which the improvements in soil parameters were achieved at the Lana site was through increased root growth and a greater diversity of species with different rooting characteristics. Plant roots provide an important source of organic substrate for soil invertebrates and microorganisms and active root growth enhances soil structure.

Infiltration rate at the higher soil tension was significantly higher under the cell grazing regime at Lana indicating a relative increase in the presence of larger pores. Bulk density (and porosity) was significantly lower and soil strength depth was showing a tendency to decrease over time under cell grazing. Organic carbon levels increased by 35% under cell grazing while declining under continuous grazing and the available soil phosphorus levels increased more than fourfold over time in the cell grazed treatment.

We will never have perfect knowledge of ecological processes and sustainability will always be a moving target (Lefroy *et al.* 1992). Technological advances are inconsequential if not applied in concert an understanding of ecosystem processes. Flexibility in the approach to management is essential to enable constant adaptations to the continual changes which occur in the landscape. A greater degree of flexibility enhances the ability of managers to respond more positively to conditions of drought or other such event-driven changes (Watson *et al.* 1996). Increasing the number of paddocks allocated to each mob, or putting all mobs together as one herd, enables the greater degree of flexibility achievable through cell grazing.

The implementation of cell grazing by skilled managers on three properties on the Northern Tablelands of NSW resulted in an improvement in the vegetation resource in comparison with continuous grazing. The more palatable species at each site maintained significantly higher basal diameters under cell grazing than when exposed to continuous grazing. These species also contributed more to pasture biomass and plant cover under cell grazing and the total plant basal cover was higher under cell grazing at all sites.

There is much evidence to indicate that grazing animals are one of the major contributors to land degradation when allowed to graze under the widely used practice of set-stocking. The same animals, when managed in a different way, may be one of the most valuable tools we have for the effective restoration of grassland communities.

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