Differences in mineral concentration among diploid and tetraploid cultivars of rhodesgrass (*Chloris gayana*)

R. J. Jones[A], *D. S. Loch*[B] *and R. P. LeFeuvre*[A]

[A] CSIRO Division of Tropical Crops and Pastures, Davies Laboratory, Townsville, Qld 4814, Australia.
[B] Department of Primary Industries, PO Box 395, Gympie, Qld 4570, Australia.

Summary. Mineral composition of a range of rhodesgrass cultivars was measured to assess if levels were suitable for cattle growth. Leafy regrowth of 11 rhodesgrass cultivars and lines was analysed for a range of elements in 2 replicated field experiments near Gympie in southern Queensland. Experiment 1 comprised 2 diploid and 2 tetraploid cultivars, while 7 diploids and 3 tetraploids were compared in experiment 2.

Overall, the tetraploids had higher nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) concentrations but lower sodium (Na) and boron (B) concentrations than the diploids. Concentrations of potassium (P), copper (Cu) and aluminium (Al) for the 2 groups were similar and showed no significant cultivar differences. Results for sulfur (S), zinc (Zn) and iron (Fe) varied between experiments, either with no significant ploidy and cultivar differences or with higher concentrations in the tetraploids (S in experiment 2, Zn in experiment 1). The tetraploids had significantly higher concentrations of Mn in experiment 2. The Na concentration found in cultivar Boma was lower (0.02%) than the other cultivars in experiment 2. Similarly, cultivar Samford in experiment 1 had a lower Na concentration than the other 3 cultivars. Both Boma and Samford, however, had the highest Mg concentrations in their respective experiments. K/(Ca + Mg) equivalent ratios in the 2 experiments were in the range 0.40–1.50. This is well below the accepted critical value of 2.2 above which grass tetany in ruminants could become a problem.

Introduction

Rhodesgrass is widely grown in the subtropics and tropics with an increasing number of cultivars becoming available. Two ploidy levels are found in rhodesgrass—diploids and tetraploids. The effect of ploidy level on forage quality, usually measured as *in vitro* organic matter digestibility (IVOMD) and nitrogen (N) content, has been noted with *Secale cereale* (Pfahler and Barnett 1986), *Lolium perenne* (Fairey 1985) and *Festuca arundinacea* (Kasperbauer *et al.* 1987). In each case, IVOMD and N concentration increased with ploidy level; and in the case of *F. arundinacea*, the potassium (K)/[calcium (Ca) + magnesium (Mg)] equivalent ratios also increased from diploid to tetraploid to hexaploid level, suggesting that the risk of the metabolic disorder, grass tetany, caused by low dietary Mg, could increase with ploidy level (Kasperbauer *et al.* 1987). However, not all studies show this trend between ploidy levels and nutrient concentrations (Hacker *et al.* 1985; Berardo *et al.* 1989). No comparable data between ploidy levels or cultivars are available for rhodesgrass. There was concern about the low copper (Cu) concentrations ($\approx$ 3 mg/kg) in

Callide rhodesgrass *(Chloris gayana)* from a grazing experiment at Lansdown, near Townsville, north Queensland (R. J. Jones unpublished data). These levels were below the suggested critical range of 8–14 mg/kg for good steer gains (Little 1982).

We investigated whether differences occurred between cultivars which could have implications for animal nutrition. Cu deficiency, for example, is common on the sandy soils of Queensland—mainly sands, sandy podsolics and yellow earths (Bruce 1978). In the soils from northern Australia, the total Cu concentrations ranged from 2 to 54 mg/kg, with most soils studied having values in the range 3–10 mg/kg (Bruce 1978). Variation in the concentration of Cu and other elements important to animal production was subsequently investigated in a range of rhodesgrass cultivars grown in 2 experiments established for other purposes near Gympie in southern Queensland. The first of these experiments was restricted to the 4 rhodesgrass cultivars released in Australia at that time. The scope of the second experiment, however, was expanded to include new Australian material and the 2 major Kenyan cultivars among the 10 cultivars examined.

Table 1. Descriptions of *Chloris gayana* (rhodesgrass) cultivars and lines in experiments 1 and 2

Cultivar line	Origin	Release/first use in Australia	Description	Source
Pioneer[A]	Introduced from South Africa	Early 1900s	Comprises mainly early-flowering, erect types	Christian and Shaw (1952), Cameron (1967)
Topcut[A]	Synthetic cultivar based on 7 plants from cv. Pioneer	1993	Leafier, finer stems, and higher dry matter production than cv. Pioneer	D. S. Loch (unpublished data)
Katambora[A]	Zimbabwean cultivar	Late 1950s	Fine stems and narrow leaves; more stoloniferous than cv. Pioneer	Cameron (1967), Oram (1990)
Line A	Commercial seed ex Bundaberg		More spreading (stoloniferous) and slightly later flowering than line B	D. S. Loch (unpublished data)
Line B	Commercial seed ex Biloela		More upright and earlier flowering than line A; some plants indistinguishable from cv. Pioneer	D. S. Loch (unpublished data)
Nemkat[A]	CPI 125663 (nematode-resistant accession of cv. Katambora)	1992	Spreading (stoloniferous) fine-stemmed cultivar	D. S. Loch (unpublished data)
Finecut[A]	Synthetic cultivar based on 10 plants from cv. Katambora	1993	Leafier, finer stemmed, and higher dry matter production than cv. Katambora	D. S. Loch (unpublished data)
Capital[A]	Synthetic cultivar based on 15 plants from cv. Katambora	u.r.	Similar to cv. Finecut with a broader genetic base	D. S. Loch (unpublished data)
Callide[B]	Q3307 (a giant rhodesgrass from Mpwapwa, Tanzania)	1961	Tall, leafy, strongly stoloniferous and with broader leaves and coarser stems than other cultivars	Cameron (1967), Oram (1990)
Samford[B]	CPI 16144 (surviving Kenyan ecotypes collected in Sierra Leone)	1963	Medium-leafed, very palatable, stoloniferous cultivar	Hutton (1961), Oram (1990)
Elmba[B]	Kenyan cultivar; synthetic based	n.r.	Selected for uniform flowering, improved nutritive value, and higher dry matter and seed yields	Boonman (1978)
Boma[B]	Kenyan cultivar bred from cv. Masaba	n.r.	Selected for uniform flowering, improved nutritive value, and higher dry matter and seed yields	J. G. Boonman (pers. comm.)

[A] Diploids ($2n = 20$). [B] Tetraploids ($2n = 40$). u.r., unreleased—experimental use only; n.r., not released in Australia.

Materials and methods

Cultivars

Table 1 briefly summarises information on the 11 different cultivars and lines of rhodesgrass examined in experiments 1 and 2. They have been grouped into diploids ($2n = 20$) and tetraploids ($2n = 40$) based on available chromosome counts (Hutton 1961; Pritchard and Gould 1964; Jones and Pritchard 1971; Nakagawa and Sato 1981; Loch 1983). In this paper, the term 'cultivar' is used in a broad sense to include one bred (but unreleased) synthetic variety, Capital; and 2 distinct types of the same cultivar (Katambora) from different commercial sources.

Experiment 1

The first experiment was sown at Upper Wonga, 30 km west of Gympie (26°10'S, 152°25'E), in December 1976 on a prairie soil (Gn 3.22; Northcote 1979) developed on diorite–andesite. The chemical analysis of the soil is given in Table 2. The original design comprised of 4 rhodesgrass cultivars (Pioneer, Katambora, Callide, Samford) in factorial combination with 3 rates of fertiliser N, and arranged in 5 randomised blocks (Loch 1983). In this study, sampling was restricted to plots that received 2 × 100 kg N/ha.year (i.e. a total of 20 plots).

All plots were slashed to 10 cm on 22 December 1984, and fertilised with 75 kg N/ha as ammonium nitrate, 250 kg/ha of single superphosphate and 75 kg/ha of potassium chloride on 24 December 1984. Rainfall of 90 mm during January produced leafy regrowth (after 31 days) that was harvested on 22 January 1985. Samples were dried at 80°C, and ground to pass through a 1 mm sieve prior to analysis for N, Ca, Mg, Cu, K, phosphorus (P), sulfur (S), sodium (Na), zinc (Zn), manganese (Mn), iron (Fe), and aluminium (Al) using a multi-element spectroscopic technique (Johnson and Simons 1972).

Experiment 2

The second experiment was planted at Tuncul Park, 35 km south-west of Gympie, in November 1992 on a krasnozem soil (Gn 3.11; Northcote 1979). The chemical analysis of the soil is given in Table 2. Ten rhodesgrass cultivars (Pioneer, Katambora A, Katambora B, Nemkat, Finecut, Capital, Topcut, Callide, Elmba, Boma) were grown in 3 by 3 m plots in a randomised block design with 6 replicates.

For this study, plots were cut to 10 cm and fertilised on 23 August 1993 with 75 kg N/ha as ammonium nitrate and 250 kg/ha of single superphosphate. Samples of leafy regrowth (after 30 days) were cut from each plot on 22 September 1993, and analysed as for experiment 1 although the presence of an additional element boron (B) was also analysed.

Table 2. Chemical properties of Upper Wonga (experiment 1) and Tuncal Park (experiment 2) soils sampled to a 10 cm depth

Chemical property or nutrient	Unit	Experiment 1	Experiment 2
pH (1 : 5 water)	—	6.1	4.90
Electrical conductivity	ms/cm	0.7	0.11
Chloride (1 : 5 water)	mg/kg	12.6	20.00
Nitrate nitrogen (1 : 5 water)	mg/kg	2.7	11.6
Phosphorus (bicarbonate)	mg/kg	71.0	55.0
Sulfate sulfur[A]	mg/kg	20.3	87.0
Calcium[B]	meq/100 g	16.0	1.6
Magnesium[B]	meq/100 g	6.9	0.54
Sodium[B]	meq/100 g	0.19	0.12
Potassium[B]	meq/100 g	0.90	0.27
Copper[C]	mg/kg	7.83	1.57
Zinc[C]	mg/kg	3.27	0.88
Manganese[C]	mg/kg	107.0	429.0

[A] 0.1 mol/L $Ca(H_2PO_4)_2$ extractable.
[B] Exchangeable aqueous NH_4Cl at pH 7.0.
[C] 0.005 mol/L EDTA extractable.

Statistical analyses

Statistical analyses were performed on untransformed data
using the SAS procedure GLM.

In experiment 1, a standard univariate analysis of variance
(ANOVA) was made for each element and the significance of
the differences between cultivars assessed. An additional
derived variate of K/(Ca + Mg) equivalent ratio was calculated
and also analysed by ANOVA. The means for 'diploid v.
tetraploid' were also compared.

In experiment 2, the data were treated in the same way as in
experiment 1. In addition, with the larger data set for this
experiment, a multivariate analysis of variance (MANOVA)
was performed to determine differences between individual
cultivars and to assess the contrasts 'diploids v. tetraploids' and
'Callide v. other tetraploids' that were of interest prior to the

Results

Experiment 1

Concentrations of Na, K, Mg, Ca, and Zn differed
significantly ($P<0.01$) between cultivars (Table 3).
Concentrations of Cu, P, S, Mn, Fe and Al were similar
for all 4 cultivars. Cu concentrations, however, were
double those recorded for Callide rhodesgrass in the
earlier grazing experiment at Lansdown.

Overall, the tetraploids had higher concentrations of
N, K, Ca, Mg and Zn ($P<0.05$), whereas the diploids had
a higher Na concentration. Compared with the other
cultivars, Samford had low Na and high Mg
concentrations (Table 3). There were significant
differences ($P<0.05$) between cultivars and between
ploidy levels in their K/(Ca + Mg) equivalent ratios, with
the 2 diploids having the lowest ratios.

Experiment 2

There were large differences ($P<0.001$) between
cultivars for concentrations of N, S, K, Na, Ca and Mg
(Table 4) and smaller but significant differences
($P<0.05$) for Mn and Fe concentrations. Differences in
the concentrations of P, B, Al, Cu and Zn were not
significant between cultivars and the concentrations of
Cu were approximately double those measured in
experiment 1. Diploids differed from tetraploids in N, S,
K, Na, Mg, Ca, Mn and Fe concentrations. There was a
significant ($P<0.05$) difference between cultivars in their
K/(Ca + Mg) equivalent ratios, with Nemkat having the
lowest ratio and Elmba the highest; the difference
between ploidy levels, however, was not significant.

Table 3. Mineral concentration of the leafy regrowth of four rhodesgrass cultivars (values are the means of five replicates) in experiment 1

	Diploids		Tetraploids		Between cultivars		Diploids v. tetraploids	
	Pioneer	Katambora	Callide	Samford	l.s.d. ($P = 0.05$)	Signif.	l.s.d. ($P = 0.05$)	Signif.
			Concentration (%)					
Nitrogen	1.49	1.59	1.71	1.71	n.s.	0.227	*	0.161
Phosphorus	0.25	0.24	0.24	0.25	n.s.	0.032	n.s.	0.022
Sulfur	0.23	0.24	0.26	0.26	n.s.	0.031	n.s.	0.022
Calcium	1.00	1.03	1.16	1.32	**	0.158	***	0.112
Potassium	0.95	1.16	1.69	1.71	***	0.179	***	0.126
Sodium	0.93	0.98	0.71	0.34	***	0.208	***	0.147
Magnesium	0.13	0.16	0.19	0.28	***	0.029	***	0.021
			Concentration (mg/kg)					
Copper	6.8	5.4	6.4	6.8	n.s.	2.11	n.s.	1.49
Zinc	12.8	12.4	14.2	16.6	**	2.30	**	1.63
Manganese	87.0	83.0	80.0	102.0	n.s.	19.7	n.s.	13.9
Iron	65.0	78.0	77.0	69.0	n.s.	12.7	n.s.	9.0
Aluminium	11.0	14.2	18.2	15.2	n.s.	6.24	n.s.	4.41
K/(Ca + Mg)	0.40	0.46	0.60	0.50	*	0.122	*	0.086

* $P<0.05$; ** $P<0.01$; *** $P<0.001$; n.s., not significant.

Table 4. Mineral concentration of the leafy regrowth of the ten rhodesgrass cultivars (values are means of six replicates) used in experiment 2

| | Diploids | | | | | | | Tetraploids | | | Between cultivars | | Diploids v. tetraploids | |
	Pioneer	Katambora A	Katambora B	Nemkat	Finecut	Topcut	Capital	Callide	Boma	Elmba	l.s.d. (P = 0.05)	Signif.	l.s.d. (P = 0.05)	Signif.
Concentration (%)														
Nitrogen	3.06	3.09	3.02	3.31	2.66	2.95	2.85	3.26	3.27	3.17	***	0.293	**	0.143
Phosphorus	0.22	0.27	0.24	0.25	0.23	0.23	0.24	0.26	0.25	0.25	n.s.	0.029	n.s.	0.014
Sulfur	0.35	0.38	0.28	0.42	0.38	0.28	0.40	0.37	0.50	0.49	***	0.067	***	0.033
Calcium	0.50	0.50	0.45	0.49	0.41	0.42	0.44	0.54	0.60	0.52	***	0.077	***	0.037
Potassium	2.10	2.29	2.36	2.11	2.17	2.09	2.35	2.34	2.99	3.12	***	0.346	***	0.169
Sodium	0.84	0.81	0.80	0.82	0.76	0.98	0.96	0.70	0.02	0.16	***	0.201	***	0.098
Magnesium	0.24	0.28	0.25	0.37	0.26	0.22	0.24	0.30	0.50	0.35	***	0.050	***	0.024
Concentration (mg/kg)														
Copper	14.5	14.3	10.8	13.0	10.2	14.3	12.0	19.8	16.5	12.2	n.s.	7.96	n.s.	3.88
Zinc	20.0	18.5	18.8	17.7	15.3	18.1	17.7	18.7	20.8	18.8	n.s.	4.43	n.s.	2.16
Manganese	231.0	233.0	229.0	201.0	193.0	197.0	216.0	172.0	201.0	182.0	*	39.9	**	19.5
Iron	161.0	173.0	154.0	167.0	138.0	155.0	148.0	192.0	166.0	165.0	*	19.0	*	9.26
Aluminium	25.7	20.8	22.5	22.8	23.7	27.5	26.5	27.5	21.3	19.8	n.s.	7.96	n.s.	3.88
Boron	7.3	6.7	4.8	8.0	6.5	6.7	6.7	6.2	6.0	5.2	n.s.	2.22	n.s.	1.08
K/(Ca + Mg)	1.22	1.23	1.41	1.02	1.35	1.39	1.47	1.18	1.10	1.50	*	0.299	n.s.	0.146

* $P<0.05$; ** $P<0.01$; *** $P<0.001$; n.s., not significant.

Table 5. Summary of the canonical variate (CV) analysis for the ten cultivars (d.f. = 9) used in experiment 2

CV	Eigen value	Cumulative proportion of variance	Canonical correlation	Likelihood ratio test (P)
1	33.292	0.8753	0.985	0.0001
2	1.431	0.9129	0.767	0.0014
3	1.216	0.9449	0.741	0.0163

Approximate F-statistics derived from 4 multivariate tests (Wilks' lambda, Pillai's trace, Hotelling-Lawly trace and Roy's maximum root) were all highly significant ($P<0.001$) for differences between cultivars and for both contrasts, 'diploids v. tetraploids' and 'Callide v. other tetraploids'.

The CVA for cultivars produced 3 significant (i.e. non-zero) canonical correlations (Table 5). A plot of the line centroids of the standardised scores for the
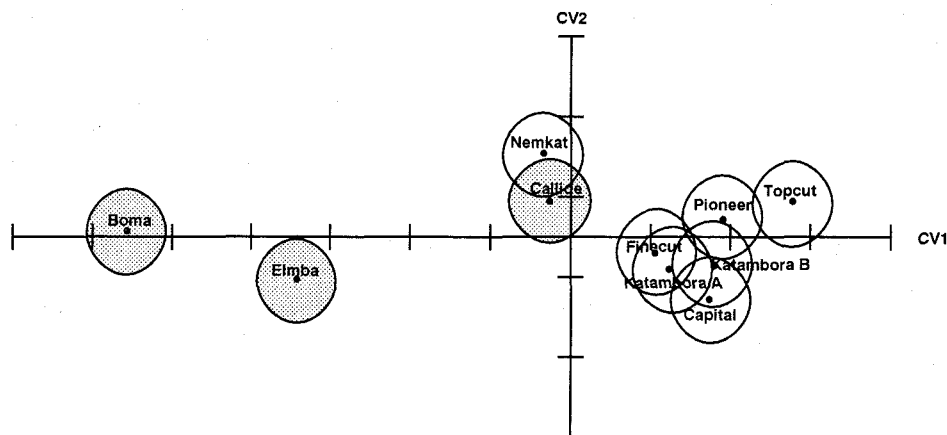

Figure 1. Canonical variate analysis of the mineral concentration of the ten rhodesgrass cultivars used in experiment 2. The groups are mapped into the subspace of the first two canonical discriminant functions CV1 and CV2 of the mineral concentration variates. Circles depict 95% confidence regions around the cultivar centroids of the standardised scores. The confidence regions for the tetraploids are shaded.
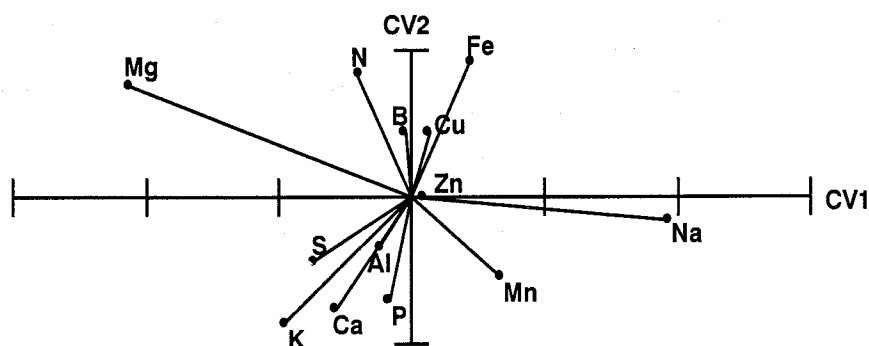
Figure 2. Contributions (standardised coefficients) of the thirteen mineral concentration variates from experiment 2 to the first two standardised canonical discriminant functions CV2 v. CV1.

first 2 canonical discriminant functions shows the differences and similarities among the 10 rhodesgrass cultivars used in experiment 2 (Fig. 1). The standardised function coefficients show the relative contributions of the elements to the canonical discriminant functions (Fig. 2).

The CVA in Figure 1 shows that the 2 Kenyan tetraploids (Boma and Elmba) were significantly different from the other cultivars (P<0.05) and from each other (P<0.05). Boma was defined by high concentrations of Mg, Ca, K and S, and extremely low Na. Elmba differed from Boma by having intermediate concentrations of Mg and Na. The third tetraploid, Callide, was not significantly different from the diploid Nemkat (P>0.05) but tended to separate from it because of higher Ca and K concentrations and lower Na, Mg, S and Mn concentrations. Apart from Nemkat, the diploids formed a fairly tight grouping. Nemkat differed from this group by having higher concentrations of Mg and N.

Discussion

It is well known that differences in mineral composition within genera and species are under genetic control, and that large differences between cultivars or lines can occur (ap Griffiths and Walters 1966; Fleming 1973; Hacker 1982; Hacker et al. 1985). In this study, mineral composition differed between experiments for those cultivars that were common to both. In particular Ca concentrations in experiment 1 were about double those in experiment 2, while all other minerals had a higher or similar concentration in experiment 2. The differences between cultivars were mainly associated with their ploidy level. All of the significant differences between cultivars in experiment 1 were associated with this factor, and Al concentrations also differed between the diploid and tetraploid groups. With a greater number of cultivars, the distinction in experiment 2 was not quite as clear, but the diploid v. tetraploid contrast was highly significant (P<0.001). There were common differences

in concentrations of N, Ca, K, Na and Mg for the 2 experiments which were conducted at different sites and in different years.

It is unlikely that yield differences between cultivars were responsible for the differences in mineral composition. Mean yields at the seeding stage over 2 years varied by only about 20% from the lowest to highest yielding. At the earlier leafy stage of growth, when samples were taken for chemical analysis, the yield differences would have been much smaller.

Differences in mineral composition are also indicative of relationships and differences between individual cultivars. Canonical variate analysis in Figure 1 shows the 2 Australian sources of Katambora closely clustered with the derived cultivars Finecut and Capital. Similarly, Pioneer and the derived cultivar Topcut occur close together. Katambora B originated from a district where Pioneer is widely naturalised, and some plants morphologically similar to Pioneer have been noted in Katambora B in spaced plant studies (D. S. Loch unpublished data); this suggests some introgression from Pioneer, and the closeness of Katambora B to Pioneer in Figure 1 is consistent with this view. Although Nemkat is a Katambora type recently introduced from Zimbabwe, it is morphologically distinct from the Australian Katambora material, a point also reinforced by CVA in Figure 1.

Low Na concentrations in Samford in experiment 1 and in Elmba and (especially) Boma in experiment 2 are consistent with Samford having originated from Kenyan ecotypes, which probably included Mbarara and Masaba from which Elmba and Boma, respectively, were selected. Since these 3 cultivars are not Na accumulators, further studies to determine their salt tolerance relative to the other Na-accumulating rhodesgrass cultivars might also prove interesting given the general reputation of rhodesgrass as a salt-tolerant species. In wheat, low Na/K ionic ratios were shown to be associated with salt tolerance (Chhipa and Lab 1995). The range in the

rhodesgrasses we evaluated was very large, 0.014–1.43, with the tetraploids having much lower ratios.

With the exception of Na, it was the tetraploids that had higher concentrations of nutrients in our study. In contrast, tetraploids have higher Na concentrations than diploids in *Setaria sphacelata* (Hacker and Jones 1969; Hacker 1974), so increasing ploidy level cannot be guaranteed to give similar results for all genera. Jones (1964) reported higher Na concentrations in Katambora rhodes (0.70%) than in Giant rhodes (0.05%) in Zambia (formerly Northern Rhodesia); these are respectively a diploid and a tetraploid cultivar (Moffett 1944; Hutton 1961; Loch 1983). Callide, however, is morphologically similar to the Zimbabwean cultivar Giant, yet contained Na concentrations only slightly lower than the various Katambora types in this study.

It is interesting to note that the available Cu levels in Australian soils are in the order kraznozems > prairie soils > yellow earths (Tiller 1983). This was the ranking for Cu concentration for the rhodesgrasses grown in experiment 2, experiment 1 and at the Lansdown site respectively. However, the soil Cu levels measured in experiment 1 were much higher than in experiment 2, and thus we cannot explain the higher Cu concentrations in the plant material from experiment 2. Although the Lansdown site had the lowest soil Cu level, 1.4 mg/kg (and the lowest plant concentration, 3 mg/kg in Callide), this did not differ greatly from that in experiment 2 of 1.57 mg/kg which gave a plant Cu concentration of 19.8 mg/kg in Callide. The similarity of the Cu concentrations across cultivars in each experiment suggests that rhodesgrass cultivars differ little in their ability to take up Cu. The differences between experiments in plant mineral composition reflected soil differences for levels of N, S, Ca, Mn and Na, but not for P, Mg, K, Cu or Zn (Tables 2, 3 and 4).

Despite the significant differences in mineral composition, all cultivars at leafy preflowering had adequate concentrations of nutrients for the growth of steers, except possibly for Cu in experiment 1 and Na in the cultivar Boma in experiment 2 (Little 1982). Furthermore, the K/(Ca + Mg) equivalent ratios were all well below 2.2, above which grass tetany in ruminants could be a problem, especially under cool conditions (Grunes *et al.* 1970). From the results of an earlier grazing experiment, Cu concentrations as low as 3 mg/kg would also appear adequate for good steer gains (R. J. Jones unpublished data), suggesting that the Cu available to steers is high in rhodesgrass or that the published standards are too high.

References

ap Griffiths, G., and Walters, R. J. K. (1966). The sodium and potassium content of some grass genera, species and varieties. *Journal of Agricultural Science, Cambridge* **67**, 81–9.

Berardo, N., Locatelli, C., Paoletti, R., Valdicelli, L., and Odoardi, M. (1989). Bio-agronomic traits and nutritional value in Italian ryegrass varieties. *In* 'Proceedings of the XVI International Grassland Congress'. 4–11 October 1989, Nice, France. pp. 845–6. (Association Francaise pour la Production Fouragere: Versailles, Cedex.)

Boonman, J. G. (1978). Rhodes grass breeding in Kenya. II. Clonal evaluation for seed yield within maturity classes of two varieties. *Euphytica* **27**, 419–26.

Bruce, R. C. (1978). A review of the trace element nutrition of tropical pasture legumes in Northern Australia. *Tropical Grasslands* **12**, 170–83.

Cameron, D. G. (1967). Rhodes grass still a major sown pasture. *Queensland Agricultural Journal* **93**, 528–36.

Chhipa, B. R., and Lab, P. (1995). Na/K ratios as the basis of salt tolerance in wheat. *Australian Journal of Agricultural Research* **46**, 533–9.

Christian, C. S., and Shaw, N. H. (1952). A study of two strains of Rhodes grass (*Chloris gayana* Kunth.) and of lucerne (*Medicago sativa* L.) as components of a mixed pasture at Lawes in south-east Queensland. *Australian Journal of Agricultural Research* **3**, 277–99.

Fairey, N. A. (1985). Productivity, quality and persistence of perennial ryegrass as influenced by cutting/fertility management and ploidy. *Canadian Journal of Plant Science* **65**, 565–71.

Fleming, G. A. (1973). Mineral composition of herbage. *In* 'Chemistry and Biochemistry of Herbage'. Vol. 1. (Eds G. W. Butler and R. W. Bailey.) pp. 529–66. (Academic Press: London.)

Grunes, D. L., Stout, P. R., and Brownwell, J. R. (1970). Grass tetany of ruminants. *Advances in Agronomy* **22**, 331–74.

Hacker, J. B. (1974). Variation in oxalate, major cations and dry matter digestibility of 47 introductions of the tropical grass setaria. *Tropical Grasslands* **8**, 145–54.

Hacker, J. B. (1982). Selecting and breeding better quality grasses. *In* 'Nutritional Limits to Animal Production from Pastures'. (Ed. J. B. Hacker.) pp. 305–26. (Commonwealth Agricultural Bureaux: Farnham Royal, UK.)

Hacker, J. B., and Jones, R. J. (1969). The *Setaria sphacelata* complex—a review. *Tropical Grasslands* **3**, 13–34.

Hacker, J. B., Strickland, R. W., and Basford, K. E. (1985). Genetic variation in sodium and potassium concentration in herbage of *Digitaria milanjiana*, and its relation to provenance. *Australian Journal of Agricultural Research* **36**, 201–12.

Hutton, E. M. (1961). Inter-variety variation in Rhodes grass (*Chloris gayana* Kunth). *Journal of the British Grassland Society* **16**, 23–9.

Johnson, A. D., and Simons, J. G. (1972). Direct reading emission spectroscopic analysis of plant tissue using a briquetting technique. *Communication in Soil Science and Plant Analysis* **3**, 1–9.

Jones, D. I. H. (1964). Mineral content of some cultivated grasses sown in Northern Rhodesia. *Rhodesian Journal of Agricultural Research* **2**, 57–9.

Jones, R. J., and Pritchard, A. J. (1971). The method of reproduction in Rhodes grass (*Chloris gayana* Kunth). *Tropical Agriculture, Trinidad* **48**, 301–7.

Kasperbauer, M. J., Karlen, D. L., and Burton, H. R. (1987). Ploidy effects on protein, *in vitro* dry matter disappearance, and potassium/(calcium + magnesium) equivalent ratio in tall fescue forage. *Crop Science* **27**, 1081–2.

Little, D. A. (1982). Utilization of minerals. *In* 'Nutritional Limits to Animal Production from Pastures'. (Ed. J. B. Hacker.) pp. 259–83. (Commonwealth Agricultural Bureaux: Farnham Royal, UK.)

Loch, D. S. (1983). Constraints on seed production of *Chloris gayana* cultivars. PhD Thesis. (University of Queensland: St Lucia, Australia.)

Mardia, K. V., Kent, J. T., and Bibby, J. M. (1979). 'Multivariate Analysis.' pp. 338–48. (Academic Press: London.)

Moffett, A. A. (1944). Note on the cytology of Rhodes grass. *Rhodesia Agricultural Journal* **41**, 11–13.

Nakagawa, H., and Sato, H. (1981). Cytological studies on tropical grasses. 1. Meiosis of pollen mother cells and the formation of pollens of Rhodes grass (*Chloris gayana* Kunth). *Bulletin of the Kyushu National Experiment Station* **21**, 317–31.

Northcote, K. H. (1979). 'A Factual Key for the Recognition of Australian Soils.' 4th Edn. (Rellim Technical Publications: Glenside, S. Aust.)

Oram, R. N. (1990). 'Register of Australian Herbage Plant Cultivars.' 3rd edn. (CSIRO Division of Plant Industry: Canberra.)

Pfahler, P. L., and Barnett, R. D. (1986). Diploid–tetraploid comparisons in rye. II. Forage quality. *Crop Science* **26**, 185–8.

Pritchard, A. J., and Gould, K. F. (1964). Chromosome numbers in some introduced and indigenous legumes and grasses. CSIRO Division of Tropical Pastures Technical Paper No 2.

Tiller, K. G. (1983). Micronutrients. *In* 'Soils: an Australian Viewpoint'. pp. 365–87. (CSIRO: Melbourne/Academic Press: London.)