CSIRO PUBLISHING

The Rangeland Journal, 2016, **38**, 553–567
http://dx.doi.org/10.1071/RJ15122

Comparison of stocking methods for beef production in northern Australia: seasonal diet quality and composition

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Abstract. Managing and measuring the grazing and nutrition of cattle are required to improve the productivity and profitability of beef businesses in northern Australia. The quality and composition of the diet selected by cattle grazing in three stocking methods (continuous, extensive rotation and intensive (cell) rotation) on nine commercial properties in Queensland were estimated using near infrared reflectance spectroscopy analyses of fresh faeces; 585 faecal samples were analysed between 2005 and 2009. Sites were in two regions (north and south Queensland) and on two vegetation communities, namely brigalow (*Acacia harpophylla* F. Muell. ex Benth.) on clay soils and eucalypts on light-textured soil types. Pastures were dominated by perennial sown exotic grass species, predominantly *Cenchrus ciliaris* L. (buffel grass) at five sites and *Urochloa mosambicensis* (Hack.) (Sabi grass) at one site, and by native perennial tussock grasses at three sites. Seasonal profiles of dietary crude protein, dry matter digestibility, faecal nitrogen concentration, proportion of non-grass, ratio of crude protein to digestibility and an estimate of liveweight gain are presented for each stocking method. Overall, dietary crude protein, digestibility, faecal nitrogen, the crude protein : digestibility ratio and liveweight gain were significantly higher for animals grazed continuously, with short rest periods, than for animals in extensive or intensive rotations. There was a significant interaction between stocking method and pasture growing conditions, measured as a simulated growth index, for dietary crude protein and faecal nitrogen. There was no difference between stocking methods during periods when the index was <0.2, indicating no pasture growth, but during periods of active growth (index >0.5), crude protein and faecal nitrogen were higher with continuous grazing than in the extensive and intensive rotations. For cattle producers considering alternative stocking methods, the results suggest they can obtain similar ecological responses under any of the three methods and diet quality will be higher during the pasture growing period in continuously grazed pastures.

Additional keywords: cell grazing, continuous grazing, dietary crude protein, digestibility, faecal near infrared reflectance spectroscopy, liveweight gain, rotational grazing.

Received 11 December 2015, accepted 7 November 2016, published online 16 December 2016

Introduction

Cattle producers in northern Australia are evaluating different stocking methods in attempts to improve land condition, reduce any previous degradation and increase the productivity and profitability of their businesses. A stocking method is defined as a procedure or technique to manipulate animals in space and time to achieve a specific objective (Allen *et al*. 2011). Improving the nutritional intake of cattle is a key component of increasing the performance of a beef herd. The traditional stocking method is continuous grazing, which some producers have replaced with rotational stocking of varying intensities, from extensive rotations with few paddocks (e.g. 6–15) to more intensive rotational stocking methods that have more paddocks (usually >30). This intensive stocking includes time-controlled grazing methods of cell grazing and short-duration grazing. Producers use high stock densities, many paddocks and short grazing periods to allow better control of defoliation and grazing pressure, and to potentially harvest forage more efficiently and improve land condition (McCosker 2000). Varying results have been reported by using these methods. Cattle and Southorn (2010) reported that high-intensity, short-duration grazing by sheep maintained soil surface condition relative to continuous stocking.

This was due to preservation of macroporosity, which affects soil structure and plant growth. However, a recent study in northern Australia of three stocking methods (continuous, extensive rotation, intensive rotation) in well-managed pastures on nine commercial cattle properties over a 4-year period (Hall *et al.* 2014) reported similar average stocking rates for all methods. There were no consistent effects of stocking methods on pasture herbage mass, plant species composition, total ground and litter cover, or on soil surface condition. These results are supported by a meta-analysis of the global literature that found holistic planned grazing (a form of intensive rotation) had no effect on plant biomass or basal cover compared with continuous or other rotational forms, although spatial utilisation of forage increased, likely due to reduced selectivity by grazing animals (Hawkins 2016).

Provided sufficient feed quantity is available, the quality of the diet consumed by cattle is one of the main determinants of productivity, including reproductive performance, growth rate and carcass quality. Although Briske *et al.* (2008) concluded from their study of stocking methods that both plant and animal production are equal or greater under continuous grazing compared with rotational grazing, it is possible that stocking methods can affect diet quality by affecting forage selectivity and availability for grazing, and hence animal production. Previous studies of the effects of stocking methods on diet quality have given equivocal results. Several studies have shown no difference in diet quality, measured as crude protein concentration and digestibility, between continuous and rotational grazing (Pitts and Bryant 1987; Olson and Malechek 1988; Ortega *et al.* 1997; Popp *et al.* 1997). Both higher- (Hirschfeld *et al.* 1996) and lower-quality diets (McCollum and Gillen 1998; Hao *et al.* 2013) have been reported for animals grazing rotational stocking methods compared with those grazing continuous methods.

In recent years, methods using faecal near infrared reflectance spectroscopy (F.NIRS) have been developed to predict the quality of a diet selected by grazing cattle (Brooks *et al.* 1984; Stuth *et al.* 1989; Lyons and Stuth 1992; Lyons *et al.* 1995). In Australia, these methods have been used to develop predictive equations that provide a better understanding of seasonal changes in diet quality selected by cattle grazing tropical pastures (Coates 1999, 2004; Coates and Dixon 2007). The accuracy of F.NIRS predictions of diet quality and the nutritional status of cattle across a range of pasture qualities from the black speargrass and *Aristida–Bothriochloa* native pasture land types (Weston and Harbison 1980), as well as from buffel grass (*Cenchrus ciliaris* L.) pastures, has been confirmed for these pastures in tropical Australia (Dixon and Coates 2005; Coates and Dixon 2007, 2008) and elsewhere (Boval *et al.* 2004). The F.NIRS method and predictive equations have also been widely evaluated on 151 commercial properties representing 119 land types across Queensland and the Northern Territory (Jackson *et al.* 2009). The F.NIRS procedure has since been commercialised, giving confidence in using the technology to compare diet quality in grass-dominant pastures in different stocking methods and environments across Queensland. The role of F.NIRS, now a relatively rapid and economic method of quantifying diet quality, in managing cattle nutrition and productivity has recently been reviewed by Dixon and Coates (2015).

Because previous results on diet quality selected between stocking methods are inconclusive, this proven, fresh faecal sample collection, drying and F.NIRS analytical method, with its associated predictive equations for Australian tropical pastures, was chosen for the present study. The F.NIRS method was used to analyse the diet quality selected by beef cattle grazing in two or three stocking methods on nine commercial grazing properties over 4 years. These diet quality estimates were related to pasture growing conditions to aid interpretation of differences and increase the generality of the results.

Methods

Property (site) details

Nine commercial cattle properties (sites) were selected in two regions: north and south Queensland. The sites were located near the towns of Blackwater, Bowen, Condamine, Clermont, Injune, Mundubbera, Richmond, Rockhampton and Surat (Fig. 1). In each of the two regions, sites were located in two vegetation communities. Brigalow forests (*Acacia harpophylla* F. Muell. ex Benth.) represent higher-fertility, heavier-textured clay soil types, whereas eucalypt woodlands (predominantly *Eucalyptus populnea* F. Muell., *Eucalyptus crebra* F. Muell., and *Eucalyptus melanophloia* F. Muell.) represent lower-fertility, light-textured loam soil types. On each property, there were two or three established stocking methods, namely continuous, extensive

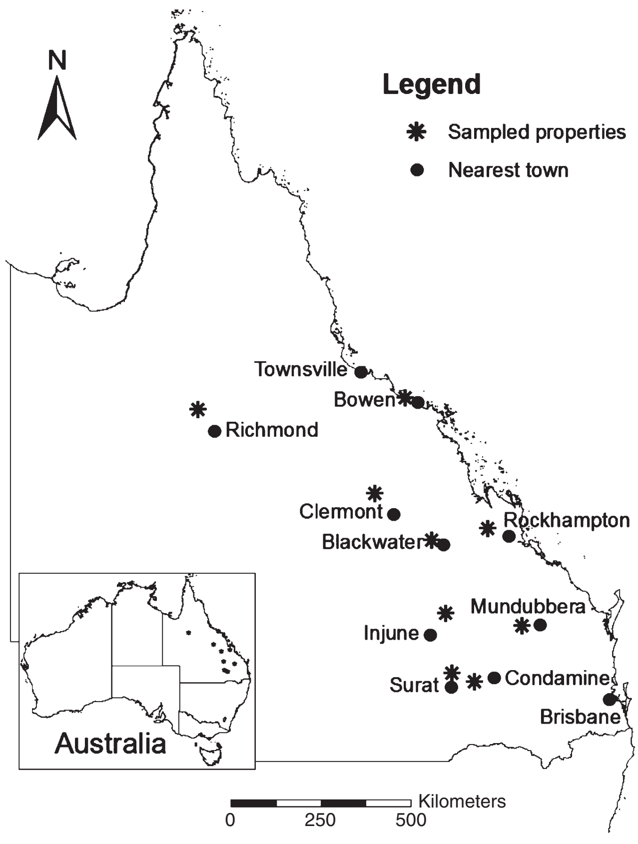

Fig. 1. Location of the nine properties and nearest towns across Queensland, Australia, sampled for faecal near infrared reflectance spectroscopy analysis between November 2005 and June 2009.

rotations and intensive rotations (locally referred to as cells; see Table 1). Further details of the nine properties, the pasture composition, which was dominated by C_4 native or sown exotic grasses, the soils (loams, duplex and clays), paddock selection, stocking methods, ecological monitoring and the research approach have been described by Hall *et al*. (2014).

The pastures on the nine properties were managed by the property owners throughout the sampling period. All owners had been trained formally in pasture management principles and they adjusted the individual paddock stocking rates and grazing periods to their assessed seasonal carrying capacity. Rest periods were included in all three stocking methods. Within each site, all stocking methods were managed similarly (stock numbers, cattle classes, grazing timing and intensity, as well as rest periods) with consideration of the annual pasture production. The property owners used various methods to assess their pastures, but stocking rates were based primarily on their past experience of each particular paddock and on their analysis of the paddock grazing charts. Classes of cattle at the sites included breeders, steers and/or heifers and mixed herds.

The continuous stocking methods were sampled at seven sites (Table 2): one paddock was sampled at each site, with an average paddock area of 551 ha (range 110–1304 ha). The extensive rotation methods were sampled at six sites: two or three paddocks were sampled at each site, but only one paddock was sampled on each occasion, with an average paddock area of 435 ha (range 38–1258 ha). The intensive rotation methods were sampled at eight sites: five to 11 paddocks were sampled at each site, with one paddock sampled on each occasion and an average paddock area of 58 ha (range 6–172 ha). The maximum distance to water points was less than 2 km in all paddocks and less than 1 km in most paddocks.

In the continuously grazed pastures, cattle were present in the paddock for most of the year and any rest periods were of short duration during the growing season. For the continuous stocking method, faecal samples were only collected from the herds when they were grazing the monitored paddocks. The average annual grazing duration was 311 days. In the extensive rotations, there were six to 18 rotation paddocks on a property. Grazing periods ranged from 5 days to 12 months (one occasion only) per paddock, with average annual grazing of 149 days. In the intensive rotations, there were 22–160 paddocks on a property. The grazing periods ranged from 1 to 17 days, with an average annual paddock grazing of 12 days. Over the nine sites, the average annual grazing pressure, measured in stock grazing days per ha (SDH) and in animal equivalents (AE), was similar ($P > 0.05$) for the 4 years at 95, 77 and 97 SDH (equivalent to 26.0, 21.6 and 26.6 AE km^{-2}) for the continuous, extensive rotation and intensive rotation stocking methods respectively.

Urea supplement programs

Three sites, namely Bowen, Condamine and Richmond, provided urea-based dry season supplements on occasions. A urea supplement was provided in the water supply during the dry seasons to both stocking methods at the Condamine site during the sampling period, and a dry urea supplement was provided in open troughs at the Bowen site in some intensive rotation paddocks in the late dry season of some years. In the first 2 years (i.e. 2005 and 2006), growing cattle in one rotation paddock sampled at the Richmond site received a nitrogen supplement (molasses with 4% urea) in the mid- to late-dry season and the cattle in the intensive rotation received urea-medicated water. These are standard beef industry supplement practices, especially in north Queensland. All samples are included in the analysis because Dixon and Coates (2005) demonstrated the capacity of F.NIRS to estimate diet quality in urea-supplemented cattle grazing on tropical grass pastures. However, there is less reliability and probably an underestimate in the liveweight gain (LWG) predictions of supplemented animals because the F.NIRS prediction is the potential for unsupplemented animals, which can be directly compared with predictions from the other sites. There were no protein concentrate supplements or hay provided in any sampled paddocks at any site, which would have affected the accuracy of the diet quality analysis (Dixon and Coates 2010).

Pasture sampling

Pasture herbage mass and species composition were recorded in the autumn of 2005, 2006 and 2009 by the Botanal method (Tothill *et al*. 1992) and are reported in Hall *et al*. (2014). For the present study, sown and native legumes, forbs and sedges were combined as the pasture non-grass component. Shrubs and woody regrowth (<3 m tall) were estimated as foliage cover (percentage). Any mature shade trees or the population of trees at

Table 1. Region of Queensland, vegetation type, soil type, land type and major grass species at nine sites in Queensland[A]
Plant names are according to Henderson (1997)

Region	Vegetation type	Sites[B]	Soil type	Land type	Major grass
North	Brigalow	Blackwater	Heavy clay	Brigalow, blackbutt	*Cenchrus ciliaris*
		Clermont	Heavy clay	Brigalow, gidgee	*Cenchrus ciliaris*
	Eucalypt	Bowen	Sandy duplex	Poplar gum	*Urochloa mosambicensis*
		Rockhampton	Loam duplex	Silver-leaved ironbark	*Bothriochloa ewartiana*
		Richmond	Sandy duplex	Sandy forest, bauhinia	*Aristida* spp.
South	Brigalow	Injune	Clay–loam	Brigalow, poplar box, bauhinia	*Cenchrus ciliaris*
	Eucalypt	Mundubbera	Loam duplex	Silver-leaved ironbark	*Heteropogon contortus*
		Condamine	Loam duplex	Poplar box	*Cenchrus ciliaris*
		Surat	Loam duplex	Poplar box, silver-leaved ironbark	*Cenchrus ciliaris*

[A]Detailed site descriptions are reported in Hall *et al*. (2014).
[B]Town nearest to the property (research site).

Table 2. Number of faecal samples analysed from three stocking methods at nine sites between 2005 and 2009

	Stocking method			Total no. samples
	Continuous	Extensive rotation	Intensive rotation	
Site				
Blackwater	29	40	35	104
Bowen	30	–	25	55
Clermont	23	32	25	80
Condamine	15	–	37	52
Injune	39	–	39	78
Mundubbera	29	29	–	58
Richmond	–	10	24	34
Rockhampton	29	31	32	92
Surat	–	14	18	32
Total no. samples	194	156	235	585
No. sites for each stocking method	7	6	8	21

the Richmond site were not recorded, and were not considered to affect the diets consumed by the cattle.

Faecal sampling

In all, 585 fresh faecal samples were collected over 4 years from the nine sites at approximately 4- to 6-weekly intervals between November 2005 and June 2009. The number of samples from each stocking method (total between 156 and 235) at the nine sites is given in Table 2. All faecal samples were collected fresh by a project team member or the property owner or staff. Each F. NIRS sample was a minimum of 200 mL bulked from 10 fresh faecal pats, usually collected mid-morning when cattle were near water. These samples were sun dried for approximately 3 days or oven dried at 60°C for approximately 30 h before posting to the laboratory at CSIRO Townsville for NIRS analysis. The samples from different stocking methods at a site were usually collected on the same day, but on occasions 1–3 days apart. At three sites (Blackwater, Clermont and Rockhampton), all three stocking methods were sampled on the same day on 25, 20 and 28 occasions respectively.

F.NIRS analyses

All 585 faecal samples were analysed by the same method on the same NIRS machine by the one operator to maintain consistency across sites and years. Samples were oven-dried at 65°C and then ground through a Model 1093 Cyclotec mill fitted with a 1-mm screen (Foss Tecator AB, Hoganas, Sweden). Analysis samples were then redried (65°C) and scanned (400–2500 nm range) in a monochromator fitted with a spinning cup module (Foss 6500; NIR Methods) using Infrasoft International software (Coates 2004).

Three standard F.NIRS predictions of diet quality were analysed: (1) dietary crude protein (DCP); (2) dry matter digestibility (DMD); and (3) faecal nitrogen (FN) concentration. Dietary non-grass proportion (DNG) and ash content were also analysed. The dietary grass component comprises the C_4 tropical exotic and native perennials and annual grasses, whereas the non-grass component comprises the C_3 legumes, forbs, sedges and browse. LWG or average daily gain (kg $head^{-1}$ day^{-1}) was predicted based on a calibration assuming a medium-frame Brahman cross steer weighing 300 kg (Coates 2002). These assessments will tend to be overestimates for older animals and pregnant or lactating cows (Dixon and Coates 2005). Because animal classes varied between stocking methods and sites (Hall *et al*. 2014), the LWG prediction data are viewed as an index of LWG potential rather than representing the actual LWG of each herd in each paddock. All calculations were made using calibration equations developed for Australian tropical C_4 grass-dominant pastures at the CSIRO Davies Laboratory in Townsville (Coates 2004; Coates and Dixon 2008). The ash content of each sample was analysed to assess sample purity and any high results were considered contaminated with soil at collection (Coates 2004) and were discarded.

Two diet quality predictions, namely DCP and DMD, were used to calculate the DCP : DMD ratio for every sample as an additional assessment of diet quality. This ratio is the reverse of the original DMD : DCP ratio (Dixon and Coates 2005) and has been recently recommended (R. Dixon, pers. comm.) because it increases as diet quality increases. Thresholds are the same with protein deficiency at approximately $\leq$0.125, which is equivalent to a DMD : DCP ratio of 8. Although the ratio has not been validated on some pasture types where cattle have a high proportion of browse in the diet, results were included from all samples because eight sites were in cleared woodlands or forests with grass-dominant pastures that had negligible palatable woody browse material. The DMD : DCP ratio can be a useful guide to the likely response to supplementary nitrogen and is valid provided there is adequate dry standing feed (Dixon and Coates 2005). The most common woody plants on the brigalow land type were brigalow suckers or seedlings, which have low palatability but may be lightly browsed (Department of Agriculture and Fisheries, Queensland Government 2012). In south Queensland, *Carissa ovata* R.Br. (current bush) occurred at the eucalypt sites and at Richmond *Carissa lanceolata* R.Br. (conkerberry), another current bush species, was the most common shrub. The *Carissa* shrubs are not readily eaten (Department of Agriculture and Fisheries, Queensland Government 2012) and were not observed to be grazed during the monitoring period.

Seasonal pasture growth

Because pasture quality varies with seasonal conditions, a growth index from the pasture simulation model, GRASP (Littleboy and McKeon 1997), was used to explore the effect of seasonal conditions during the recording period on diet quality across all sites. GRASP is a point-based, dynamic, soil–pasture–animal growth model (McKeon *et al*. 2000) developed and validated for Australian tropical grasslands. GRASP simulates soil water from daily inputs of rainfall, temperature, humidity, evaporation and solar radiation. Pasture growth is calculated from transpiration but includes the effects of vapour pressure deficit, temperature, radiation, soil nitrogen availability and grass basal area.

The GRASP model was run for the major vegetation type of the monitored paddocks on each of the nine sites. Basic 'mrx' files developed by the Queensland Departments of Agriculture and Fisheries and Natural Resources and Mines were selected for the different land types (Whish 2011). These were calibrated by comparing model output with measured presentation yields at the end of the growing season (Hall *et al*. 2014) at each of the nine sites. Daily weather data (maximum and minimum temperatures, rainfall, pan evaporation, radiation and vapour pressure) were taken from the SILO database (Jeffrey *et al*. 2001). Although there was some variation in the stock numbers on properties over time and between stocking methods (Hall *et al*. 2014), a common and locally acceptable pasture utilisation rate of 20% for well-managed pastures was used for all properties. This rate is near or below the safe utilisation rate at each site and is consistent with the generally good condition of the pastures (Hall *et al*. 2014). Grass basal area was set to 4% for all land types. GRASP was run using climate data (rainfall, temperature, humidity, evaporation and solar radiation) from 2002 to 2009, which covered a spin-up period of 3 years and the period over which the faecal samples were collected. The values for important soil and pasture parameters that varied between sites are given in Table 3. A full description of the GRASP equations used in the calculations is given in Littleboy and McKeon (1997).

The GRASP model calculates a pasture growth index (GI) as a function of water, temperature and nutrient (nitrogen) supply. This GI varies from 0 to 1, where 0 indicates there is no growth and 1 indicates conditions are optimal and there are no limitations to pasture growth. The average GI over the 30 days before each faecal sample collection date was calculated to provide an estimate of growing conditions during the period likely to most affect recent pasture growth and hence current diet quality on the sampling date. Three GI classes were created: <0.2, 0.2–0.5 and >0.5. When the average GI was <0.2, pastures were dry and there was little or no pasture growth; when the average GI was >0.5, pastures had green leaf and conditions were good for growth; and when the average GI was between 0.2 and 0.5, there was some growth and green forage available.

Statistical analyses

Full F.NIRS dataset

The complete dataset (585 faecal samples) was analysed with linear mixed models using residual maximum likelihood (REML; Payne *et al*. 2011) in GENSTAT (VSN International 2012). All interactions were screened, and the non-significant ones omitted from the final model. For all variables, the residual plots were approximately normal, so no transformations were considered. The fixed effects (independent terms) were: (1) stocking method (continuous, extensive rotation, intensive rotation); (2) region (north, south); (3) vegetation type (brigalow, eucalypt); (4) year (of wet season: 2005–06, 2006–07, 2007–08, 2008–09); and (5) pasture growth seasons (as GI classes <0.2, 0.2–0.5, >0.5).

The random effects in the mixed models were: (1) sites (nine) within each region; (2) stocking methods within the sites (continuous, extensive rotation, intensive rotation); and (3) faecal samples within each stocking method.

Significance was tested using the *F*-statistic (the Wald statistic divided by the degrees of freedom). Where significant differences ($P < 0.05$) were observed, least significant differences (l.s.d.) were calculated to compare means.

The relationship between DCP and FN was estimated for each stocking method using general linear models, testing for an interaction with (and hence any differences between) each of the design factors.

F.NIRS sample subsets

The samples from different stocking methods at a site were not always taken on the same day. To avoid any effect the 1–3 day difference in sampling date may have on results, a separate REML analysis was conducted for the three sites (Blackwater, Clermont and Rockhampton) where the three stocking methods were sampled on the same day, on 25, 20 and 28 occasions respectively.

To investigate any relationships between dietary non-grass in the faecal samples and the two forms of non-grass in the pastures (i.e. the herbaceous layer (exotic and sown legumes, forbs and sedges) and the woody layer (trees and shrubs)), a separate correlation analysis was conducted. The pasture non-grass and woody plant data collected in autumn of 2006, 2007 and 2009 were correlated with the mean F.NIRS diet non-grass values during March–June each year. Diet samples collected in these months more closely represent the time the paddock pastures were recorded.

Results

Rainfall

Daily rainfall was recorded at the property homestead at each site. Annual totals and long-term means (Table 4) indicate there was a drought period in the first 2 years (2005–06 and 2006–07; average decile 3.4) and above-average rainfall in the last 2 years (2007–08 and 2008–09; average decile 6.3). The pasture growing conditions varied widely between the wet and dry seasons, as well as between the drought and above-average

Table 3. GRASP[A] pasture growth model parameters for nine sites in Queensland

TUE, transpiration use efficiency (i.e. the amount of pasture biomass produced per unit transpiration); BA, pasture basal area

GRASP parameter	Blackwater	Bowen	Clermont	Condamine	Injune	Mundubbera	Richmond	Rockhampton	Surat
Tree basal area (m^2 ha^{-1})	1	1	1	1	1	0	3	1	0
Soil water-holding capacity (mm)	183	120	102	90	84	76	150	202	110
Maximum N uptake[B] (kg ha^{-1})	25	25	20	20	20	20	15	25	20
Regrowth[C] (kg ha^{-1} per % BA^{-1})	6.5	6	3.5	3.5	6	2	5	6	7
TUE (kg ha^{-1} mm^{-1})	25	15	20	16	15	13.5	13.5	15	20
Minimum N concentration (%)	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.5

[A]GRASP is a point-based, dynamic, soil–pasture growth–animal growth simulation model (McKeon *et al*. 2000).
[B]Maximum N uptake is maximum annual nitrogen uptake by the pasture.
[C]Regrowth is potential pasture regrowth rate per unit grass BA.

rainfall years across the sites during the 4 years of measurements. The tropical pastures rely on the summer rainfall at all sites, with potential for additional herbage growth in winter–spring (April–September) at the southern sites in the winter dry season. The two most southern sites (Condamine and Surat) received above-average 'winter rain' between June and September (>200 mm) in the dry season of 2007. Only the first 2 years of rainfall at the Richmond site were recorded before the stocking methods were changed, so only the rainfall for these 2 years are presented.

Relationships between DCP and FN

There was a strong relationship between DCP and FN (regression $r = 0.867$) with a significant but relatively small difference between stocking methods. The relationships for the intensive and extensive rotations were effectively the same, but the continuous method was consistently 0.048% higher than both rotation methods (Fig. 2). Region, vegetation community or season had no significant effect on this relationship.

F.NIRS diet quality

The main effect of stocking method was significant for DCP, DMD, LWG and DCP : DMD ratio (Table 5). Diet quality was highest for continuously grazed animals and lowest for animals in intensive rotations. Diet quality was intermediate for animals from the extensive rotations.

There were significant differences in diet quality between years and pasture growth seasons (as GI classes) for the diet quality measurements (Table 5). Overall, the probabilities for year and season were much stronger than those for stocking method, indicating climatic conditions of the year and seasons had a greater effect on diet quality than the stocking method.

There was a consistent and dominant interaction between stocking method and GI class for diet quality parameters (Fig. 3), although this interaction was not significant for DMD and LWG. When growing conditions were poor (GI <0.2), there were no significant differences between stocking methods. Under intermediate growth conditions (GI 0.2–0.5), levels of DCP and DCP : DMD were all significantly higher with continuous grazing than in the intensive rotations; levels for the extensive rotations were between those for continuous and intensive rotations. Under good growing conditions (GI >0.5), levels of DCP (Fig. 3*a*), FN (Fig. 3*b*), DMD (Fig. 3*c*) and DCP : DMD (Fig. 3*f*) were significantly higher for continuous grazing than for both the rotational methods. There was a wide variation in non-grass within the three stocking methods and GI classes (Fig. 3*d*) and LWG followed the same trend, increasing for each method as the GI class increased (Fig. 3*e*).

The mean monthly values for diet quality, non-grass and LWG are shown in Fig. 4. Values for DCP ranged from a high of 12.6% (mean of stocking methods and sites) in February 2007 to a low of 5.3% in August 2008. There was a similar seasonal and annual variation in DMD from a mean high of 63% to a low of 51.5% in the same months of these 2 years. Both diet parameters, and in particular DCP, were sensitive to seasonal rainfall conditions. The continuous method tended to have higher peaks and shallower troughs in DCP (Fig. 4*a*) and DMD (Fig. 4*b*) through time than either of the rotational stocking methods. The DCP : DMD ratio followed a similar pattern to the DCP, with highest values from the continuous method and lowest from the intensive rotations (Fig. 4*d*). The ratio was below the approximate limiting value of 0.125, indicating protein deficiency, on a greater proportion of sample occasions for the intensive method than in the continuous method. The non-grass in the diet fluctuated with all methods and had higher values in the continuous method, with the highest values (>30%) in the continuous method in the winter of 2007 and lowest values (<10%) in the rotation methods in the late summer of 2008–09 (Fig. 4*c*). Mean monthly

Table 4. Annual rainfall recorded at site homestead between 2005–06 and 2008–09 and long-term mean rainfall at nine sites
NA, not applicable (because stocking methods were altered and site was not recorded in these years)

	Annual rainfall (mm)				
	2005–06	2006–07	2007–08	2008–09	Long-term (>100 years)
Site					
Blackwater	332	534	576	636	573
Bowen	771	758	1232	1318	987
Clermont	532	548	682	600	572
Condamine	418	435	662	667	541
Injune	445	432	659	803	710
Mundubbera	460	564	559	606	693
Richmond	636	524	NA	NA	503
Rockhampton	590	488	898	692	690
Surat	495	301	586	617	537
Mean across sites	520	509	732	742	

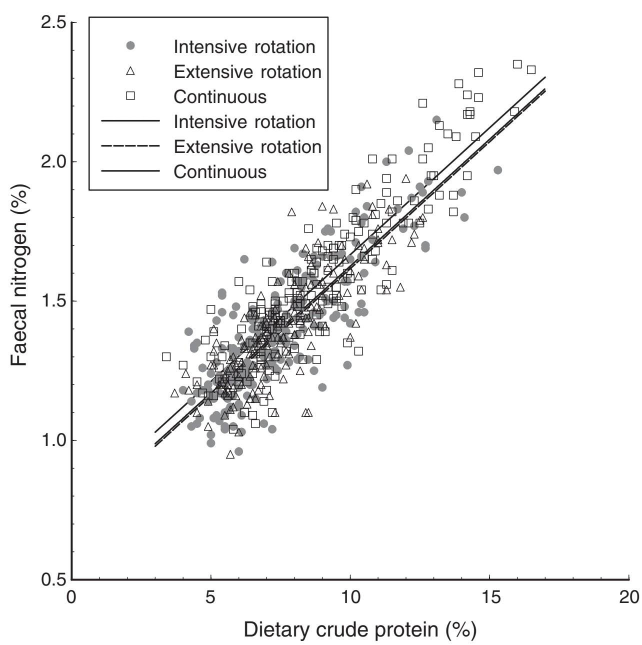

Fig. 2. Relationship between dietary crude protein and faecal nitrogen for three stocking methods (intensive rotation, extensive rotation and continuous) across nine sites and 4 years (585 samples). The functions are as follows: for intensive rotation, faecal N = 0.09104 × crude protein + 0.7148; for extensive rotation, faecal N = 0.09104 × crude protein + 0.7059; and for continuous, faecal N = 0.09104 × crude protein + 0.7560.

Table 5. Diet quality and composition main effects for stocking method, season (growth index (GI) class), vegetation type, year and region for 585 samples at nine sites

Data show adjusted means and average s.e. from the residual maximum likelihood (REML) analysis. For main effects: NS, not significant ($P>0.05$); *$P<0.05$; **$P<0.01$; ***$P<0.001$. For mean values for a main effect, different letters indicate significant differences ($P\leq 0.05$). LWG, liveweight gain; DCP, dietary crude protein; DMD, dry matter digestibility

Parameter	No. observations	Crude protein (%)	Faecal N (%)	Digestibility (%)	Non-grass (%)	LWG (kg head^{-1} day^{-1})	DCP : DMD ratio
Stocking method		**	*	*	NS	*	**
Continuous	194	9.24a	1.6a	57.8a	20.6	0.81a	0.158a
Extensive rotation	156	8.45ab	1.48ab	56.6ab	21.3	0.71b	0.147b
Intensive rotation	235	8.14b	1.46b	56.4b	18.1	0.71b	0.143b
s.e.		0.3	0.04	0.6	1.7	0.04	0.004
Season (GI class)		***	***	***	NS	***	***
<0.2	253	7.15c	1.37b	54.3c	20.6	0.48c	0.130c
0.2–0.5	180	8.92b	1.54a	57.4b	20.0	0.81b	0.153b
>0.5	152	9.77a	1.63a	59.0a	19.4	0.94a	0.164a
s.e.		0.29	0.04	0.5	1.6	0.04	0.004
Vegetation type		*	NS	*	NS	*	NS
Brigalow	283	8.87a	1.52	57.5a	16.9	0.79a	0.151
Eucalypt	302	8.36b	1.51	56.3b	23.1	0.70b	0.147
s.e.		0.33	0.04	0.6	1.9	0.05	0.004
Year		***	**	***	***	***	***
2005–06	114	8.49b	1.5ab	58.8a	17.9bc	0.80a	0.143b
2006–07	162	8.94ab	1.53ab	57.0b	22.0ab	0.75a	0.154a
2007–08	160	9.49a	1.56a	57.3ab	23.7a	0.86a	0.163a
2008–09	149	7.52c	1.46b	54.6c	16.4c	0.56b	0.136b
s.e.		0.3	0.04	0.6	1.6	0.04	0.004
Region		NS	NS	NS	NS	NS	NS
North Queensland	365	8.11	1.47	56.1	19.7	0.67	0.143
South Queensland	220	9.11	1.56	57.7	20.3	0.82	0.155
s.e.		0.37	0.05	0.7	2.1	0.05	0.004

LWG fluctuated from a high of 1.4 kg head^{-1} day^{-1} in the continuous method in the summer of 2007–08 to a low of 0.2 kg head^{-1} day^{-1} in the rotation methods in the winter of 2008 (Fig. 4*e*).

There were significant ($P<0.05$) differences between vegetation types (Table 5). The brigalow sites produced a higher mean DCP (by 0.5%), DMD (by >1%) and projected LWG (by 0.09 kg head^{-1} day^{-1}) than the eucalypt sites.

Although there were no significant differences in diet quality parameters between the two regions (Table 5), the GI class × region interaction was significant There were no differences in diet quality between north and south regions when the GI was <0.2. When the GI was between 0.2 and 0.5, levels were higher in the south, significantly so for DCP, DMD, DCP : DMD and LWG. Under good growing conditions (GI >0.5), levels were again higher in the south region, but the differences were significant only for LWG. The seven highest DCP values (mean 14.4%) were recorded at Condamine and Injune, two southern sites in the winter of 2007, reflecting the temperate forbs and legumes responding to the above-average winter rainfall in that year.

Three sites with three stocking methods sampled on the same day

Results from individual sites sampled on the same dates (Table 6) were consistent with trends across all sites, where sampling times were sometimes offset by 1–3 days between stocking methods. However, there were some between-site differences.

At Blackwater (heavy clay), DCP was significantly higher ($P<0.05$) in the continuous method than in either rotation (Table 6). Digestibility was also higher in the continuous method, but this difference was only marginally significant ($P=0.05$). On the other heavy clay soil site, Clermont, there were no significant differences between the three stocking methods for any of the diet quality or composition parameters. At Rockhampton (light-textured soil), the continuous method had higher DCP and DMD than the intensive rotation; the extensive rotation was intermediate and not significantly different from the continuous method for DCP and DMD. The predicted LWG was highest for the continuous method, lowest for the intensive rotation and intermediate for the extensive rotation. The mean DCP : DMD ratio declined significantly ($P<0.05$) from the continuous method (0.143) to the intensive rotation method (0.122), the latter being in the protein-deficient range (Table 6).

Effects on DNG

Overall there was no significant effect of stocking method on DNG (Table 5). However, there were some differences at individual sites (Table 6), although these differences were not consistent. The relative amounts of DNG in the diet from the two sources (herbaceous forbs and woody browse) could not be separated in the F.NIRS analysis. Relationships between DNG

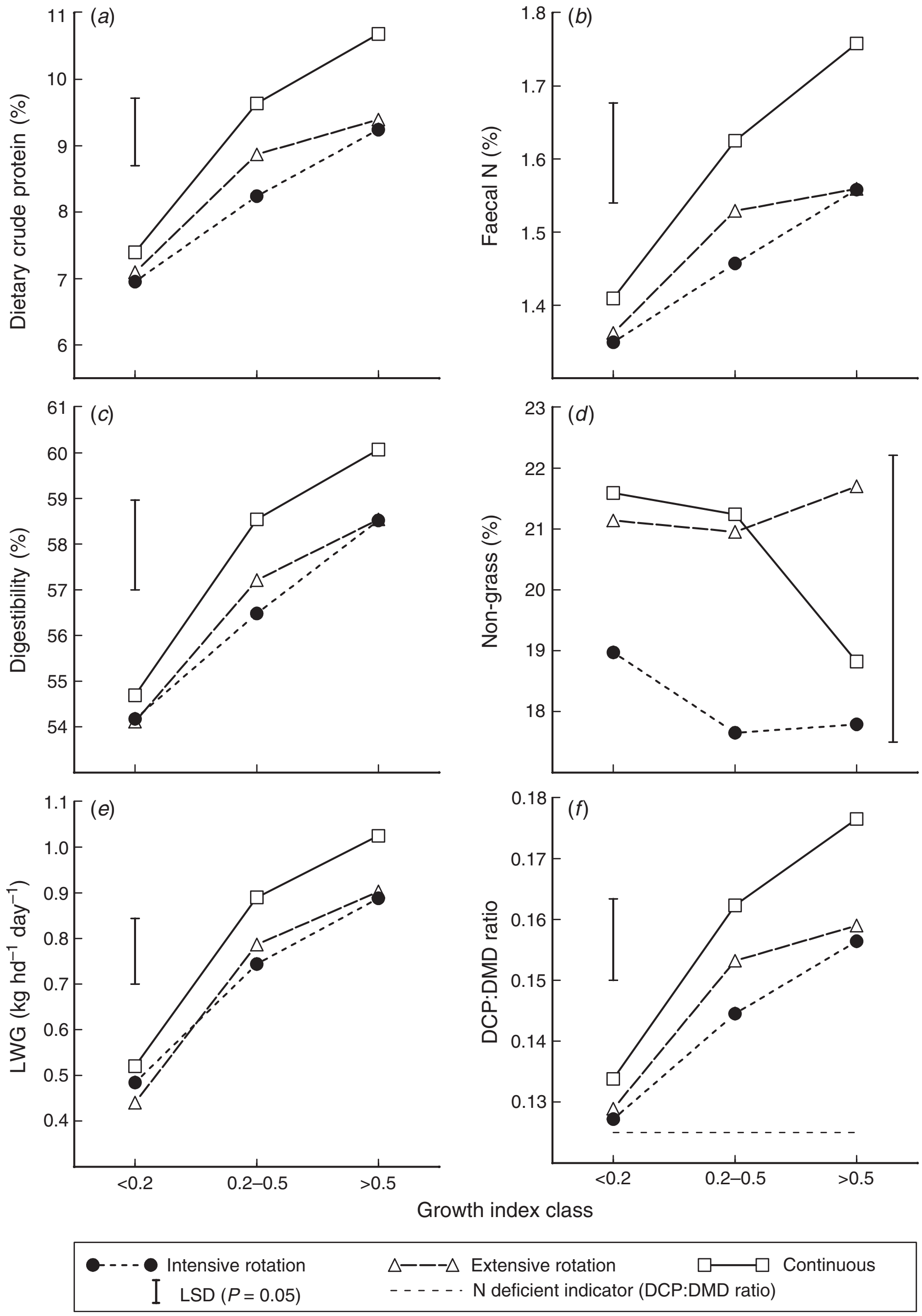

Fig. 3. Diet quality and composition in relation to three stocking methods (intensive rotation, extensive rotation and continuous) and three pasture growing condition states (growth index classes) at nine properties. (*a*) Crude protein, (*b*) faecal nitrogen, (*c*) digestibility, (*d*) non-grass, (*e*) predicted liveweight gain (LWG) and (*f*) dietary crude protein (DCP) : dry matter digestibility (DMD) ratio. Error bars show the least significant difference (l.s.d.; $P = 0.05$). The minimum indicator line for nitrogen deficiency is shown in (*f*).

and these two sources were examined further, but there were no consistent relationships. Pasture forbs and the canopy cover of woody plants were estimated at the end of the growing season in 2006, 2007 and 2009 (Hall *et al*. 2014); Table 7 shows mean (over 3 years) values for site by stocking method. When these values are compared with DNG values in Table 5, there are no consistent relationships. At Blackwater, the diet for the extensive rotation had more DNG than the diets in the other two stocking methods, but there were no significant differences in pasture forbs, and the woody plants were more common in the intensive rotation paddocks. At Clermont, where there were no differences in DNG between stocking methods, there were similar

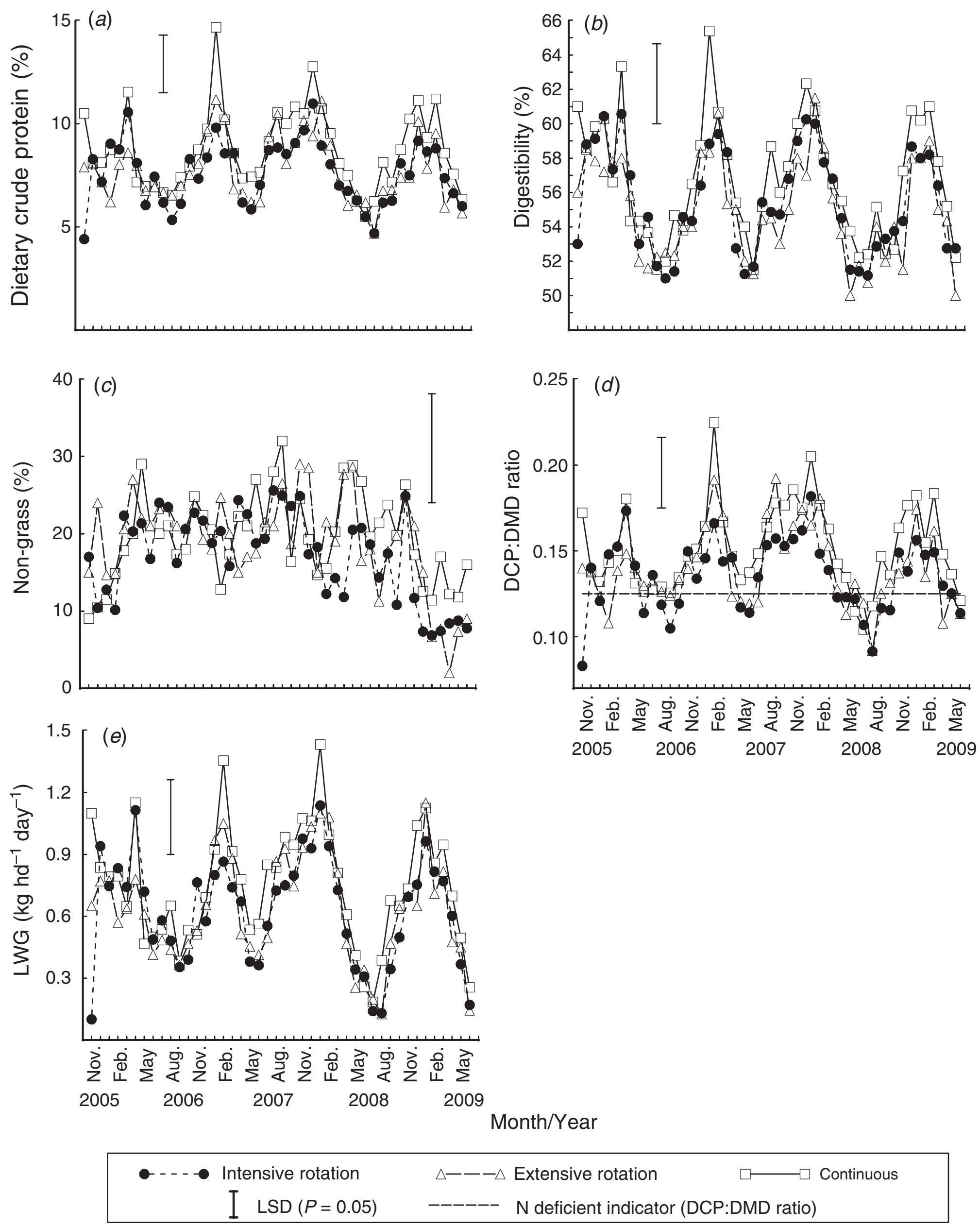

Fig. 4. Mean monthly diet quality. (*a*) Dietary crude protein (DCP), (*b*) dry matter digestibility (DMD), (*c*) non-grass, (*d*) DCP : DMD ratio and (*e*) liveweight gain (LWG) in three stocking methods at nine sites between November 2005 and June 2009 (total 585 faecal samples). The vertical bar shows the least significant difference (l.s.d.; $P = 0.05$). The dashed horizontal line in (*d*) is indicative of potential nitrogen (protein) deficiency below this level.

proportions of forbs in the pastures, but woody plants were more prominent in the intensive rotation. Brigalow seedlings were the most common woody species at both sites. At Rockhampton, where the diets in the intensive rotation contained less DNG than those in the other stocking methods, the pasture forbs showed a similar pattern but there were no differences in woody plants.

The pasture values in Table 7 were from the end of the growing season, but the dietary values are means of all samples over 4 years. Because DNG values may vary over the seasons, a further examination was made using only the DNG values from the end of the growing season (March–June). The mean DNG values for these 4-month periods in each of 3 years were correlated with the pasture forbs and woody plants for the different stocking methods at all sites. These correlations showed there was a small positive relationship between DNG and pasture forbs ($r = 0.468$; $P < 0.01$), but not between DNG and woody plants ($r = 0.035$). Over all sites, non-grass in the diet was not significantly affected by season, vegetation type or region, although it did vary between years.

Table 6. Diet composition and quality at Blackwater, Clermont and Rockhampton sites when the three stocking methods were sampled on the same day

Data show adjusted means and average s.e. from the residual maximum likelihood (REML) analysis. For main effects: NS, not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. For mean values for a main effect, different letters indicate significant differences ($P \leq 0.05$). The number of samples from each stocking method collected on the same day was 25 for Blackwater, 20 for Clermont and 28 for Rockhampton. LWG, liveweight gain; DCP, dietary crude protein; DMD, dry matter digestibility

Site and stocking method	Crude protein (%)	Faecal N (%)	Digestibility (%)	Non-grass (%)	LWG prediction (kg head^{-1} day^{-1})	DCP : DMD ratio
Blackwater (brigalow)	*	*	NS	*	NS	NS
Continuous	9.30a	1.62a	57.2	10.3b	0.91	0.152
Extensive rotation	7.70b	1.43b	55.0	15.2a	0.73	0.130
Intensive rotation	7.56b	1.48b	54.7	9.8b	0.69	0.130
s.e.	0.49	0.05	0.9	1.6	0.07	0.008
Clermont (brigalow, gidgee)	NS	NS	NS	NS	NS	NS
Continuous	7.36	1.31	54.9	10.5	0.51	0.130
Extensive rotation	7.61	1.30	54.8	11.7	0.57	0.133
Intensive rotation	6.61	1.22	53.8	13.3	0.44	0.119
s.e.	0.61	0.04	0.9	3.5	0.13	0.011
Rockhampton (eucalypt)	**	***	*	**	*	*
Continuous	8.33a	1.53a	56.4a	22.0a	0.68a	0.143a
Extensive rotation	7.68ab	1.38b	55.2ab	22.9a	0.60ab	0.133ab
Intensive rotation	6.83b	1.34b	54.0b	15.6b	0.49b	0.122b
s.e.	0.32	0.04	0.6	1.6	0.05	0.006

Table 7. Proportions of total herbaceous non-grass (sown legumes, native legumes, forbs and sedges) in the pastures and canopy cover of shrubs and woody regrowth in relation to stocking method at nine sites across 2006, 2007 and 2009

The s.e. of the overall stocking method means is 0.29 for the proportion of non-grass and 0.12 for woody canopy cover; the s.e. for the site–stocking method combinations are 0.86 and 0.36 respectively. Within variables and site rows, mean values for stocking methods followed by different letters differ significantly (l.s.d. $P < 0.05$)

	Total herbaceous non-grass (%)			Woody canopy cover (%)		
	Continuous	Extensive rotation	Intensive rotation	Continuous	Extensive rotation	Intensive rotation
Site						
Blackwater	1.1	1.2	0.7	0.77b	0.87b	2.13a
Bowen	19.5b		25.3a	0.10		0.71
Clermont	2.8	3.0	2.4	0.47b	0.13b	1.83a
Condamine	2.9		0.8	0.73		0.40
Injune	1.1		1.8	3.17a		1.63b
Mundubbera	1.7	2.3		1.50	0.77	
Richmond		15.6a	5.8b		3.68b	5.35a
Rockhampton	10.0a	11.4a	7.2b	0.73	0.57	0.83
Surat		1.5	1.1		1.40	0.53
Mean	5.5b	7.5a	5.1b	1.45ab	1.12b	1.66a

Although there was a high correlation ($r = 0.946$; $n = 4$) between the four annual mean values for dietary non-grass and DCP (Table 5), there was no relationship between the monthly mean values ($r = 0.032$; $n = 44$), the values from the end of the growing season ($r = 0.237$; $n = 61$) or the values for all individual samples ($r = 0.176$; $n = 585$).

Across all sites, the lowest ($P < 0.01$) non-grass in the pastures was in the autumn of 2007 (mean 4.0%) compared with 2006 (8.0%) and 2009 (6.1%). There were no differences between years in the woody regrowth (mean cover 1.41%). The pasture non-grass was not significantly correlated with dietary DCP, DMD, FN or LWG for the March–June samples (r = –0.067, –0.082, –0.052 and –0.245 respectively).

LWG prediction

Over all sites, the predicted cattle LWG was highest for continuous grazing (0.81 kg head^{-1} day^{-1}; $P < 0.05$), compared with 0.71 kg head^{-1} day^{-1} for the two rotation methods (Table 5). The predicted liveweight response followed the seasonal pasture GI, with a significant decline ($P < 0.01$) from the growth phase (GI >0.5) to the dormant phase (GI <0.2).

The higher DCP and DMD of the high-fertility soils from the brigalow vegetation type produced a higher ($P < 0.05$) predicted mean LWG than for the eucalypt sites. The second consecutive year of above-average rainfall (2008–09) produced the lowest predicted annual mean LWG results. There was no difference between the first 3 years (Table 5). There was no correlation between LWG and DNG ($r = 0.017$).

Discussion

The approach used in the present study of conducting grazing research on commercial properties raises some issues of experimental design. In studies of grazing management, the importance of addressing concerns about scale of commercial operations (both spatial and temporal) and the need for adaptive management have been stressed (Teague *et al*. 2013; Teague 2014). Both these concerns were addressed in the present study. First, all paddocks were of commercial size, and the comparisons included stocking methods that had been established for periods of a few months to more than 10 years when measurements commenced. Second, the property owners and managers had all been formally trained in pasture and grazing management, and made all decisions related to grazing management in response to factors affecting their properties and operations. Using commercial properties meant that the selection of land for the different stocking methods was made by the owners rather than areas being allocated at random to different stocking methods. It is possible some of the differences we measured between stocking methods may reflect differences between the locations, rather than differences between stocking methods. However, the chance of this occurring was minimised when selecting properties by ensuring all stocking methods on a property were on the same land type and that their management had been similar (e.g. tree clearing, pasture development and prior grazing history). In addition, the selection of the paddock to be monitored within a stocking method at each property was based on similar soil types and prior histories, so any pasture differences would most likely be caused by the stocking method. There was no replication of the stocking methods on the individual properties, but the comparisons of stocking methods were made at nine sites, and on the individual properties measurements were made on multiple paddocks in the two rotation methods. Because there was no replication of stocking method at the property level, the statistical analyses had limited power to detect differences on individual properties, so we have emphasised overall results for the nine properties rather than results for individual properties.

Stocking methods and growing season

The most important results over 4 years at nine sites across Queensland show the main diet quality parameters (DCP and DMD) were higher for continuous grazing than for the intensive rotation, whereas values for the extensive rotation were intermediate. The differences occurred over the spring and summer period when pasture growing conditions were good, with green grass leaf in the pasture. There were no differences in diet quality between stocking methods during the dry season when growing conditions were poor. The higher-quality diet in the continuous paddocks was most likely due to the animals in those paddocks being able to select more of the higher-quality components of the pastures over a longer time period, because animals on tropical pastures are known to be highly selective (Gardener 1980). When adequate forage is available, the selection ability of cattle can provide a superior diet compared with the total forage on offer (Kirch *et al*. 2007), and Provenza *et al*. (2003) suggest animals can better meet their nutritional needs when offered a variety of foods that differ in nutrients. Such feed variety is more likely to occur in the relatively larger areas at lower stocking rates in the continuous method paddocks than in the rotation methods. The animals in the extensive rotation generally had intermediate values or levels similar to those in the intensive rotation method. As discussed earlier, we attribute these differences to the stocking method because differences due to variations in land type or previous management were minimised during property and paddock selection.

During the wet season, the pastures contained forage ranging from young green leaf, through more mature material (leaf, stem and seed heads), to old, dry material remaining from the previous growing season. In the pastures of the continuous stocking method, animals have all the forage available to them at one time, providing distance to water is not a limitation, and are given maximum opportunity to select a high-quality diet for the duration of the growth period. Distance to water was always less than 2 km in the paddocks monitored, so had no effect on the results. In the two rotation methods, the animals had only a part of the total forage supply available for consumption at any one time and less opportunity to select, particularly in the smaller paddocks of the intensive rotations. In these smaller intensive rotation paddocks with their inherently higher density stocking for a short grazing period, the animals tended to graze the tops of most of the pasture plants, including recent growth plus older, lower-quality leaf and stem material. In the continuous method, animals were usually spread across the paddock and occasionally concentrated on preferred patches within the pasture, especially in the dry season. Hence, during the growing season, the differences in diet quality between stocking methods were largest and strongly favoured the continuous grazing method. During the dry season, in all stocking methods, the forage available was observed to consist mostly of dry mature herbaceous forage with a higher proportion of stem. This limited the ability of animals to select high-quality material regardless of how much forage was available to them, or the availability of non-grass forages, or the stocking method in use.

The lower-quality diet selected in the pastures of the two rotation methods indicates animal production will be lower unless animals can compensate by eating more dry matter or they are supplied with additional nutrients. Some producers have used intensive rotations without reporting potential nutrient deficiencies (McCosker 1994, 2000; McArthur 1998; Gatenby 1999; Joyce 2000; Sparke 2000). However, nitrogen supplementation, as urea, through the water system is a frequent feature of the intensive stocking methods in commercial practice to increase feed intake and consequently production. This supplement will help compensate for a possible lower diet quality in this intensive method, but at an additional financial cost. The economics of the effects of the methods and supplementation options was not evaluated at these sites. At the sites with the rotation methods, the concentration of the herd and piped water supplies made water medication for additional nitrogen, as urea, an easier option than in some of the continuous stocking method paddocks. A continuous stocking method does not exclude water nutrient medication systems, which have the potential to further increase the production potential of this method. Urea water medication was used in the trough water supply, during the dry seasons, at the Condamine site in both their continuous and intensive stocking methods throughout the monitoring period.

Ratios of digestibility and dietary protein are useful indicators of the availability of metabolisable energy and rumen-degradable nitrogen (Dixon and Coates 2005). Originally, the DMD : DCP ratio was used, but the value of this ratio decreases as diet quality increases, and the reverse ratio (DCP : DMD) is now favoured (R. Dixon, pers. comm.). The DCP : DMD ratios were lower during the dry season (low pasture GI) and higher during the wet season (high pasture GI). Although the annual mean DCP : DMD ratio was >0.14 for all stocking methods, the diet quality from some samples was lower than the deficiency indicator ratio level of 0.125 (equivalent to a DMD : DCP ratio of 8) for potential protein deficiency, regardless of the stocking method, particularly in the dry season. The lowest ratios of individual samples in the three methods were <0.08, indicating severe protein deficiency in these diets. This indicates periods of severe protein deficiency for the grazing animals, regardless of stocking method, pasture type or region. There were also high DCP : DMD ratios (>0.2; equivalent to a DMD : DCP ratio of 5) in all three stocking methods, predominantly in the pasture growing season, showing that high-quality diets can be available regardless of the stocking method. However, protein deficiency occurred more frequently in the intensive method and peaks in diet quality were consistently higher in the continuous method. This suggests a direct protein or urea supplement program may be of greater value in the intensive methods and possibly for over a longer period of time.

Vegetation type, year and region

Diet quality was higher at the brigalow sites, by 0.5% DCP and 1.2% DMD, than at the eucalypt sites, as may be expected. These soils have both a higher water-holding capacity and a generally higher fertility than the lighter loam soils of eucalypt communities. There is no obvious explanation why there were consistently lower DCP and DMD values on the brigalow and gidgee clay soil types at the Clermont site compared with both the brigalow clay soil at Blackwater and the eucalypt soils at Rockhampton. Soil fertility was not measured across the properties to determine whether this was a contributing factor; however, the 50-year-old buffel grass pastures may be in an advanced nitrogen run-down phase (Graham *et al.* 1985; Robbins *et al.* 1986; Peck *et al.* 2011). Some brigalow soils are also known to be low in phosphorus (<5 mg P kg^{-1} Colwell bicarbonate analysis; Peck *et al.* 2015).

Diet quality varied more from year to year than between the stocking methods. Consecutive high-rainfall years are known to produce higher pasture dry matter yields, but at lower protein concentrations, as the available soil nitrogen is diluted in the additional herbage mass. Further, additional nitrogen available from the death and breakdown of plants during a drought, the 'Birch effect' (Birch 1960), produces a flush of pasture growth during the first good rainfall year after a drought. The F.NIRS results demonstrated these seasonal and annual diet quality changes across the range of land types and regions over the 4-year sampling period.

Non-grass (dietary and pasture)

The only significant differences in the proportion of non-grass in the diet were between years, although there were small differences between stocking methods at Blackwater and Rockhampton. Other studies have shown that the proportion of non-grass selected varies both between years and between seasons (Gardener 1980; Taylor *et al.* 1980; Ash *et al.* 1995). Taylor *et al.* (1980) also found different selection preferences between stocking methods. The significant correlation between pasture non-grass, measured in April–May, and mean dietary non-grass during the period March–June, and the lack of a correlation between woody regrowth and dietary non-grass, suggests it was predominantly the herbaceous layer providing the non-grass component of the diet. We have no F.NIRS species feeding studies from these pastures to have confidence in using the sample ash concentrations to suggest which components of the pasture were being selected in the diet.

Use of F.NIRS

The strong relationship between the DCP and FN analyses suggests that, in future, the FN analysis could be omitted from the diet quality parameter set with little loss in the interpretive value of the F.NIRS analyses for managing the nutrition of grazing cattle. The analysis and interpretation could concentrate on the DCP and DMD components to best describe the nutritional value selected from these pastures.

On some land types, the interpretation of F.NIRS results is more complex, especially if the diet includes high-quality forbs or particular browse species. Examples include where there are high yields of winter herbage or legume species, such as naturalised medics (*Medicago* spp.), or there is a high proportion of browse trees, such as *Acacia aneura* (mulga) trees in western Queensland. Similarly, when livestock are supplemented with high levels of protein and energy supplements, such as whole cottonseed, protein meals or grain and molasses (Dixon and Coates 2005; Jackson *et al.* 2009), the accuracy of diet quality predictions using NIRS can be reduced. These issues either did not occur with the tree-cleared and perennial grass-dominated pasture sites in the present study, or were potentially only present for a few samples in winter at the southern sites after winter rainfall. Mulga did not occur and protein concentrate feed supplements were not fed at any site. Richmond was the only site where there had been no timber treatment and potentially offered browse as non-grass from fallen leaf off Bauhinia (*Lysiphyllum hookeri* F. Muell.) trees in the late dry season.

The highest monthly average dietary non-grass was recorded in the winter of 2007, suggesting that additional palatable winter-growing species grew on the above-average rainfall received at this time, following a low-rainfall summer. For example, the southern sites Surat and Condamine received above-average winter rainfall in that year and it may have produced additional herbage, such as *Medicago* species, but it would have grown after the autumn pasture recording. The north region has negligible winter rainfall and no legumes that would affect the F.NIRS predictions during this period. However, there can also be higher nitrogen and phosphorus contents in forbs than in mature grasses during the dry season (Holm and Eliot 1980; Hall 1981), which may affect grazing preference. The results presented herein do not separate the dietary non-grass components of herbaceous non-grass and the shrub or woody plant browse, but with a correlation between the dietary and herbaceous non-grass and not with woody regrowth, we consider the majority of dietary non-grass was from the herbaceous pasture component. Differentiating between herbaceous and browse non-grass in F.NIRS analysis of these pastures is an area for future research.

Conclusions

Across these nine well-managed sites and 4 years, diet quality was lower in the intensive rotations than in the continuous methods, with the extensive rotations being intermediate. Unless this lower diet quality is compensated for by higher dry matter intake or by supplying feed supplements, per animal production will be lower in these intensive stocking methods. The results presented here and in Hall *et al*. (2014) suggest that with appropriate grazing management based on annual pasture production, cattle producers can obtain similar ecological responses and carry similar numbers of livestock under any of the three methods, and diet quality will be higher in summer from the continuous stocking method in most environments.

Acknowledgements

The authors thank the nine property owners for their cooperation and support in sample collection over the 4 years, for sharing their grazing records and management knowledge, and for their generous hospitality to the project team. The authors also thank David Coates for processing and conducting the F. NIRS analyses of all samples, Christina Playford for the initial statistical analyses, the beef producers who recognised the need for this work and others who contributed to developing the project. We thank the anonymous reviewers for their suggestions on the paper. Meat and Livestock Australia and the Queensland and Australian governments are acknowledged for their financial support.

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