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Diets selected and growth of steers grazing buffel grass (*Cenchrus ciliaris* cv. Gayndah)–Centro (*Centrosema brasilianum* cv. Oolloo) pastures in a seasonally dry tropical environment

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Abstract

Context. Liveweight (LW) gain of grazing cattle in the seasonally dry tropics is usually moderate during the wet season (WS) and declines to slow growth or LW loss during the dry season (DS). Cattle growth can often be improved by inclusion of herbaceous legumes into pastures to improve their nutritional quality.

Aims. A study examined the quality of the diet selected and the growth of young cattle grazing a buffel grass (*Cenchrus ciliaris*)–Centro (*Centrosema brasilianum*) pasture in a high-rainfall, seasonally dry, tropical environment in northern Australia to relate the diet selected to cattle growth.

Methods. During three annual cycles, young steers grazed a grass–Centro legume pasture at moderate stocking rate. LW was measured monthly, and diet attributes (legume content, DM digestibility (DMD) and crude protein concentration) were measured fortnightly by near-infrared reflectance spectroscopy analyses of faeces. Pasture available and species were measured twice annually.

Key results. The annual LW gain and diet attributes followed a consistent profile through the annual cycles. Following the seasonal break, the diet DMD and crude protein concentration increased abruptly to maxima (means 732 and 184 g/kg respectively), and then declined approximately linearly during the remainder of the WS and the wet–dry transition season (TS); DMD decreased by 0.49, 0.74 and 0.88 g/kg units per day. DMD and crude protein averaged 561 and 61 g/kg respectively during the DS. Centro comprised 86–291 g/kg of the pasture on offer, and averaged 283 and 205 g/kg of the diet during the TS and DS, respectively, but only 58 g/kg during the WS. Cattle selected for Centro during the TS and the DS, but not during the WS. Cattle LW gain reflected diet quality averaging 0.86, 0.59 and 0.12 kg/day during the WS, TS and DS respectively.

Conclusions. The Centro legume contributed substantially to the diet of growing cattle during the TS and DS, but not during the WS. The LW gains of cattle were moderate during the WS and TS, and low during the DS.

Implications. Centro in a buffel grass pasture contributed substantially to the diet, but nevertheless annual LW gain was only modest (mean 179, range 159–209 kg/annum).

Additional keywords: cattle growth, diet selection, near-infrared spectroscopy, tropical legumes.

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Introduction

The benefits associated with legumes as companion species for grasses in tropical pastures are well established (Minson 1990; Humphries 1991; Coates 1995). Tropical legumes are generally higher in nutritive value than tropical grasses, particularly in their concentrations of crude protein (CP) and essential minerals (Norton 1982). In addition, nitrogen (N) fixation by legumes often increases both the amount and nutritive value of the grasses. In the seasonally dry tropics, legumes are particularly useful to provide plant N and to maintain diet CP concentration during the late wet season (WS) and the dry season (DS) as grasses mature and their protein content declines. Numerous studies have investigated specific legumes as companion species for grasses in a wide range of climatic and agronomic circumstances in the tropics and subtropics (Winter *et al*. 1989; Humphries 1991;

Miller and Stockwell 1991). Legume inclusion has typically allowed increases in stocking rate and in liveweight (LW) gain both per animal and per ha; the increases in growing cattle have been typically 20–50 kg animal/annum with commensurate increases in conception rates, milk production and calf growth in breeder herds (Winter *et al*. 1991; Mannetje 1997). General information is available to understand and predict diet selection and the productivity of cattle grazing common grass–legume species combinations, and provides guidance for grazing management. However, selection during grazing does vary with the pasture species. The huge variety of grass–legume combinations, agronomic environments and interactions leads to an enormous range of grazing situations, and thus uncertainty in the prediction of outcomes. In particular, although considerable information is available from the tropics of northern Australia on the selection, improvement in diet quality and production responses from including *Stylosanthes* spp. as companion species into grass pastures (Gardener 1980; Gardiner 1984; Miller and Stockwell 1991), there is little information available on inclusion of less common legumes, such *Centrosema* spp. legumes, into grass pastures in northern Australia.

Most studies examining diet selection by ruminants grazing grass–legume tropical pastures have depended on laborious and costly methods using oesophageally-fistulated animals or the δ^{13}C concentration of faeces to determine the diet proportions of C_4 tropical grasses to C_3 legumes (Jones *et al*. 1979; Coates 1996), or a combination of these techniques (Clements *et al*. 1996; Coates 1999). The development of near-infrared reflectance spectroscopy of faeces (F.NIRS) to measure several attributes of the diet, including the proportions of C_3 legumes, diet DM digestibility (DMD) and diet CP concentration, allows low-cost and frequent measurements of diet attributes in grazing ruminants (Stuth *et al*. 1999; Dixon and Coates 2009). Studies utilising F.NIRS to measure the diet selected by cattle grazing tropical pastures, including the contents of legume and N and digestibility, have been reported (Coates and Dixon 2007, 2008; Dixon and Coates 2009, 2015; Decruyenaere *et al*. 2009). An understanding of diet selection and voluntary intake by grazing cattle is clearly required to manage grazing of pastures for optimal animal production per ha and per head, and to achieve the high metabolisable energy (ME) intakes required for high growth or milk production.

The present study measured pasture availability, and utilised F.NIRS to measure attributes of the diet selected, in cattle grazing a grass–Centro (*Centrosema brasilianum*) legume pasture. At the site, a long-term (1968–2008) grazing trial had evaluated a range of introduced grass and legume pasture species for their regional suitability. It was found that annual LW gain of young steers grazing C_4 grass pastures at moderate stocking rates was typically ~150 kg/annum, and inclusion of a herbaceous legume companion species with the grasses increased steer LW gain by ~25 kg/annum (Shotton 2011). During these trials, *Centrosema brasilianum* cv. Oolloo, a short-lived twining perennial (Cameron and Lemke 1997), had been identified as among the more promising companion legume species for use in the region, and for this reason was chosen for more detailed investigation in the present study. An experiment investigated the hypothesis that the selection and intake of Centro as a companion species with buffel in a grass–legume pasture contributed to diet quality of grazing steers primarily in the late wet season and the dry season in a high-rainfall, seasonally dry, tropical environment in the Northern Territory of northern Australia. In addition, the reliability of F.NIRS to estimate Centro content of a pasture was examined.

Materials and methods

Site, pasture and animals

The experiment was conducted with growing steers grazing an established pasture at Douglas Daly Research Farm (13°50′S, 131°12′E) in the high-rainfall, seasonally dry tropics of the Northern Territory of northern Australia. The soil was a sandy red earth classified as a deep red magnesic kandosol (Hill *et al*. 2011). The grass–Centro legume pasture (4 ha) used in the study had been established 3 years before the experiment commenced. *Centrosema brasilianum* was sown into an established introduced buffel grass (*Cenchus ciliaris* cv. Gayndah) pasture by broadcasting seed in conjunction with an interval of heavy grazing. The pasture was destocked during the 2002/2003 WS, and also during the 2004 wet–dry transition season (TS), to enhance establishment of the Centro. Thereafter, the pasture was continuously grazed. Centro content of the pasture in the TS (May) ranged up to 300 g/kg during the 7 years after establishment and through to the end of the present study. Paddocks were top-dressed annually in December with a commercial fertiliser that provided ~7 kg phosphorus and ~9 kg sulfur/ha. Dicotyledonous weeds were controlled by spot-spraying with herbicide as necessary. Measurements were made of the pasture available in May (in the TS) and in December (at the beginning of the WS), steer LW gain, and the diet selected during three annual cycles (June to June 2005–2006, 2007–2008 and 2008–2009; Drafts 1, 2 and 3 respectively). The paddock was grazed with a draft of animals during 2006–2007, but no experimental measurements were made.

The animals used in the experiment comprised *Bos indicus* and *Bos indicus* × *Bos taurus* genotype steers from the research station herd that had been weaned shortly before their entry to the present experiment. Each year in June a replacement draft ($n = 5$ for Draft 1, $n = 6$ for Drafts 2 and 3), initially 150, 168 and 168 kg LW respectively, entered the grazing trial. The steers were treated for buffalo fly with insecticidal ear tags (Y Tex python maxima (piperonyl butoxide 200 g/kg/Zeta-Cypermthrin 100 g/kg; Y Tex Corporation, Kenmore, Qld, Australia) or were sprayed with Sumifly Buffalo Fly Insecticide (Fenvalerate 200 g/L; Zoetis, Silverwater, NSW, Australia), as required, when the animals were mustered monthly. The steers were given *ad libitum* access to feed block supplements to provide primarily N during the DS, and phosphorus during the WS and TS (Uramol and Phosrite respectively; LNT, Townsville, Qld, Australia). The DS blocks were specified by the manufacturer to contain 138 g N/kg (of which 48 g/kg was non-protein N), 36 g phosphorus/kg and 14 g sulfur/kg. The blocks offered during the WS and TS were specified to contain 72 g N/kg (of which 24 g/kg was non-protein N), 50 g phosphorus/kg and 10 g sulfur/kg.

Measurement of diet ingested from F.NIRS

Pasture species composition and yield were assessed in the TS (May) and in the early WS (December) using Botanal procedures (Tothill *et al.* 1992). The cattle were weighed monthly without fasting. Faecal samples were obtained from all steers by rectal sampling when the animals were weighed or from recently voided dung pats. The lick blocks were weighed monthly to measure supplement intake.

Faecal samples were oven-dried (65°C) and then ground (1-mm screen, Model 1093 Cyclotec mill; Foss Tecator AB, Hoganas, Sweden). The milled samples were redried (65°C), cooled in a desiccator and then scanned (400–2500-nm range) using a monochromator fitted with a spinning cup module (Foss 6500; NIRSystems, Silver Spring, MD, USA). Chemometric analysis used ISI software (Infrasoft International, Port Matilda, PA, USA). The dietary non-grass content, diet CP concentration and diet DMD were predicted from faecal spectra using established calibration equations appropriate for northern Australian tropical pastures (Coates 1999; Coates and Dixon 2008, 2011; Dixon and Coates 2009).

To confirm the accuracy of the F.NIRS predictions of diet non-grass for the buffel grass–Centro legume pasture, a subset of faecal samples (n = 28) was selected by stratified randomisation from the present experiment to represent the range in non-grass diet as measured by F.NIRS. These faecal samples were also analysed by mass spectrometry to determine the δ^{13}C ratios, and these ratios were compared with the values measured by F.NIRS. The δ^{13}C ratio of representative buffel grass and Centro legume (each n = 5) were also analysed by mass spectrometry to determine these values for the environmental conditions. As the pasture measurements indicated that most of the dicotyledonous plants present in the pasture were legumes, the non-grass in the diet is hereafter referred to in this report as diet legume.

Calculation of LW change, estimated DM and metabolisable energy intake of the steers

The annual cycle was considered as three seasonal intervals from the commencement of the DS as follows:

1. the DS from 1 July through to the seasonal break, which occurred on 19 October 2005, 6 November 2007 and 19 November 2008 for DS1, DS2 and DS3 respectively (Table 1); thus the duration of the DS was 110, 128 and 141 days respectively,
2. the WS from the seasonal break until the 31 March; thus, the duration of WS1, WS2 and WS3 were 163, 145 and 132 days respectively,
3. the wet–dry TS from 1 April to 30 June (91 days).

The seasonal break was defined as the first rainfall event of at least 50 mm over a period of 3 days after 1 July.

Changes in animal LW were calculated by the difference between the measured LW at the commencement and the end of each of the WS, TS and DS seasons, or from June to June for annual LW gain. In addition, the LW gain per day of the steers on each day when faeces were weighed was calculated as the tangent to a polynomial regression of measured LW with time within the DS, and the combined WS and TS. The estimated ME intake of the steers at each sampling time was calculated according to CSIRO (2007) as the ME required to achieve the measured LW gain for respective animals. These calculations of ME intake included the following assumptions: (i) the standard reference weight of animals was 600 kg, (ii) the ME required for maintenance was calculated using Eqn 1.19, (iii) the net energy content of LW change used Eqns 1.29 and 1.30, (iv) efficiency of utilisation of ME for LW gain used Eqn 1.37, (v) the ME concentration of the diet was calculated from the DMD measured by F.NIRS following Eqn 1.12A and

Table 1. Rainfall (mm) and the date of the seasonal break at the experimental site

The seasonal break was defined as the first rainfall event of at least 50 mm over a period of 3 days after 1 July. s.d., standard deviation

Month	Rainfall				
	Draft 1 2005–06	2006–2007	Draft 2 2007–2008	Draft 3 2008–2009	Median (1969–2012)
July	0	0	0	0	2
August	0	0	18	0	1
September	0	0	4	14	4
October	115	0	33	0	35
November	247	47	176	90	115
December	232	307	274	251	202
January	338	256	320	346	275
February	236	145	673	377	287
March	312	360	444	81	249
April	410	1	3	0	49
May	0	14	0	0	5
June	0	5	0	0	2
Total	1892	1133	1946	1159	1220
Seasonal break	19 Oct 2005	8 Dec 2006	6 Nov 2007	19 Nov 2008	22 Nov (s.d. 29 days)

Table 2. Availability and botanical composition of the pasture measured using BOTANAL procedures during annual cycles from 1 July to 30 June

The pasture was grazed during each of three seasons by three annual drafts of growing cattle (dry season, DS1, DS2, DS3; wet season, WS1, WS2, WS3; and wet–dry transition season, TS1, TS2, TS3). In May 2005 and May 2006, the 'Other legumes' comprised primarily *Stylosanthes hamata* cv. verano with smaller proportions of *Alysicarpus vaginalis* (buffalo clover), *Chamaecrista rotundifolia* (*Wynn cassia*) and *Stylosanthes scabra* cv. Seca. In May 2006 and December 2007, the 'Other dicots' comprised primarily *Sida acuta*, *Sida cordifolia* (flannel weed) and *Hibiscus malacanensis* (hyptis) with small quantities of *Ipomea* spp. (bellvines), *Crotalaria* spp. (rattle pod) and *Senna obtusifolia* (senna). Other grasses present as minor proportions were *Urochloa mosambicensis* (sabi grass) and *Digiaria and Brachiaria* spp. n.d., not determined

Month of sampling	Time of sampling in relation to each draft of steers	DM on offer (t/ha)	Botanical composition (g/kg)				
			Buffel grass	Other grasses	Centro legume	Other legumes	Other dicots
May 2005	55 days before commencement of DS1[A]	6.3	855	0	86	39	20
Dec 2005	DS1 Day 146[B]	4.7	868	1	104	6	21
May 2006	TS1 Day 313[B]	7.8	647	9	155	42	147
May 2007	76 days before commencement of DS2[C]	8.3	817	31	134	5	13
Dec 2007	DS2 Day 104[B]	2.5	549	16	291	8	136
May 2008	TS2 Day 256[B]	7.7	861	12	88	1	38
Dec 2008	DS3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
May 2009	TS3 Day 296[B]	5.9	745	46	158	2	49

[A] The paddock was grazed at the same stocking rate during the annual cycle before Draft 1 commenced.

[B] Day of the annual grazing cycle.

[C] No experimental measurements were made during the 2006–2007 annual cycle, but the paddock was grazed at the same stocking rate.

(vi) the animals walked 2 km per day on level terrain. Total DM intake (TDMI) was calculated from the estimated ME intake and the ME content of the diet calculated from the DMD, as the amount of DM required to provide for the measured LW gain. Legume DM intake was calculated from the TDMI and the legume content of the diet measured with F.NIRS, whereas the grass DM intake (GDMI) was then calculated by the difference. During the 4 weeks after the seasonal break, the calculated intakes of DM and ME were disregarded due to the difficulties associated with changing digesta load and body water, and low intakes of new growth pasture during this interval, which often lead to a large error in the estimation of the changes in LW and body energy content (McLean *et al*. 1983; Dixon and Coates 2010).

Statistical analyses

Statistical analyses were conducted by analysis of variance to compare drafts, seasons, and interactions between drafts and seasons, using the animals as replicated experimental units, in GENSTAT release 16.1 (VSN International, Hemel Hemstead, UK). Linear regression models were used to investigate relationships between the response variables.

Results

Rainfall, seasonal conditions, pasture availability and supplement intakes

Total annual rainfalls (1 July to 30 June) during 2005–2006 (1892 mm) and 2007–2008 (1946 mm) (Drafts 1 and 2) were substantially higher than the long-term median of 1220 mm (Table 1). This was associated with abnormally high rainfall in March and April 2006 during Draft 1. Total annual rainfall in Draft 3 was similar to the long-term median, but the late WS rainfall (March 2009) was lower than average. In May in each year, the total pasture DM on offer was ≥5.9 t/ha, and total legumes ranged from 89 to 197 g/kg and Centro from 86 to 158 g/kg (Table 2). In May 2005 and May 2006, the legume other than Centro (39 and 42 g/kg) was primarily Verano stylo (*Stylosanthes hamata* (L.) Taub.). Buffel grass comprised ≥941 g/kg of the grass on offer. Voluntary intake of feed block supplements averaged 7.4 g N/head·day during the DS, and 5.3 and 3.8 g P/head·day during the WS and TS seasons respectively (Table 3).

Table 3. Voluntary intake of two types of feed blocks, and the intakes of supplementary nitrogen (N) and phosphorus (P) from these feed blocks during each of three seasons (dry season, DS; wet season, WS; and wet–dry transition season, TS) in three annual drafts of growing cattle

Commercial feed blocks high in N (Uramol) were offered during the dry season and contained 138 g N/kg (of which 48 g/kg was urea) and 36 g/kg P. Commercial feed blocks high in P were offered during the wet season and the wet–dry transition season, and contained 50 g P/kg and 72 g N/kg (of which 24 g/kg was urea). Intake of the feed blocks was measured by weighing monthly

Season	Voluntary intake (g/head. day)	Intake of supplementary N (g/head·day)	Intake of supplementary P (g/head·day)
Dry season			
DS1	74	10.2	2.7
DS2	57	7.9	2.1
DS3	30	4.2	1.1
DS mean	54	7.4	2.0
Wet season			
WS1	94	6.8	4.7
WS2	105	7.6	5.2
WS3	121	8.7	6.1
WS mean	107	7.7	5.3
Transition season			
TS1	97	7.0	4.8
TS2	65	4.7	3.2
TS3	66	4.7	3.3
TS mean	76	5.5	3.8

Validation of the F.NIRS measurement of legume content of the diet

The relationship between the legume content of the diet measured by mass spectroscopy to determine the δ^{13}C ratio in faeces or by F.NIRS (Fig. 1) indicated that there was only minor bias and increase in variability when F.NIRS was used to measure the Centro legume content of the diet selected.

Legume content, DMD and CP concentration of the diet

The Centro content of the diet selected by the steers varied between the seasons and between years, and also varied through a wide range within seasons (Table 4; Fig. 2). Centro content was highest during the TS (mean 283, range 221–400 g/kg) and the DS (mean 205, range 197–209 g/kg), but averaged only 58 g/kg (range 12–166 g/kg) during the WS (Table 4).

The profiles of diet DMD and diet CP were similar in each of the annual cycles, as shown for Draft 3 in Fig. 2. These diet attributes characteristically increased abruptly to maxima shortly after the seasonal break, declined approximately linearly through the WS and the TS, and then changed little through the DS. Diet DMD was on average 680 g/kg during the WS, 591 g/kg during the TS and 561 g/kg during the DS (Table 4). Diet CP was on average 157, 97 and 61 g/kg during the WS, TS and DS respectively. As the F.NIRS calibrations for diet measured the CP concentration of the forage and not of

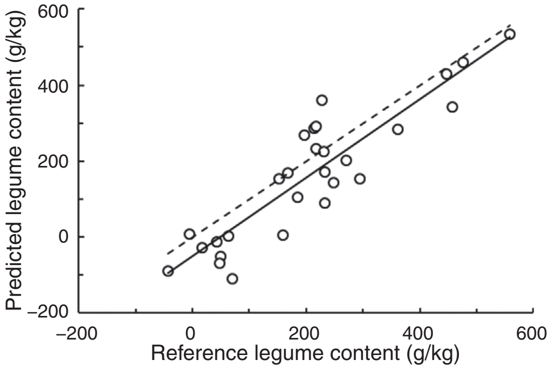

Fig. 1. The relationship between the legume content of the diet (g/kg) calculated from the reference values of the $^{13}\delta$ C ratio of faeces measured by mass spectrometry, and the legume content predicted from the faecal near-infrared reflectance spectroscopy calibration equation used for the present study. The regression relationship is shown as (—) and the 1 : 1 relationship as (- - - -). The relationship was: $y = 1.04x - 51.5$ ($n = 28$; $R^2 = 0.81$; $P < 0.001$).

Table 4. Faecal near-infrared reflectance spectroscopy measurements of the legume content, DM digestibility (DMD) and crude protein (CP) concentrations of the diets selected, the liveweight (LW) gain, and the intakes of grass, legume and total DM by three drafts (D1, D2 and D3) of steers grazing a buffel grass–Centro pasture during three annual cycles

n, number of faecal samples contributing to the respective measurement

Season	*n*	Legume content (g/kg)	DMD (g/kg)	CP concentration (g/kg)[B]	LW gain (kg/day)	DM intake (g DM/kg LW·day)		
						Grass	Legume	Total
Dry season								
DS1	4	209	560	57	0.19	19.0	5.0	24.0
DS2	6	197	571	69	0.05	14.4	2.9	17.3
DS3	8	209	554	57	0.11	16.8	4.4	21.2
DS mean	–	205	561	61	0.12	16.5	4.1	20.6
Wet season								
WS1	6	166	683	147	0.81	22.8	4.4	27.2
WS2	10	12	679	158	0.87	27.3	0.2	27.5
WS3	8	35	679	163	0.89	26.0	1.3	27.3
WS mean	–	58	680	157	0.86	25.7	1.6	27.3
Wet–dry transition season								
TS1	3	400	617	129	0.75	16.6	11.7	28.3
TS2	6	221	589	90	0.59	20.6	5.9	26.5
TS3	6	286	579	87	0.44	16.9	7.4	24.3
TS mean	–	283	591	97	0.59	18.5	7.5	26.0
s.e.m.[A]								
Seasons		26.5	7.3	5.1	0.021	0.73	0.74	0.46
Drafts		28.6	7.9	5.4	0.022	0.79	0.80	0.49
S × D		59.2	16.4	11.3	0.046	1.64	1.66	1.02
Significance								
Seasons		<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
Drafts		0.007	0.391	0.858	0.017	0.231	0.001	0.002
S × D		0.386	0.578	0.016	<0.001	0.004	0.629	<0.001

[A] Maximum standard error of the means; where the S × D interaction was significant, this applies only to the interaction means. Measurements during the 4 weeks after the seasonal break were not used for the calculation of DM intakes.

[B] The CP concentration of the diet measured with faecal near-infrared reflectance spectroscopy was of the forage component of the diet and did not include the diet N derived from the ingestion of non-protein N in the feed blocks.

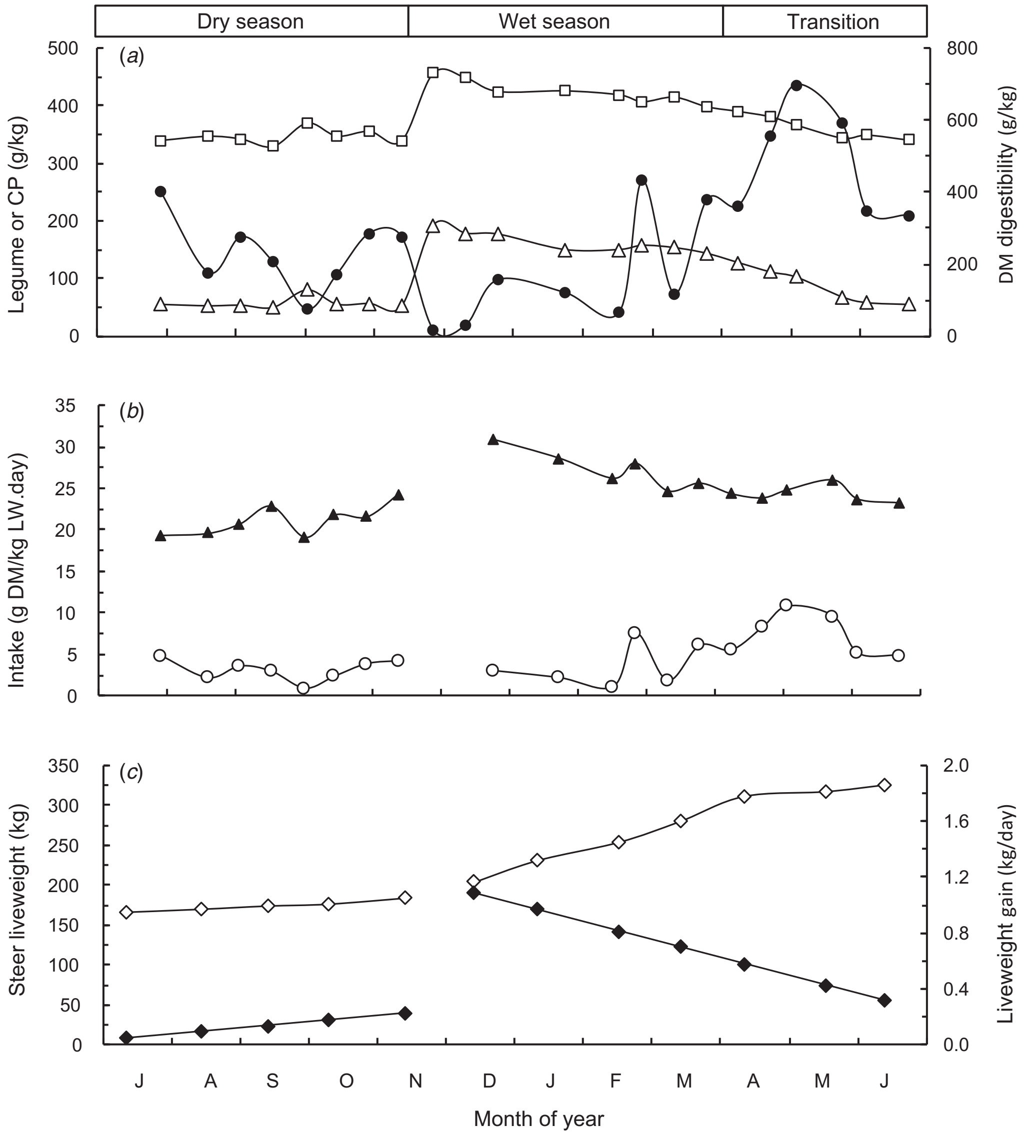

Fig. 2. (a) The concentrations of legume (●) and crude protein (CP; Δ), and DM digestibility (□; g/kg DM) measured by faecal near-infrared reflectance spectroscopy; (b) the voluntary intakes of total DM (▲) and legume DM (○); and (c) the measured liveweights (◇) and liveweight changes (◆) of Draft 3 steers during the 2008–2009 annual cycle. The diet attributes were measured using faecal near-infrared reflectance spectroscopy. Voluntary DM intakes were calculated from the liveweight change and the metabolisable energy content of the diet, but no estimates were made during the 4 weeks after the seasonal break.

any urea present (Dixon and Coates 2009), and some urea N was ingested from the feed block supplements, the actual concentrations of CP in the entire diet were slightly higher than the F.NIRS measurements given in Table 4. From the estimated intakes of forage (see below) and the measured intakes of the feed blocks, it was estimated that the diet CP concentration derived from both forage and supplement averaged 73, 85 and 65 g CP/kg DM during DS1, DS2 and DS3 respectively. Thus, the N ingested in the feed blocks was estimated to increase the average diet CP concentration during the WS, TS and DS to 164, 101 and 74 g CP/kg respectively. This increase would likely not have had any important nutritional consequences, even during the DS. The Centro content of the diet was not correlated ($P > 0.05$), or was poorly correlated ($R^2 \leq 0.60$), with the DMD and the CP concentration of the diet forage within seasons.

Diet DMD was closely correlated with diet CP concentration within drafts and across seasons (R^2 0.89–0.95). The linear regressions of diet DMD and CP with time during the WS and TS from their maxima in the early WS indicated that the diet DMD declined by an average of 0.49, 0.74 and 0.88 g/kg DM units per day for Drafts 1, 2 and 3 respectively (Table 5). Also, the diet CP declined by an average of 0.12, 0.52 and 0.64 g/kg DM units per day for Drafts 1, 2 and 3 respectively. The lower rate of decline in both DMD and CP for Draft 1 were associated with lower

Table 5. The number of observations (*n*), the maxima and the minima, and the rates of change in DM digestibility and crude protein concentration of the diet selected, total DM intake, and the nitrogen (N) concentration of faeces (g N/kg DM) in grazing steers

The rates of change were from the seasonal break at the commencement of the wet season through to the end of the wet–dry transition season each year

Diet attribute	Draft	*n*	Maximum	Minimum	Rate of change/day	R^2	Significance
DM digestibility (g/kg)	1	9	720	590	–0.49	0.74	0.002
	2	16	744	552	–0.74	0.86	<0.001
	3	14	731	545	–0.88	0.94	<0.001
	Pooled	39	732	562	–0.72	0.82	<0.001
Crude protein concentration (g/kg)	1	9	161	103.0	–0.12	0.09	0.222
	2	16	197	57.9	–0.52	0.79	<0.001
	3	14	193	55.2	–0.64	0.94	<0.001
	Pooled	39	184	72.0	–0.46	0.66	<0.001
Total DM intake (g DM/kg LW·day)	1	8	31.4	25.7	–0.0090	–	0.474
	2	15	30.8	23.8	–0.0026	–	0.762
	3	12	30.8	23.3	–0.0352	0.70	<0.001
	Pooled	35	31.0	24.3	–0.0090	0.04	0.143
Faecal N concentration (g N/kg DM)	1	9	24.5	15.7	–0.024	0.41	0.036
	2	16	24.7	13.2	–0.051	0.75	<0.001
	3	14	26.3	12.0	–0.071	0.96	<0.001
	Pooled	39	25.2	13.6	–0.051	0.72	<0.001

maxima early in WS1, and also with unusually high rainfall during April in TS1, which likely maintained pasture growth and diet quality.

Intakes of total DM, legume DM and grass DM and LW gain of the steers

TDMI (Fig. 2; Table 4) ranged from 24.3 to 28.3 g DM/kg LW·day, and averaged 27.3 and 26.0 g DM/kg LW·day during the WS and the TS. During DS1, the TDMI (24.0 g DM/kg LW·day) was similar to that during the WS and TS, but was lower (17.3 and 21.2 g DM kg LW·day; $P < 0.05$) during DS2 and DS3 respectively. Overall, TDMI averaged 20.6 g DM/kg LW·day during the DS. Annual LW gain averaged 179 kg (209, 170 and 159 for Drafts 1, 2 and 3 respectively), and averaged 0.86, 0.59 and 0.12 kg/day during the WS, TS and DS (Table 4).

Discussion

Reliability of the measurement of legume content, CP concentration and DMD of the diets selected

The northern Australian F.NIRS calibrations relating the spectra of faeces of cattle to the attributes of tropical forage diets have been described and validated for grass and grass–legume pastures in the northern Australian rangelands (Coates and Dixon 2007, 2008; 2011; Dixon and Coates 2009). The errors associated with the predictions of diet DMD and CP contents in the present experiment could not be evaluated directly, as this requires diet–faecal pair samples obtained by feeding cattle harvested forage in pens or by using oesophageally-fistulated cattle. However, the calibrations used have satisfactorily predicted diet DMD and CP for cattle ingesting tropical forage diets, and the calibration data included some samples with DMD >700 g/kg (Coates and Dixon 2011). Also, the average Mahalanobis distances for the predictions of diet CP and DMD were 1.5 (s.d. 0.63) and 1.7 (s.d. 0.71) respectively, and were thus much lower than the desirable maximum of 3.0 recommended by Shenk and Westerhaus (1993). Similar reliability and robustness of F.NIRS calibrations have been reported for ruminants ingesting temperate forages (Lyons and Stuth 1992; Decruyenaere *et al*. 2009). The high DMD of the diet selected by the steers during the WS (mean 680 g/kg) is consistent with several reports of the DMD of separated young leaf of C_4 grasses exceeding 700 g/kg (Wilson 1976; Wilson *et al*. 1989) and of pasture hand-plucked to mimic selection during grazing (Campos *et al*. 2016). It is also consistent with *in vivo* DMD measurements of hays or fresh forage of C_4 grasses during the early regrowth (Kozloski *et al*. 2003; Fanchone *et al*. 2012). This evidence supports the conclusion that the estimated high DMD of the pasture diet during the WS was indeed associated with selection by the steers and not an error or artefact of use of F.NIRS to make this measurement.

Because the proportions of C_3 *Centrosema brasilianum* legume and C_4 buffel grass in the diet could be measured from the $\delta^{13}C$ concentration in faeces measured by mass spectrometry (Jones *et al*. 1979), the errors associated with the estimation of the proportion of Centro in the diet could be directly evaluated. The F.NIRS calibration used to measure diet Centro, as a legume, depended on a calibration dataset ($n = 2002$; Coates 1999) where reference values of the $\delta^{13}C$ concentration in faeces were determined with mass spectrometry, and then related to the NIR spectra of faeces. Determination of the $\delta^{13}C$ concentration in faeces with mass spectrometry of a subset of faecal samples in the present study allowed examination of the errors associated with these established F.NIRS calibrations to measure the $\delta^{13}C$ concentration and thus Centro legume content of the diet for the specific experimental circumstances. The results (Fig. 1) showed that the F.NIRS calibration used was associated with a small underestimate of the diet legume (average 44 g/kg). This small error is consistent with the reported 62 g/kg standard error of performance in validation of this F.NIRS calibration for C_4 grass and C_3 legume diets

(Coates and Dixon 2008; Dixon and Coates 2008), and the error reported by Jones *et al*. (1979) for the measurement based on mass spectrometry. Some negative values for the legume content were obtained with both the mass spectrometry reference method and the F.NIRS method. This demonstrated the error associated with this measurement. The negative values should clearly be interpreted as nil content of legume in these samples. The experiment supported the hypothesis that the northern Australian F.NIRS calibration was appropriate to estimate the proportion of Centro in the diet selected during grazing by the steers. These observations for diet Centro content, as well as for CP and DMD, provided strong evidence that the F.NIRS calibration equations used provided reliable estimates of diet quality for cattle grazing buffel grass–Centro legume pastures, and that the measurement errors were comparable with those for other tropical grass–legume pastures.

Diet selected, intake and LW gain of the steers

The average LW gain of the steers during the WS (0.86 kg/day) was in the range often reported for young tropically adapted cattle grazing comparable tropical grass or grass–legume pastures. A review of >140 published experiments involving cattle grazing grass and grass–legume pastures in northern Australia concluded that peak growth rates during the WS exceeded 1.0 kg/day in only 14% of experiments, ranged from 0.8 to 1.0 kg/day in another 12% of experiments and were <0.8 kg/day in 74% of experiments (Winter *et al*. 1991). Also, a recent meta-analysis of growth and intake of cattle grazing tropical pastures (based on 41 experiments, 140 treatments and with standardisation for animal size) reported that the LW gain for 250 kg animals was usually in the range of 0.5–1.0 kg/day, and seldom exceeded 1.0 kg/day (Boval *et al*. 2015). In the present experiment, the average WS LW gain was only 0.86 kg/day in spite of the diet DMD averaging 680 g/kg DM during this season (Table 4). Intakes of both rumen degradable N and phosphorus were expected to be in excess of the requirements of the animals, and there was no evidence of deficiencies of any other minerals in the pasture system. Several hypotheses have been proposed to explain the usually modest growth rates of cattle grazing tropical wet season pastures with high nutritional quality and availability, but where cattle growth rates are usually substantially lower than for cattle grazing high-quality temperate pastures. First, it has been suggested that the lower growth rates are due to a low metabolisable protein : energy ratio of absorbed nutrients (i.e. a low availability of absorbed amino acids per MJ metabolisable energy) in tropical pasture diets (Poppi and McLennan 1995). A second hypothesis is that voluntary intakes and hence growth rates are often constrained by subclinical heat stress during the humid summer conditions of the wet season. For example, heat stress was implicated in unexpectedly low wet season growth rates of steers grazing irrigated grass–*Leucaena* pastures in a region of north-west Australia with a hot and humid summer environment comparable with the site of the present experiment; during the summer, the LW gain was generally <0.7 kg/day (Petty *et al*. 1998; Petty and Poppi 2012). A third hypothesis is that in cattle grazing tropical pastures, the voluntary intake is constrained by a low bulk density of the upper and higher nutritive value parts of the pasture sward, the amount of pasture DM that can be ingested per bite and the potential number of bites per day by the animal (Chacon *et al*. 1978; Fanchone *et al*. 2012; Boval *et al*. 2015). Regardless of the validity of each of these hypotheses, the modest steer growth rates during the WS and TS in the present experiment were consistent with many previous studies, and were associated with modest voluntary intakes of pasture DM and ME.

In the present study, the diet CP : ME ratio (g CP : MJ ME) was >15 during the WS and >10 during the TS. However, because the CP of tropical grasses, including buffel grass, is usually extensively degraded in the rumen, and the efficiency of microbial protein synthesis in cattle ingesting tropical forages is often low (e.g. <5 g microbial crude protein : MJ fermentable metabolisable energy); (Dixon *et al*. 1998; Bowen 2003; Mullik 2007), the metabolisable protein : ME ratio was possibly lower than that required for high voluntary intakes and high growth rates in young cattle. In the present experiment, the estimates of voluntary DM intake calculated from the ME required by the steers for the measured LW gain and the diet DMD support the hypothesis that voluntary intake was constrained by factor(s) other than the digestibility of the forage. The estimated TDMI during the WS and TS were generally in the range of 24–28 g DM/kg LW, and thus lower than in cattle grazing high-quality temperate pastures.

The frequent measurements of diet DMD and diet CP concentration during the WS and the TS allowed calculation of the declines in these diet quality attributes during the 7–8 months from the seasonal break through to the end of the TS (Table 5). The much slower rate of decline in DMD in Draft 1 (0.49 g/kg·day) than in Drafts 2 and 3 (0.74 and 0.88 g/kg·day) was likely due to the abnormally high rainfall in April 2006 in the early TS of Draft 1 (Table 1); this would have provided soil moisture for continuation of pasture growth into the TS. We are not aware of any other frequent detailed measurements of the rate of decline in the quality of the diet selected by cattle grazing tropical grass–legume pastures in a comparable high-rainfall environment. This measurement was only possible in the present experiment by the availability of F.NIRS with appropriate calibration equations. As might be expected, the rates of decline in diet DMD and CP in the present experiment were much slower than the rates of decline of the entire plant during regrowth of tropical grass, as summarised by Minson (1990). In the present experiment, there was a large amount of pasture DM on offer, so that the steers had the opportunity to select a diet much higher in DMD and CP than the average of the pasture. The extent of selection of higher-quality pasture components apparently increased as the seasons progressed, and this was at least in part associated with increasing selection of Centro in the pasture. As for many herbaceous legume species in tropical grass–legume pastures, the Centro legume comprised only a low proportion of the diet during the early to mid WS, but increased to a substantial or large proportion of the diet selected in the late WS and thereafter as the season progress. This pattern is similar to that reported for *Stylosanthes* spp., *Chamaecrista rotundifolia* (Wynn cassia), *Pueraria phaseoloides* and *Zornia latifolia* (Gardener 1980; Gardiner 1984; Böhnert *et al*. 1985; Miller and Stockwell 1991; Clements *et al*. 1996). However, some other herbaceous legume species, such as *Macroptilium atropurpureum* cv. Siratro and *Arachis pintoi*, and browse species, such as Leucaena, have been reported to be readily selected and consumed by cattle during the wet season (Lascano and Thomas 1988; Miller and Stockwell 1991; Hess *et al*. 2002). Hence, it is clear that the extent of selection of pasture legume during the wet season varies with the legume species. We are not aware of any other reports where very frequent measurements of the diet selected allowed calculations of the declines in DMD and CP during the WS and TS by cattle grazing pastures in the high-rainfall, seasonally dry tropics.

In conclusion, it was shown that the quality of the diet selected by cattle grazing a grass–Centro legume pasture in a high-rainfall, seasonally dry, tropical environment was high during the WS and, as expected, declined during the TS to be low in the DS. The pattern of contribution of Centro to the diet selected through the annual cycle was similar to that previously observed for several other tropical legumes, including *Stylosanthes hamata* and *S. scabra*. Cattle preferentially selected grass over legume during the pasture growing season, so that intake of Centro was minor and would have had little effect on cattle LW gain during the WS. However, intake of Centro was substantial during the TS and DS, would have increased the diet CP and DMD during these seasons, and would have provided some increase in LW gain in the TS and/or reduction in LW loss during the DS. This knowledge is important to understand the nutritional advantages and limitations of Centro as a companion legume in grass pastures and to inform optimal grazing management strategies. The experiment also demonstrated major advantages in using F.NIRS to measure selection and nutrient intake of grazing ruminants.

Conflict of interest

The authors declare no conflicts of interest. The research for this paper did not receive any specific funding. R. M. Dixon is an Associate Editor of *Animal Production Science*, but had no role in the review or evaluation of the manuscript.

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