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Seasonal changes in pasture quality and diet selection and their relationship with liveweight gain of steers grazing tropical grass and grass–legume pastures in northern Australia

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Abstract. The variation in liveweight gain in grazing beef cattle as influenced by pasture type, season and year effects has important economic implications for mixed crop–livestock systems and the ability to better predict such variation would benefit beef producers by providing a guide for decision making. To identify key determinants of liveweight change of Brahman-cross steers grazing subtropical pastures, measurements of pasture quality and quantity, and diet quality in parallel with liveweight were made over two consecutive grazing seasons (48 and 46 weeks, respectively), on mixed *Clitoria ternatea*/grass, *Stylosanthes seabrana*/grass and grass swards (grass being a mixture of *Bothriochloa insculpta* cv. Bisset, *Dichanthium sericeum* and *Panicum maximum* var. *trichoglume* cv. Petrie). Steers grazing the legume-based pastures had the highest growth rate and gained between 64 and 142 kg more than those grazing the grass pastures in under 12 months. Using an exponential model, green leaf mass, green leaf %, adjusted green leaf % (adjusted for inedible woody legume stems), faecal near infrared reflectance spectroscopy predictions of diet crude protein and diet dry matter digestibility, accounted for 77, 74, 80, 63 and 60%, respectively, of the variation in daily weight gain when data were pooled across pasture types and grazing seasons. The standard error of the regressions indicated that 95% prediction intervals were large ($\pm$0.42–0.64 kg/head.day) suggesting that derived regression relationships have limited practical application for accurately estimating growth rate. In this study, animal factors, especially compensatory growth effects, appeared to have a major influence on growth rate in relation to pasture and diet attributes. It was concluded that predictions of growth rate based only on pasture or diet attributes are unlikely to be accurate or reliable. Nevertheless, key pasture attributes such as green leaf mass and green leaf % provide a robust indication of what proportion of the potential growth rate of the grazing animals can be achieved.

Additional keywords: faecal near infrared reflectance spectroscopy, pasture production.

Introduction

Tropical pasture legumes have been in general use in northern Australia since the 1960s (Mannetje 1997) with the integration of legumes into grass pastures being demonstrated to increase animal production through an increase in the intake of protein and digestible energy (DE). Perhaps most notably, the *Stylosanthes*-based pastures on the lighter textured soils of northern Australia have had a major impact in terms of commercial application (Coates *et al*. 1997). On the heavier textured soils of the cropping region in central and southern Queensland the benefits of incorporating tropical legumes into the system are now being recognised, aided by the development of more suitable legume species and varieties (Pengelly and Conway 2000). Tropical legume-based pastures on cropping soils are well suited to beef finishing. They offer high annual growth rates and consequently younger turnoff and improved market opportunities, particularly in the key markets of South-East Asia and Japan.

Some of the species most suitable for both short-term and long-term pasture phases include *Stylosanthes seabrana* (Caatinga stylo), *Clitoria ternatea* (Butterfly pea), *Macroptilium bracteatum* (Burgundy bean) and *Desmanthus virgatus* (Desmanthus) (Clem and Hall 1994; Pengelly and Conway 2000). Only limited information is available on animal production from these tropical legumes. Clem (2004) found that in the first year of establishment there was no improvement in animal production from *C. ternatea*/grass and *S. seabrana*/grass pastures compared with sown grass pastures without a legume component, but the benefit thereafter generally ranged from 20 to 40 kg/ha liveweight gain (LWG) each year for

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the following 4 years. The increase in animal production attributable to legume-based pastures compared with grass pasture (either native or sown), is largely attributed to improved protein content and digestibility of the pasture on offer (Coates *et al*. 1997). The productivity and quality of grass pastures in this summer rainfall-dominant environment declines rapidly as the season progresses, whereas pastures with a robust legume component offer a more prolonged supply of adequate protein, helping to overcome the major limitations of low protein and digestibility that usually occurs in all but the early wet season for grass-only pastures (Coates *et al*. 1997).

The strong linkage between weight gain, efficiency of production and meeting high value market requirements means that the variation in annual LWG between pastures and between years has important economic implications (Bindon and Jones 2001; Bortolussi *et al*. 2005). The ability to better predict animal production and its variability, in the highly variable climates of the northern mixed-farming zone, would benefit producers by providing a guide for decision making to meet target markets. Relationships for predicting LWG have been developed for other tropical pasture systems. In studies of beef cattle production in the Australian tropics, Siebert and Hunter (1977) predicted animal growth rates on native grass and *Stylosanthes*/grass pastures using the nitrogen concentration of extrusa collected from oesophageal fistulated cattle. Day *et al*. (1997) developed a mechanistic grass production model (GRASP) for predicting LWG from native grass pastures of northern Australia while McLennan (1997) derived an empirical model using the quality and quantity of the pasture on offer. More recently, Coates (2000, 2002, 2004) has developed calibration equations for predicting LWG in growing cattle using faecal near infrared reflectance spectroscopy (F.NIRS) where daily weight gain (DWG) is related to faecal spectra using chemometric procedures. However, these models have limitations for predicting LWG from tropical legume-based pastures of the northern grain belt. The GRASP model does not include legumes; little is known about the quality of the pasture on offer and diet selection for the tropical legumes investigated in this study; and because the F.NIRS model was developed from cattle grazing pastures only at conservative stocking rates it appears not to cope with intake limitations caused by low pasture dry matter on offer. Moreover, separate equations may be required for different pasture types (Coates 2002).

The development of relationships between pasture and/or diet quality variables and liveweight change would enhance the capability of predicting beef production from legume-based pastures on cropping soils. A study was therefore undertaken at the Brian Pastures Research Station in the South Burnett district of southern Queensland on established grass-only and grass–legume pastures. Pasture quantity attributes were measured in parallel with diet quality and DWG in order to identify key predictors of DWG of beef cattle grazing these pastures.

Materials and methods

Experimental site and pasture systems

The experiment was conducted at Brian Pastures Research Station near Gayndah, Queensland (25°39′S, 151°45′E; altitude 120 m). The soil was a brown Vertosol (Isbell 1996) with a depth of 0.9–1.2 m. Soil pH (water) was 6.5–7.5 with an alkaline trend with depth, and Colwell extractable phosphorus was 40–80 mg/kg of soil in the top 150 mm.

Commencing in 2003, pasture and animal production measurements were made on four pasture systems that were part of a larger grazing trial that was established in 1998 and that comprised eight replicated pasture systems in two blocks and with pasture systems randomised within blocks (Clem 2004; Whitbread and Clem 2004). The four pasture systems were as follows:

(1) Grass (sown grass pasture with no sown legume),
(2) Stylo (mixed *S. seabrana*/grass pasture),
(3) BP-mod [mixed *C. ternatea* (Butterfly pea)/grass with a moderate component of *C. ternatea*], and
(4) BP-low (grass/legume pasture incorporating the legumes *C. ternatea* and *Desmanthus virgatus* but where the proportion of *C. ternatea* and total legume was lower than in BP-mod).

The grass component was a mixture of *Bothriochloa insculpta* cv. Bisset, *Dichanthium sericeum* and *Panicum maximum* var. *trichoglume* cv. Petrie. By 2003, the dominant grass in BP-mod and BP-low paddocks was *B. insculpta*, whereas a more even mixture of grasses remained in the stylo paddocks. In addition, the proportion of legume in each pasture system varied substantially with 80, 49 and 15% legume in the stylo, BP-mod and BP-low pastures, respectively, in early December 2003.

Paddocks were 2.5 ha and they were grazed continuously with two Brahman crossbred steers. For this experiment grazing of the grass, stylo and BP-mod paddocks began in August 2003 with steers aged ~8 months and weighing (mean ± s.d.) 173 ± 3.1 kg while grazing of the BP-low paddocks commenced in December 2003 (draft 1). In July 2004 draft 1 steers were removed and replaced with 11-month-old steers weighing (mean ± s.d.) 249 ± 10.9 kg. These steers remained on the experiment until May 2005 when weight gains ceased (draft 2). Draft 1 steers were bred at Swans Lagoon Research Station, Millaroo, in northern Queensland. Calving time was in December and they were weaned early due to poor seasonal conditions and were transferred to Brian Pastures in May 2003. Draft 2 steers were purchased locally and were born in August, the recommended calving time for the district.

Measurements

Rainfall

Daily rainfall was recorded at the weather station at Brian Pastures close to the experimental site.

Animal liveweight

Unfasted liveweights were recorded between 0900 and 1100 hours by weighing cattle directly off the plots at fortnightly intervals between December and June of each year and at 6-weekly intervals between July and December of each year.

Herbage mass and components

Herbage mass was determined for each paddock at ~6-weekly intervals between December and June each year. Pasture samples were harvested by cutting with a shearing handpiece close to ground level from 0.25-m^2 quadrats (10–15 per plot) placed randomly along a diagonal transect within each paddock. Samples were sorted into legume and grass fractions. The grass fraction was sorted into green leaf, green stem, dead leaf and dead stem while the legume fraction was sorted into green leaf, green stem and woody stem. Dry or dead legume leaves are not retained on the plant. All samples were dried to constant weight at 65°C before being weighed. These fractions enabled the following components to be derived: (i) green leaf herbage mass (kg/ha); (ii) green leaf percentage (as proportion of total herbage mass); (iii) adjusted green leaf percentage (as proportion of total herbage mass not including woody stem); (v) total green herbage mass (kg/ha); and (vi) total herbage mass (kg/ha).

F.NIRS estimates of diet quality

Faecal samples were collected per rectum on weigh days from 24 December 2003. They were bulked by paddock until 6 April 2004 after which they were maintained separately for individual animals. Faecal samples were processed for analysis by drying in a forced draft oven at 65°C and grinding through a Model 1093 Cyclotec laboratory mill (Foss Tecator AB, Hoganas, Sweden) fitted with a 1-mm screen. Faecal NIR spectra were obtained by scanning in a monochromator (400–2500 nm range) fitted with a spinning cup module (Model 6500, NIRSystems, Silver Spring, MD, USA). Moisture content of the scanned samples was controlled by redrying samples overnight at 65°C and cooling in a desiccator before loading the ring cups, which were again stored in a desiccator until scanning. Coates (2004) calibration equations for predicting the dietary crude protein (CP) concentration, dietary dry matter digestibility (DMD), and dietary non-grass percent (DNG) were used to estimate diet quality. Calibration statistics for these equations are presented in Table 1.

Data analysis

In all analyses the paddocks were used as the experimental unit. A repeated-measures ANOVA (over the whole 2-year period of the investigation) was used to test for significant interactions between pasture systems and harvest dates for the pasture and diet attributes (green leaf mass, green leaf %, adjusted green leaf %, green herbage mass, total herbage mass, diet CP, diet DMD and DNG). Differences in cumulative LWG for specific periods and at the end of each draft were analysed using conventional ANOVA. Comparisons between pasture systems, harvest dates and pasture system × harvest date interactions were made using protected Fisher's l.s.d. tests.

Regressions were derived for the relationship between DWG and various sward components and between DWG and diet quality estimates using an exponential model of the form $y = A + B(R^x)$ where y is DWG and x is the measured or estimated pasture/diet attribute and A, B and R are fitted constants. The regressions were derived for all combinations of pasture types either separately or combined, and years (draft of animals) separately or combined and compared statistically for differences between pasture types and/or years. The regressions relating DWG to sward components were based on pasture yield components made on nine occasions, five during draft 1 and four during draft 2, as described previously, whereas the regressions relating DWG to diet quality were made using F.NIRS predictions of diet quality on 29 occasions, 14 during draft 1 and 15 during draft 2.

Relationships between pairs of pasture/diet attributes were determined by simple linear regression.

Results

Rainfall

Rainfall (Table 2) during 2003–04 was 20% above average for the 6 months from October to March. The December to March period was particularly wet and resulted in good soil moisture for summer and autumn pasture growth. Rainfall was well below average for the autumn/winter period of May to

Table 1. Calibration statistics of the equations used for predicting diet quality attributes from faecal near infrared reflectance spectroscopy analysis

SEC, standard error of calibration; SECV, standard error of cross validation

Attribute	No. of samples in calibration	Analyte range	SEC	SECV	R^2
Diet crude protein (%)	1202	1.5–27.4	1.03	1.08	0.95
Dry matter digestibility (%)	1121	38–72	1.95	1.99	0.89
Dietary non-grass (%)	1501	0–100	5.4	5.6	0.94

Table 2. Monthly and mean long-term (1968–2004) rainfall (mm) for Brian Pastures Research Station, Gayndah, Queensland

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2003	0	113	63	62	43	10	17	41	0	60	46	179
2004	142	91	109	28	11	5	1	1	22	92	76	182
2005	50	62	31	10	43	–	–	–	–	–	–	–
Mean	106	95	67	35	38	28	35	29	31	62	76	101

August 2004 (18 mm compared with an average of 130 mm) but above average rainfall was received during the final quarter of 2004. Rainfall for January to April 2005 was much lower than average, resulting in an early finish to the growing season.

Liveweight gain

Each grazing year was divided into three periods, nominally the late winter and spring (period 1), the summer and early autumn (period 2) and the autumn or autumn and early winter (period 3). The effect of pasture system on LWG (kg/head) was consistent throughout the experiment with gains for all periods being highest for stylo, followed by BP-mod, followed by BP-low and lowest for grass. Although differences were often large they were frequently not significant ($P > 0.05$, Table 3) due to high variability between replicates. In draft 1, most of the difference between pasture types occurred in periods 1 and 3 while gains were almost identical during the main growing season (period 2). Conversely, the biggest overall differences occurred during the main growing season for draft 2 steers although the differences were not significant ($P > 0.05$). Draft 1 steers gained weight during all periods while draft 2 steers suffered weight losses in periods 1 and 3 for all pasture types except stylo. Total LWG of the stylo treatment from August 2003 to May 2005 was more than double that of the grass treatment while BP-mod had a 69% advantage over the grass treatment.

Table 3. Liveweight change (kg/head) of steers grazing four pasture systems in 2003–04 (draft 1) and 2004–05 (draft 2)

BP-low and BP-mod indicate low and moderate proportions of butterfly pea (*Clitoria ternatea*) in a legume/grass pasture. Within rows, values followed by different letters are significantly different at $P = 0.05$

Period	Grass	BP-low	BP-mod	Stylo
		Draft 1		
1 (5/8/03–1/12/03)	37.0a	–	63.5b	76.5c
2 (1/12/03–6/4/04)	114.0	–	114.5	115.5
3 (6/4/04–6/7/04)	8.0a	–	35.5ab	48.5b
All (5/8/03–6/7/04)	159.0a	–	213.5ab	240.5b
		Draft 2		
1 (5/7/04–19/10/04)	–33.0	–12.0	–12.0	1.5
2 (19/10/04–29/3/05)	102	150	156	190
3 (29/3/05–24/5/05)	–18.5	–11.0	–5.5	1.5
All (5/7/04–24/5/05)	50a	126.5ab	139b	192b

Differences between pasture treatments in steer growth rate over the course of the experiment were most clearly and elegantly displayed when DWG (calculated from the polynomial fits to cumulative LWG curves) was plotted over time (Fig. 1). Except for the period from December 2003 to March 2004, steers grazing stylo pasture always had the highest growth rate and those grazing grass pasture the lowest growth rate with those on BP-mod and BP-low intermediate. In general the differences between pasture types were least during the period of fastest growth (December to March).

Pasture yield attributes

Green leaf herbage mass differed between pasture types and there was a significant interaction between harvest date and pasture system. Green leaf herbage mass in stylo pasture was higher than in BP-mod, BP-low and grass pastures during the period from December to March ($P < 0.05$) with the exception of grass and BP-mod in March 2004 (Fig. 2*a*). Later in the season (from April to June) green leaf herbage mass did not differ significantly between the pasture types ($P > 0.05$). Green leaf herbage mass in BP-mod was significantly higher than in grass and BP-low pasture in January of 2004 and higher than grass pasture in January 2005 ($P < 0.05$) but not at other harvest dates. Green leaf herbage mass peaked in January of both years for all pasture types except for grass pasture where the peak yield was in February of 2004.

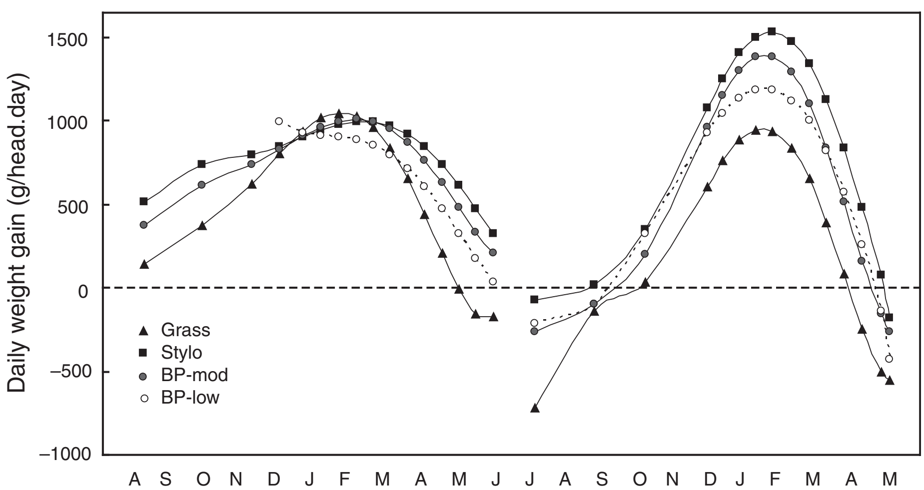

Fig. 1. Daily weight gain (DWG) profiles of steers grazing four different pasture types starting in August 2003 until May 2005. DWG was calculated from the 6th order polynomial fits to cumulative liveweight gain curves for each pasture type. Grass pasture (▲), solid line; stylo pasture (■), solid line; BP-mod pasture (●), solid line; BP-low pasture (O), dashed line. BP-low and BP-mod indicate low and moderate proportions of butterfly pea (*Clitoria ternatea*) in a legume/grass pasture.

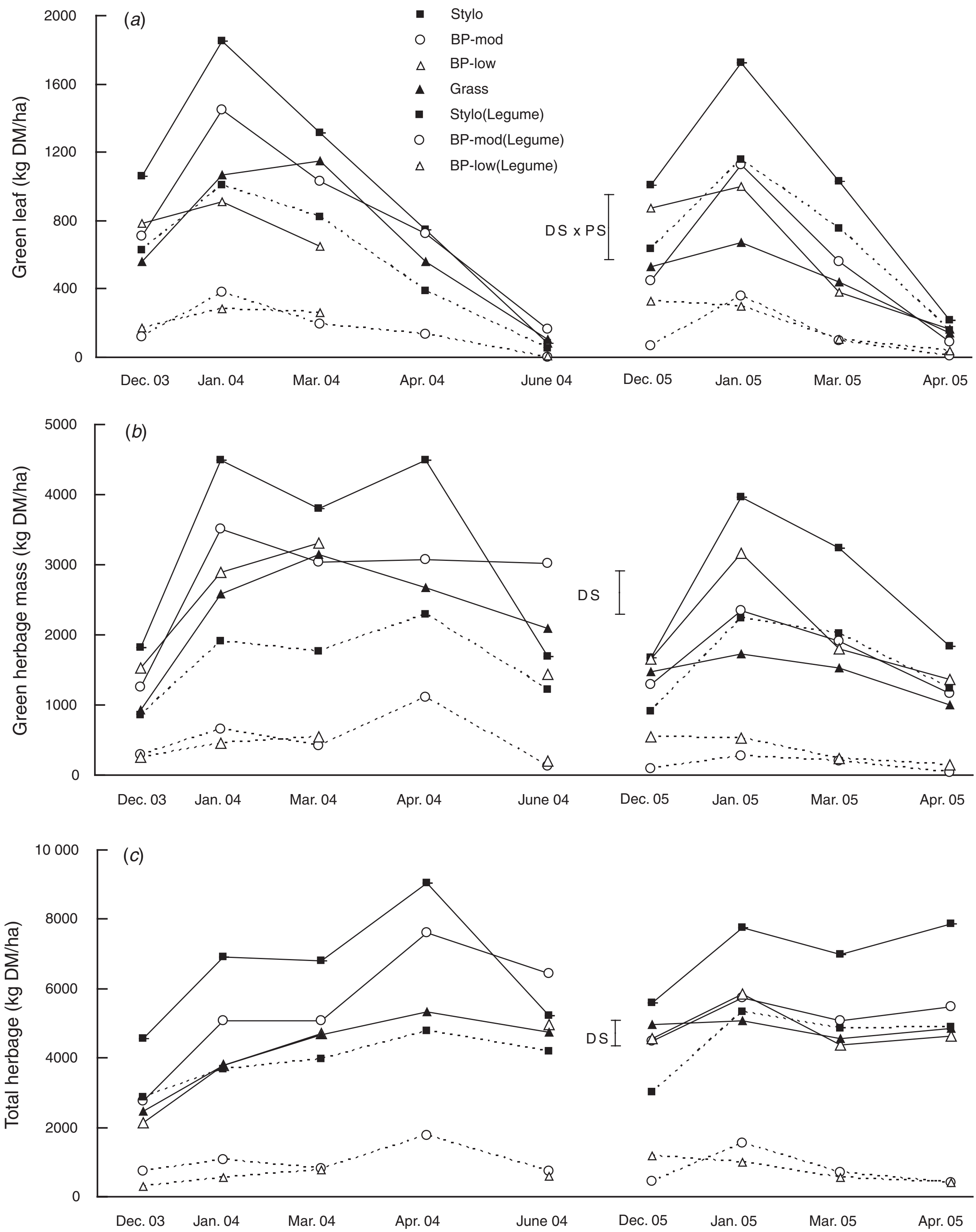

Fig. 2. Green leaf herbage mass (*a*), green herbage mass (*b*) and total (green + dead + woody) herbage mass (*c*) in grass (▲, solid line), stylo (■, solid line), BP-mod (O, solid line), BP-low (Δ, solid line) pasture systems on harvest dates over two growing seasons, 2003–05. Dashed lines represent the legume herbage mass in the legume-based pasture systems. The vertical bars represent the l.s.d. values ($P = 0.05$) for date of sampling × pasture system interaction or the main effects of date of sampling. BP-low and BP-mod indicate low and moderate proportions of butterfly pea (*Clitoria ternatea*) in a legume/grass pasture.

Green herbage mass, the sum of green leaf and stem, peaked in January of both years with the exception of the BP-low and grass pastures in 2004 which peaked at the March sampling (Fig. 2*b*). In 2004, green herbage mass was maintained with little change through the January, March and April samplings. For the period from April to June of 2004 there was a significant decline ($P < 0.05$) in green herbage mass in stylo pasture, a non-significant decline in the grass pasture, and no change in BP-mod. April data was not available for BP-low but in this treatment green herbage mass declined by more than 50% between March and June. In 2005 green herbage mass declined after the January sampling in all pasture systems ($P < 0.05$), declining slightly from January to March and more rapidly from March to April except for BP-low where the major decline was from January to March. Overall, green herbage mass was substantially higher in stylo pasture than in the other pastures but neither the main effect of pasture type nor the pasture × sampling date interaction effect was significant ($P > 0.05$).

Total herbage mass exceeded 2 t/ha at the first harvest date in December 2003 and remained above 4 t/ha from March 2004 to the end of the experiment (Fig. 2*c*). In 2004, peak yields were measured at the April harvest in all pastures but in 2005 yields were highest in January except for stylo where the April yield was highest but not significantly different from the January yield.

In both years, the proportion of legume biomass in the green leaf, total green or total herbage fractions was much higher in the stylo pasture (ranging from 52 to 74% for green leaf, 42 to 73% for total green and 53 to 80% for total herbage mass) than in BP-mod (ranging from 1 to 32% for green leaf, 3 to 25% for total green and 7 to 27% for total herbage mass) and in BP-low (ranging from 18 to 40% for green leaf, 10 to 33% for total green, and 8 to 26% for total herbage mass) (Fig. 2). The high percentage of stylo in total herbage mass was due to the large amount of woody stem that averaged 39% (ranging from 27 to 57%).

Estimated diet quality

The main effects of pasture type and time of sampling on predicted diet CP were significant ($P < 0.01$) and there was also a significant pasture type by sampling date interaction ($P < 0.05$) (Fig. 3*a*). The average diet CP concentrations for 30 samplings from December 2003 to May 2005 were 11.7, 11.3, 10.4 and 8.1% for stylo, BP-mod, BP-low and grass pastures, respectively, and the differences were all significant ($P < 0.05$). However, pasture type × sampling date interaction differences between the stylo and BP-high pastures were not significant ($P > 0.05$) on 26 of 30 sampling dates. Diet CP concentrations for BP-low were lower than for the other legume pastures on 19 of 30 occasions. These differences were rarely significant for specific sampling dates but the main effect was significant (l.s.d. = 2.18%). BP-low had significantly higher diet CP concentration than for grass pasture on 9 of 14 sampling dates in 2003–04 but on only 3 of 16 occasions in 2004–05.

The main effect of pasture type and time of sampling on predicted diet DMD differed slightly from that on diet CP in that diet DMD for BP-low was significantly higher than for BP-mod ($P < 0.05$) and diet DMD for the stylo and BP-low pastures did not differ ($P > 0.05$). Average diet DMD values were 57.9, 57.1, 58.3 and 53.3% for stylo, BP-mod, BP-low and grass pastures, respectively (Fig. 3*b*).

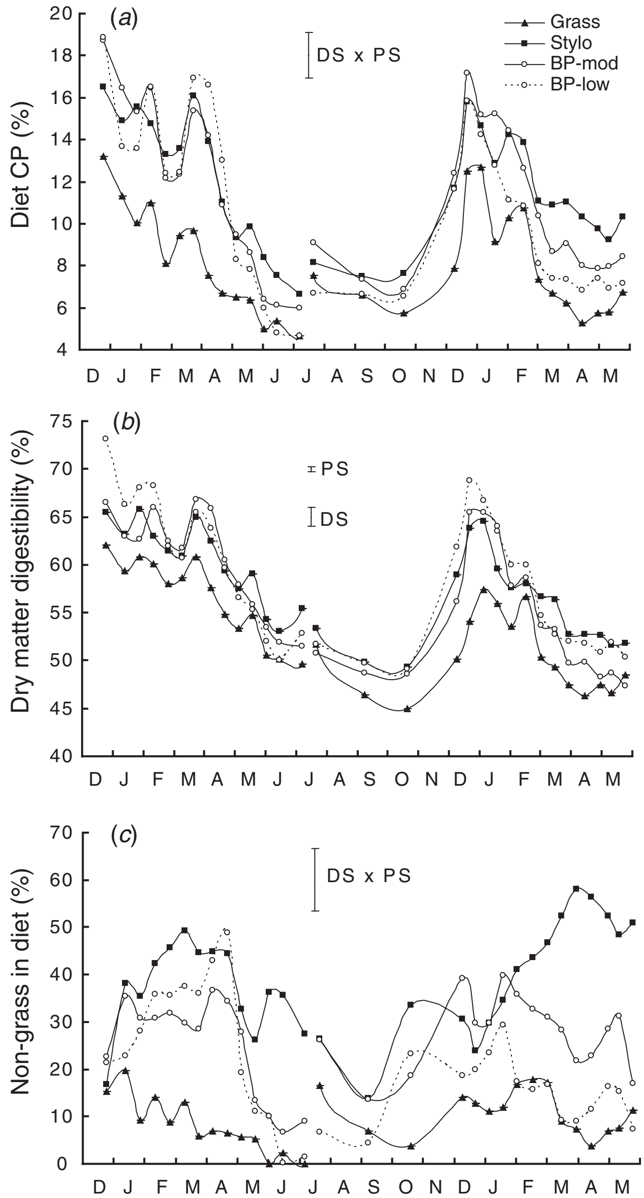

Fig. 3. Faecal near infrared reflectance spectroscopy prediction profiles of diet crude protein, diet digestibility and diet non-grass for the period December 2003 to May 2005. Grass pasture (▲), solid line; stylo pasture (■), solid line; BP-mod pasture (O), solid line; BP-low pasture (O), dashed line. The vertical bars represent the l.s.d. values ($P = 0.05$) for date of sampling × pasture system interaction or the main effect of pasture system or date of sampling. BP-low and BP-mod indicate low and moderate proportions of butterfly pea (*Clitoria ternatea*) in a legume/grass pasture.

Temporal changes in diet quality followed the expected seasonal pattern in relation to rainfall distribution and temperature. For draft 1 steers diet CP and diet DMD were highest at the first sampling in December 2003 and apart from fluctuations in diet quality associated with specific rainfall events (e.g. a short-term increase in diet quality following a rainy period 4–7 March) the overall trend was for a decline in both diet CP and diet DMD as the season progressed through autumn and winter (Fig. 3*a*). For draft 2 steers, diet quality remained low during the dry winter and early spring period until good rain fell in October. Diet quality then peaked again in December and declined progressively through to mid May. In both years, diet CP fell below 7% by April in the grass pasture, whereas in the legume pastures diet CP was maintained at higher levels until May and June. Diet CP in the BP-low pasture declined to a greater extent than in the other legume pastures and this was associated with lower proportions of non-grass in the diet. In late winter/early spring of 2004 diet CP was similar for all pastures. Predicted diet DMD was highest at the first faecal sampling in December 2003 and, although levels fluctuated thereafter, high diet DMD levels were maintained through to the end of March in 2004 and then declined progressively through autumn, winter and early spring until new growth occurred after the October rain (Fig. 3*b*). After peaking in late December/early January there was a general trend for a sharp decline in diet DMD to the end of March 2005. Diet DMD was maintained at higher levels on the stylo pasture than on BP-mod and BP-low pastures during periods from May to July 2004 and March to May 2005 though the differences were not significant on most sampling occasions. For the comparable periods late December to mid May, predicted diet DMD averaged 6.7 percentage units higher for draft 1 steers than for draft 2 steers.

Pasture type and time of sampling had a significant effect on dietary non-grass proportions ($P < 0.01$) with means values of 39% for stylo, 26% for BP-mod, 20% for BP-low and 9% for grass. Large temporal fluctuations in the relative proportions of dietary non-grass between the different pasture types gave rise to a significant pasture type × sampling date interaction ($P < 0.05$, Fig. 3*c*). Of particular importance were the lower non-grass proportions of steers grazing BP-mod and BP-low pastures compared with stylo pasture during periods from May to September 2004 and February to May 2005. Low dietary non-grass proportions for steers grazing BP pastures at these times were probably associated with low yields of green legume. The proportion of non-grass in the diet of steers grazing grass pasture was highest in summer (up to ~20%), and it declined to low levels (0–10%) during autumn and winter (Fig. 3*c*). Diet CP and diet DMD were poorly correlated with dietary non-grass proportions (R^2 of 0.35 and 0.16 for diet CP and DMD, respectively), while there was a much better correlation between diet DMD and diet CP (R^2 of 0.76). Moreover, the regressions of diet DMD on diet CP did not differ in slope or intercept between pasture types ($P > 0.05$).

Regression analyses

Paddock means for DWG ranged between –792 and 1666 g/head.day during the course of the experiment and were positively correlated ($P < 0.001$) with green leaf herbage mass, green leaf %, adjusted green leaf %, diet CP, diet DMD, diet non-grass % and total green herbage mass (e.g. Fig. 4 and Table 4) but not with total herbage mass. The relationships were exponential, with DWG reaching a maximum beyond which there was no additional response (represented by the A value in the regression model of DWG = A + B(R^X).

Using the full set of data, adjusted green leaf % was the best predictor of DWG but based on the standard errors of the regressions there was little difference between the efficacy of adjusted green leaf %, green leaf % and green leaf mass, all of which were better predictors than diet CP and diet DMD. Although the regressions of DWG on green herbage mass and diet non-grass were significant ($P < 0.001$), R^2 values were low (Table 4) and these parameters were therefore rejected as predictors of DWG. The exponential regression model was also used to determine the effect of pasture type and draft of cattle on the relationships (Table 4). The year or draft effect was significant for green leaf yield, green leaf %, adjusted

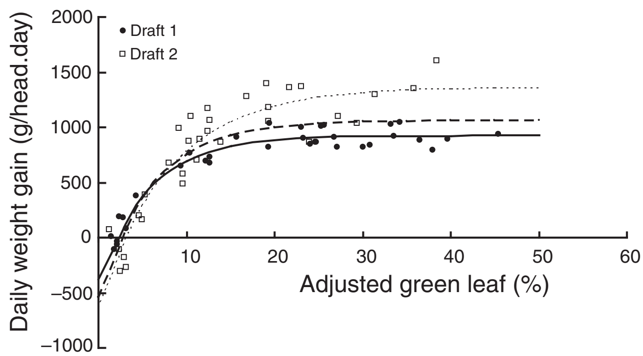

Fig. 4. Daily weight gain plotted against adjusted green leaf % for draft 1 (●) and draft 2 (□) steers. Data were from the four pasture types. Fitted regressions for draft 1 (dashed line), draft 2 (dotted line), and for the drafts combined (solid bold line) are shown.

Table 4. Regression statistics for exponential relationships between daily weight gain (g/day) and pasture or diet parameters

Parameter	Drafts 1 and 2 combined			Draft 1			Draft 2		
	R^2	s.e.	A[A]	R^2	s.e.	A	R^2	s.e.	A
Green leaf (kg/ha)	0.768	219	1099	0.906	112	998	0.820	228	1328
Green leaf (%)	0.744	229	1053	0.878	126	943	0.801	239	1437
Adjusted green leaf (%)	0.802	202	1061	0.945	85	925	0.857	203	1354
Total green (kg/ha)	0.168	415	932	–	–	–	–	–	–
Diet crude protein (%)	0.634	304	1257	0.743	186	991	0.702	332	1772
Diet dry matter digestibility (%)	0.596	319	1287	0.730	191	1151	0.688	340	1687
Diet non-grass (%)	0.354	361	919	–	–	–	–	–	–

[A]Fitted constant (asymptote in g/day) in the regression model daily weight gain = A + B(R^x).

green leaf %, diet CP and diet DMD with asymptote values being substantially and significantly higher for draft 2 than for draft 1. The measured pasture or diet parameters accounted for a higher percentage of variation in DWG when data were confined to a single draft and the relationships were stronger for draft 1 than for draft 2 steers. There was also a significant draft effect on the relationship between DWG and the pasture/diet parameters in all cases when the regression analysis was confined to a single pasture type (data not shown). Within drafts, significant differences between pasture types were due to differences in the shape of the curve (B and R coefficients) as well as differences in the asymptote or A value. The effect of pasture type was also significant when data from the two drafts were combined except with regard to DWG regressed on green leaf yield.

Using the fitted exponential models the values of the pasture/diet parameters required for steers to achieve 90% of maximum growth rate (i.e. A × 0.9) were calculated (Table 5). Higher proportions of green leaf and higher diet CP and DMD were needed for near maximum growth rates in draft 2 steers despite draft 2 steers growing faster than draft 1 steers at equivalent levels of green leaf %, diet CP or diet DMD. However, there was no difference between drafts in the green leaf mass needed for near maximum growth rate, the amount being ~1000 kg DM/ha.

Diet CP and diet DMD were both linearly correlated with green leaf yield, green leaf % and adjusted green leaf % ($P < 0.001$, Table 6). Correlations were better with green leaf % than with green leaf yield but there was no difference between green leaf % and adjusted green leaf %. Correlations between diet DMD and green leaf fractions were also generally better than those between diet CP and green leaf parameters. Regression relationships (R^2, intercept and slope) were influenced by pasture type and year so that pooling data across pasture types and drafts generally weakened the relationships.

Discussion

LWG from pasture systems

The LWG benefit attributable to tropical legumes adapted to the heavy textured cropping soils at the experimental site was clearly demonstrated (Table 3, Fig. 1). The increases in annual LWG from legume-based pasture systems compared with grass pasture were comparable with or greater than benefits previously reported for pasture systems on lighter textured soils of the tropics and subtropics. For example Jones *et al.* (1990) reported a mean benefit in annual gain of 45 kg/head for steers on sown stylo/grass pastures compared with native pasture at Lansdown Research Station near Townsville. Coates *et al.* (1997) reported a 30–60-kg annual LWG advantage for cattle grazing pastures that included Verano (*Stylosanthes hamata*) and/or Seca (*S. scabra*) for a range of experiments in north Queensland. For cattle grazing sown buffel grass pasture with and without Siratro (*Macroptilium atropurpureum*) at Narayen Research Station 100 km west-north-west of Brian Pastures, Mannetje and Jones (1990) reported mean annual LWG benefits of 56 and 86 kg/head over two 3-year periods, respectively. The LWG benefits to legume in our study were 112 and 72 kg/head for the stylo and BP-mod pasture systems, respectively, (mean of 2 years) and 76 kg/head for BP-low in 2004–05. Differences between the three legume-based pastures were probably associated with the availability of legume in the pastures (Fig. 2). For the same experiment, Clem (2004) also reported weight gain differences between the pasture systems of similar magnitude to those presented in this paper.

Pasture yield, quality and diet selection

Pasture DM on offer (excluding the woody components) was never limiting in any of the pasture systems during the experiment so that intake was limited by quality and availability of the specific pasture components (e.g. green leaf), sward structure and the quality of the different pasture components, rather than total herbage mass. Seasonal changes in green material and diet quality followed the expected pattern as determined by the climatic conditions (rainfall and temperature) and the presence and availability of legume. The legume yields, particularly of stylo, indicated that they were well adapted to the soil and climate of the experimental site. The stylo increased from 6% of total herbage mass in 1998 (Whitbread and Clem 2004) to over 60% in 2005. The ability of *S. seabrana* to flourish under continuous grazing is indicative not only of its adaptation to the soil and climate of the site but also of its resistance to the fungal disease Anthracnose and of the high seed setting ability of stylos in general, even under heavy grazing (Gardener *et al.* 1993). Yields of BP were lower than those of stylo even after adjustment for woody stem which was very high for stylo.

Table 5. Pasture and diet parameters in relation to 90% maximum growth rate of steers calculated from fitted exponential models

Pasture/diet parameter	Draft 1	Draft 2
Green leaf mass (kg/ha)	1000	1000
Green leaf (%)	16.5	22
Adjusted green leaf (%)	15.5	21.5
Diet crude protein (%)	14	21.5
Diet dry matter digestibility (%)	70.5	73

Table 6. Coefficients of determination for linear regressions of diet crude protein (CP) and diet dry matter digestibility (DMD) on green leaf yield (kg/ha) and green leaf percentage

BP-low and BP-mod indicate low and moderate proportions of butterfly pea (*Clitoria ternatea*) in a legume/grass pasture. Regressions were calculated for the pooled data (all pasture types for drafts 1 and 2) and separately for each pasture type

	Pooled data	Grass	Stylo	BP-high	BP-low
	Regressions on green leaf yield				
Diet CP	0.45	0.34	0.50	0.47	0.68
Diet DMD	0.49	0.53	0.49	0.64	0.76
	Regressions on green leaf percentage				
Diet CP	0.60	0.53	0.77	0.76	0.83
Diet DMD	0.69	0.76	0.71	0.75	0.89
	Regressions on adjusted green leaf percentage				
Diet CP	0.65	0.53	0.78	0.81	0.82
Diet DMD	0.66	0.76	0.71	0.80	0.87

Nevertheless, persistence since sowing was satisfactory and there was sufficient legume in both BP-mod and BP-low to result in large increases in LWG compared with grass pasture.

The overall correlations (i.e. pooling data across pasture types) of diet quality (CP and DMD) with green leaf herbage mass and green leaf % were significant but a substantial proportion of the variation in diet quality was not explained by the green leaf parameters. This was due in part to the relationships differing between the pasture systems and between years. For example, at a given level of green leaf, diet quality of steers grazing grass pasture was lower than that of steers grazing the legume pastures (Fig. 5) and this demonstrates the nutritional benefit of legumes with respect to both protein and energy supply.

Also, seasonal differences in the relative proportions of legume and grass consumed would influence diet quality and contribute to unexplained variation in the relationships. The results from the December sampling in both years were outliers from the general relationship between diet quality and green leaf with diet CP and diet DMD being much higher in relation to the green leaf yield than at other times. The very high quality of young, new growth at this time of the year, accessibility of the new growth, and intense selection for the young green leaf may have all contributed. The stronger relationship between diet quality and green leaf % compared with that between diet quality and green leaf mass (Table 5) may be due to green leaf % being a better index of the grazing accessibility of preferred plant components than green leaf mass.

Based on the assumption that legume made up virtually all the non-grass fraction in the legume pastures, the pattern of selection for legume species was similar to that found for other *Stylosanthes*-based pastures in northern Australia, where new grass growth is preferred early in the wet season followed by a progressive increase in dietary stylo content as the pasture matures through the wet and early dry seasons and then a progressive decline with increasing maturity and drying off of pasture through the drier winter and spring until the break of the following wet (Coates 1996; McLennan 1997). Peak dietary stylo levels were somewhat lower than the 80% reported by Coates (1996) for pastures containing moderate to high proportions of Verano and/or Seca stylos in the seasonally dry tropics of north Queensland. The difference may have been due in part to better quality of sown grasses on these clay soils relative to sown or native grasses on poorer soils in the seasonally dry tropics. The appreciably lower dietary legume proportions in the BP-mod and BP-low pastures on most sampling occasions (Fig. 3*c*) were probably associated with the much lower green leaf and total green legume yields compared with those for stylo (Fig. 2). Edible forbs composed the dietary non-grass proportions in the grass pasture (mean of 10%, range 0–20%, Fig. 3*c*). These were most abundant in the more disturbed areas around the water troughs, shade shelters and along the fencelines.

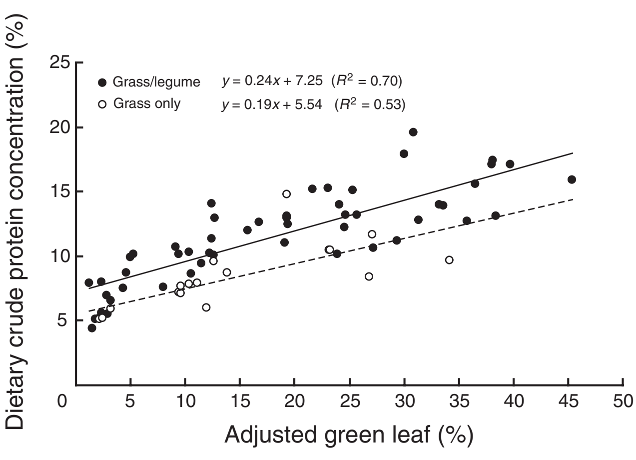

Fig. 5. Relationship between diet crude protein and adjusted green leaf % for grass/legume (●) and grass-only pasture (O) types.

Relationship between DWG and pasture/diet parameters

Given that plant factors such as the proportion of green leaf in the available forage and the digestibility and protein content of the diet have a strong influence on intake in grazing animals (Dove 1996) we expected significant relationships between DWG and both pasture and diet parameters. Using the exponential model, green leaf mass, green leaf %, adjusted green leaf %, diet CP and diet DMD accounted for 77, 74, 80, 63 and 60%, respectively, of the variation in DWG when the data were pooled across pasture types and drafts. However, the regression standards errors (Table 4) indicated that the 95% prediction intervals were quite large at approximately ±0.42–0.64 kg/head.day and the magnitude of these potential errors suggests that the derived regression relationships would have limited practical application for making reliable estimates of growth rate. Relationships were generally stronger when data were limited to one pasture type and/or one draft but such relationships would also be of little practical use. The regression relationships were weakened considerably by combining data from the two drafts (Table 4) and it could be reasonably concluded that the relationships would probably be further weakened by including data from additional drafts. Although the strength of the relationships varied among pasture types (strongest for grass pasture and weakest for stylo pasture), combining pasture types had a lesser impact on the relationships than combining drafts such that the mean coefficients of determination of the four pasture types when developed separately were little different from those when the data were pooled across pasture types. The effect of year or draft on the relationships highlighted a deficiency in previous reports where data were often restricted to 1 year (e.g. Yates *et al.* 1964; Mannetje 1974).

Pasture or animal factors could both contribute to year or draft effect on the regression relationships. In this study, the evidence pointed to a major animal effect. First, DWG asymptote values were appreciably higher for draft 2 than for draft 1 indicating a greater capacity for high growth rate in draft 2 steers. Moreover, the fitted exponential regressions also indicated that at equivalent levels of diet DMD, green leaf herbage mass and green leaf %, DWG values of draft 2 steers were substantially higher than those of draft 1 steers. For diet CP, the fitted curves indicated that DWG values of draft 1 steers were higher than those of draft 2 steers at equivalent diet CP levels up to ~10% CP but the reverse occurred for diet CP levels above 10%. In draft 2, the lower diet CP levels (<10%) occurred at the beginning and end of the grazing year when the pastures were dry and when green leaf mass and green leaf % were very low. During these intervals the cattle were able to select diets of moderate CP concentrations but digestibility levels were low (Fig. 3) so that DWG would have been limited by energy intake and the more general relationship between DWG and diet CP did not hold. For the most part, however, draft 2 steers had substantially higher growth rates than draft 1 steers at equivalent green leaf mass, green leaf %, diet CP and DMD levels. Higher growth rates are mediated via higher intakes of DE, or increased efficiency of utilisation of DE, or via differences in the partitioning of DE between muscle and fat synthesis. Draft 2 steers clearly behaved differently from draft 1 steers in one or more of these factors. Observed differences in the DWG relationships were probably associated with one or both of the following factors. First, differences between draft 1 and draft 2 steers in genetic potential, adaptation to the Brian Pastures environment, and birth date/age effects related to the origin of the steers (see 'Materials and methods' section), may have contributed to the differing relationships. Second, growth pathways were probably important. Draft 1 steers experienced abnormally good pasture conditions from the beginning of the experiment in August so that there was no opportunity for compensatory growth later in the year. Conversely, draft 2 steers experienced relatively poor pasture conditions from July until a break in the season in the second half of October so that there was opportunity for substantial compensatory growth during the summer and early autumn. Whatever the reason or reasons, the difference between the two drafts in the exponential relationships illustrates the difficulties in accurately predicting animal growth rate purely from pasture and/or diet attributes.

Adjusted green leaf % was the best predictor of DWG. That it was better than unadjusted green leaf % was almost certainly related to the abundance of woody stem in the legume-based pastures, particularly the stylo pasture where woody stem averaged 39% of total herbage mass. The proportion of green leaf provides an index of the ease with which the preferred component (i.e. green leaf) can be selected and logically this depends on both the amount and accessibility of green leaf. The results indicated that adjusted green leaf % provided a better index of both amount and accessibility across pasture types than unadjusted green leaf % presumably because the variable amount of woody stem, unlike dead leaf and non-woody stem, had little effect on accessibility. We rejected total green herbage mass as a potentially useful predictor of DWG because it accounted for only 17% of the variation in DWG. By way of contrast, Mannetje (1974) reported that with cattle grazing buffel grass (*Cenchrus ciliaris*) and buffel grass/Siratro (*M. atropurpureum*) pastures, LWG was related to total green material, green grass, or green legume and concluded that total green material was the best available predictor of LWG, accounting for ~50% of the variation in LWG. In that work (Mannetje 1974) green leaf, as distinct from green material (leaf and stem), was not assessed as a predictor.

In the absence of specific mineral deficiencies, disease and parasites, digestibility is regarded as the primary limitation to productivity in cattle grazing tropical pastures during the interval from the break of the growing season until protein becomes the primary limiting nutrient later in the season. It was therefore unexpected that of the five potentially useful predictors of DWG (green leaf mass, green leaf %, adjusted green leaf %, diet CP and diet DMD), DMD was the least effective. Although the higher DWG and cumulative LWG of steers grazing the legume pastures compared with those for grass pasture were consistent with F.NIRS estimates of diet digestibility (Fig. 3) digestibility differences between the three legume pastures were not mirrored by similar DWG rankings except for steers on stylo pasture having the highest DWG over the final few months of draft 2. There were two other apparent anomalies regarding steer DWG relative to predicted digestibility. During the period from December 2003 to early April 2004, LWG was almost identical for the four pasture types (Table 3) but the mean digestibility of the three legume pastures was four percentage units higher than that of the grass pasture. One explanation for this apparent anomaly could be related to compensatory gain of steers on grass pasture since their LWG during the previous 4 months was a lot less than for steers on the legume pastures (Table 3). The other anomaly related to the differences between draft 1 and draft 2 in the regression relationships between DWG and pasture parameters as discussed previously. For diet DMD specifically, predicted DMD during the main growing season from December to March averaged 62.9 and 57.4% for draft 1 and draft 2, respectively, but mean DWG over the same period was higher in draft 2 than in draft 1 (1.01 *v.* 0.93 kg/day). Animal effects including compensatory gain, interactions between diet selection and availability of preferred components and intake, and F.NIRS prediction errors, probably contributed to this anomaly and to the poorer than expected overall relationship between DWG and diet DMD.

Diet CP was also a relatively poor predictor of DWG compared with the green leaf parameters in this experiment. This was not unexpected because diet CP was rarely, if ever, the primary limiting nutrient during the course of the experiment, particularly for steers grazing the legume-based pastures. The only evidence of a deficiency of rumen degradable protein occurred during the final few weeks of draft 1 when DMD : CP ratios (Dixon and Coates 2005) exceeded 9 in steers grazing grass and BP-low pastures. That there was a significant relationship between DWG and diet CP in this dataset was probably due primarily to CP being linearly correlated with each of green leaf mass, green leaf %, adjusted green leaf % and diet DMD.

In conclusion, the results of this experiment demonstrated major benefits in annual LWG of cattle from incorporating productive, adapted legumes into pastures growing on clay soils in the cropping region of southern Queensland. Importantly, in this experiment at least, the benefit due to legume was greater in the drier year of the 2-year experiment. While there were moderately strong and highly significant relationships between growth rate and the pasture parameters of green leaf mass and green leaf % or between growth rate and F.NIRS predictions of diet CP and diet DMD, regression prediction intervals were of such a magnitude to cast doubts on the accuracy of growth rate predictions at any point in time. Nevertheless, the results also showed that near maximum growth rates, relative to the potential for the particular class if animal to gain weight on pasture, are achieved when green leaf mass exceeds 1000 kg/ha and that growth rate declines rapidly with decreases in green leaf mass below that threshold.

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References

Bindon BM, Jones NM (2001) Cattle supply, production systems and markets for Australian beef. *Australian Journal of Experimental Agriculture* **41**, 861–877. doi: 10.1071/EA01052

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005) The northern Australian beef industry, a snapshot. 3. Annual liveweight gains from pasture-based systems. *Australian Journal of Experimental Agriculture* **45**, 1093–1108. doi: 10.1071/EA03098

Clem RL (2004) Animal production from legume-based ley pastures in south-eastern Queensland. In 'Tropical legumes for sustainable farming systems in southern Africa and Australia'. (Eds AM Whitbread, BC Pengelly) pp. 136–144. (Australian Centre for International Agricultural Research: Canberra)

Clem RL, Hall TJ (1994) Persistence and productivity of tropical pasture legumes on three cracking clay soils (Vertisols) in north-eastern Queensland. *Australian Journal of Experimental Agriculture* **34**, 161–171. doi: 10.1071/EA9940161

Coates DB (1996) Diet selection by cattle grazing *Stylosanthes*-grass pastures in the seasonally dry tropics: effect of year, season, stylo species and botanical composition. *Australian Journal of Experimental Agriculture* **36**, 781–789. doi: 10.1071/EA9960781

Coates DB (2000) Faecal NIRS – what does it offer today's grazier? *Tropical Grasslands* **34**, 230–239.

Coates DB (2002) Using faecal NIRS to predict growth rate in grazing cattle. Final Report of project NAP3.116 to Meat and Livestock Australia, Sydney.

Coates DB (2004) Improving reliability of faecal NIRS calibration equations. Final Report of Project NAP3.121 to Meat and Livestock Australia, Sydney.

Coates DB, Miller CP, Hendricksen RE, Jones RJ (1997) Stability and productivity of Stylosanthes pastures in Australia. II. Animal production from Stylosanthes pastures. *Tropical Grasslands* **31**, 494–502.

Day KA, McKeon GM, Carter JO (1997) Evaluating the risks of pasture and land degradation in native pasture in Queensland. Final Report for Rural Industries and Research Development Corporation project DAQ124A, Queensland Department of Natural Resources, Brisbane.

Dixon RM, Coates DB (2005) The use of faecal NIRS to improve nutritional management of cattle in northern Australia. *Recent Advances in Animal Nutrition in Australia* **15**, 65–75.

Dove H (1996) Constraints to the modelling of diet selection and intake in the grazing ruminant. *Australian Journal of Agricultural Research* **47**, 257–275. doi: 10.1071/AR9960257

Gardener CJ, McCaskill MR, McIvor JG (1993) Herbage and animal production from native pastures and pastures oversown with *Stylosanthes hamata* 1. Fertiliser and stocking rate effects. *Australian Journal of Experimental Agriculture* **33**, 561–570. doi: 10.1071/EA9930561

Isbell RF (1996) 'The Australian soil classification.' (CSIRO Publishing: Melbourne)

Jones RJ, Coates DB, McCaskill MR (1990) Pasture and climatic effects on cattle liveweight gain from stylo-based pastures in the seasonally dry tropics. *Proceedings of the Australian Society of Animal Production* **18**, 260–263.

Mannetje L't (1974) Relations between pasture attributes and liveweight gains on a sub-tropical pasture. *Proceedings of the X11 International Grasslands Congress* **3**, 299–304.

Mannetje L't (1997) Harry Stobbs Memorial Lecture, 1994. Potential and prospects of legume-based pastures in the tropics. *Tropical Grasslands* **31**, 81–94.

Mannetje L't, Jones RM (1990) Pasture and animal productivity of buffet grass with Siratro, lucerne or nitrogen fertilizer. *Tropical Grasslands* **24**, 269–281.

McLennan SR (1997) Developing profitable strategies for increasing growth rates of cattle grazing tropical pastures. Final Report of Project DAQ.100 to Meat and Livestock Australia, Sydney.

Pengelly BD, Conway MJ (2000) Pastures on cropping soils: which tropical pasture legume to use? *Tropical Grasslands* **34**, 162–168.

Siebert BD, Hunter RA (1977) Prediction of herbage intake and liveweight gain of cattle grazing tropical pastures from the composition of the diet. *Agricultural Systems* **2**(3), 199–208. doi: 10.1016/0308-521X(77)90005-1

Whitbread A, Clem R (2004) Grain-Graze as sustainable farming systems in sub-tropical Queensland. In 'New directions for a diverse planet. Proceedings of the 4th international crop science congress 26 September–1 October 2004, Brisbane, Australia'. (CD-ROM) Available at http://www.regional.org.au/au/cs [Verified 1 May 2009]

Yates JJ, Edye LA, Davies JG, Haydock KP (1964) Animal production from a *Sorghum almum* pasture in south-east Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **4**(15), 326–335. doi: 10.1071/EA9640326

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