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Optimising growth paths of beef cattle in northern Australia for increased profitability

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Abstract

This project investigated reducing slaughter age of northern cattle through modifications of growth paths using supplements or improved pasture. In a grazing trial at Swans Lagoon steers grazing native pasture were fed from weaning either at low-plane (urea only - Control) or with high-input molasses-based supplement (MUP) in either one or both dry seasons prior to slaughter. A further group were finished on leucaena. Steers fed in only one dry season reached similar slaughter weight to those fed in both with 22% less supplement intake. Hormonal growth promotants (HGPs) given to half the steers continuously from weaning increased growth rate by 8% in most groups, and by 22% whilst steers grazed leucaena, and increased the net value added to steers despite impeding compliance with Meat Standards Australia (MSA). An economic analysis showed that leucaena, but not high-input supplements, increased profitability - the use of improved forages, combined with manipulation of body composition and associated compensatory gain offer the most cost-effective options for reducing slaughter age. Associated pen-feeding studies established that young (8-12 mo) and older (30-33 mo) steers responded similarly (kg extra gain/kg supplement) to additional nutrients and that responses increased in order of MUP, barley/urea and cottonseed meal. Studies indicated that the Australian feeding standards could not currently be relied upon to predict intake of grazing cattle in the tropics.

Executive summary

Producing beef of consistently high eating quality in much of northern Australia will ultimately depend on reducing age of cattle at slaughter. This usually requires improving nutrition for part of the growth path. This project examined several strategies for modifying the growth path of grazing steers between weaning and slaughter and included detailed pen studies on response relationships to different supplements by cattle of varying age. The questions asked were: at what stage of the growth path will additional nutrients be used most efficiently, and do cattle of different ages respond similarly to added nutrients? The other question of importance is how modifying the growth path impacts on utilisation of the pasture. so a further aspect of the project was to validate a decision support tool designed to predict intake of forage by grazing cattle.

The grazing study at 'Swans Lagoon' near Ayr compared several post-weaning growth paths for steers grazing native pasture, across two drafts of steers. Some groups received a high-input supplement based on molasses/urea/protein meal (MUP) in either the second, or first and second, dry seasons post-weaning and were slaughtered at about 30 months of age. Another group, considered the industry Control, received minimal supplement throughout other than a dry lick of salt/urea/sulphur in the first dry season and was slaughtered at about 42 months of age. A further group was transferred, at about 18 months of age, to leucaena pasture at 'Brian Pastures', Gayndah, and was slaughtered at 27 months. Half the steers in each group were implanted with hormonal growth promotants (HGPs) continuously from weaning. Seasonal conditions varied such that Draft 1 of the trial experienced, successively, a mild and then a harsh dry season and for Draft 2, a harsh and then mild dry season, and these seasonal conditions influenced the results. The main findings of the grazing study, across drafts, were:

- Steers fed high-input MUP in only the second year achieved the same slaughter weight (*ca.* 532 kg) as those fed in both years, with 22% less MUP intake overall (Draft 1). By comparison, the low input group were only 464 kg at the same age.
- In the second draft an abnormally wet second 'dry season' which disrupted supplement feeding prevented steers fed only in the second year from catching up in liveweight to their counterparts fed in both years, highlighting the risk of seasonal conditions intervening in the attainment of target end-points when long-term feeding programs are undertaken.
- Compensatory gain in the wet seasons following MUP feeding eroded between 34 and 52% of the liveweight advantage accrued by MUP-fed steers during the dry seasons (both drafts).
- Steers grown out on leucaena had high growth rates over 8 mo (*ca.* 0.8 kg/day), and were slaughtered about 3 months earlier than their high-input supplemented counterparts.
- Steers on native pasture at Swans Lagoon implanted with HGP were *ca.* 8% heavier at 30 months of age than those not implanted, whilst the response to HGP by steers on leucaena was *ca.* 22%, emphasising the positive relationship between diet quality and HGP response.
- Use of HGPs increased the MSA boning group score by 2.4-4.7 units compared with non-implanted steers and whilst 80% of non-implanted steers were in boning groups 10 or less that qualified for the MSA price premium, virtually none of the implanted steers qualified.

- Hip height of the steers changed independently of liveweight during the dry seasons such that the steers continued to grow skeletally even during dry periods when they were only maintaining or even losing weight.
- The economic analysis showed a positive response in net value added to finishing steers on leucaena and to use of HGPs, but not to the use of high-input supplement in either 1 or 2 dry seasons.

The results indicated that, although the slaughter age could be reduced by 12 mo using high-input supplement and efficiencies could be achieved by limiting this supplementation to 1 year post-weaning only, the high cost of supplements, the erosion of some of the feeding response by compensatory growth, the slim premiums for younger-finished carcasses and the need to carry more (drought-risk) breeders, all conspired to render feeding high-input supplements unprofitable. Use of improved areas of specialist high-quality pastures are much more likely to be a more profitable option. Despite reducing MSA compliance, HGPs increased returns due to the increased steer growth rate.

Two pen feeding studies were carried out to compare the growth responses of young (weaner; 8-12 mo) and older (30-33 mo) steers to several supplement types. A further pen trial investigated the effect of modifications to the MUP supplement described above. The main findings were:

- With both age groups of steers, the growth response was greater to cottonseed meal compared with barley/urea (Experiment 1) which in turn gave a higher response than a molasses/urea/protein meal mix (MUP; see above).
- For all supplement types, the growth response (per kg supplement intake) was higher for young compared to old steers when measured in relative terms (kg additional gain/kg liveweight), indicating the more efficient use of nutrients by young animals, but there was no difference between ages when it was measured in absolute terms (kg additional gain).
- The inclusion of whole cottonseed (15% of total) but not small amounts of barley (8%) in the MUP supplement markedly improved the growth response by weaner steers.

From a practical point of view, the results indicate that both weaners and older steers would increase in growth rate by the same amount given the same amount of supplement. This finding has important practical implications for supplement formulation. Inclusion of whole cottonseed in molasses-based supplements may result in cost-effective improvements in their efficacy.

Data sets were assembled to validate a spreadsheet-based intake calculator (QuikIntake) which was designed to estimate intake from known diet digestibility and cattle liveweight gain using the energy balance equations from the Australian feeding standards. The results indicated that the calculator predicted intake well with some data sets based on higher quality mainly temperate forages but not with others which included both tropical and temperate forages of varying quality. The reasons for the discrepancies are currently unknown but it reduces confidence in the use of the feeding standards for tropical grazing systems.

Key recommendations

- Priority should be given to improving discovery of, and/or access to, cost-effective sources of protein for northern cattle producers, either as new and novel forms of supplement or as improved high-protein forages for both survival and growth of cattle.

- Interrelationships in the deposition of bone, muscle and fat in *Bos indicus*-type cattle in the highly seasonal northern Australian environment are poorly understood yet they probably provide the key to improving efficiencies in growth whilst minimising use of costly nutritional inputs. Research into the manipulation and management of body composition at various stages of the growth path of cattle between weaning and slaughter is a priority.
- Compensatory growth is a major contributor to the economic outcomes from nutritional interventions applied during the dry season in northern Australia, yet it remains largely unpredictable in occurrence or magnitude. Studies into compensatory growth are a priority if advances in improving the cost-efficiency of early finishing systems are to be achieved.
- Further investigation is required into the application of the Australian feeding standards to tropical grazing systems to improve their use for predicting cattle performance and pasture intake and for supplement formulation in the northern Australian beef industry.

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1 Background

Over the last 2 or 3 decades there has been increasing emphasis on improving beef quality for both the domestic and export markets and this trend is only likely to continue into the future. However, growth rates of cattle in northern Australia often do not support the desire for younger turnoff of carcasses to meet this increasing demand. For instance, Bortolussi (2005b) in surveying the northern Australian beef industry, reported an average annual liveweight gain of steers for the black speargrass (*Heteropogon contortus*) community of northern Queensland of 116 kg, well short of the projected gains of 180 kg/year required for higher value markets such as Japan and Korea or to reliably comply with the Meat Standards Australia (MSA; Anon. 2003) grading system. Cattle producers in the region, when surveyed on future goals for their herds (Bortolussi et al. 2005a), listed increasing turn-off weight and reducing turn-off age of their cattle to increase profitability, as major priorities. To ensure higher meat quality, a realistic goal would be to target a final steer liveweight in excess of 500 kg at about 2.5 years of age (at least 160 kg annual gain post-weaning).

Economic modelling commissioned by MLA in the past has shown that increasing growth rate of cattle is a major contributor to increased profitability of cattle production in northern Australia. Strategies to increase growth rates of cattle and achieve heavier turnoff at younger age almost invariably involve improving the nutrition of the animals, either by use of improved or alternative pasture species (especially legumes), or through use of supplements at some stage in their growth path. The alternative, where available, is to shift cattle from lower production regions to those supporting higher growth rates (the endowed zones), and this option is often used, particularly by the larger cattle companies which own breeding and finishing properties in different regions. However, where this option is not available or undertaken the cattle are often finished on-property using a combination of the strategies mentioned above.

Over the last decade or so a considerable body of research has been carried out in other states and more temperate regions, into the effects of either pre-weaning (Cafe *et al.* 2006, 2009; Greenwood *et al.* 2006) or post-weaning (Robinson *et al.* 2001; Graham *et al.* 2009; Wilkins *et al.* 2009; McIntyre *et al.* 2009; McKiernan *et al.* 2009) growth of cattle on the efficiency of production, final carcass composition and meat quality for cattle finished on either pasture or in feedlots. Often a breed interaction with growth rate was incorporated into the experimental design. Whilst the general principles will still apply to the tropical areas of Australia, the application of their results is limited by their use of *Bos taurus* breeds of cattle compared with *B. indicus* in northern regions, by the much higher pasture-based growth rates usually achieved in the backgrounding phase which allowed earlier finishing ages than normally achieved in northern Australia, and by the practice of regularly finishing the steers in feedlots compared to total grass-fed systems predominating in the far northern region. A similar systems approach to cattle production research in northern Australia is required.

Whilst there has been substantial component research investigating nutritional treatments for discrete parts of the animal's growth path (e.g., first dry season post-weaning), there is a relative dearth of information on how best to incorporate these components into an extended part of the growth path from, for instance, weaning through to eventual disposal of the animal. Under conditions where nutrition was never limiting the growth of an animal would follow a typical sigmoidal growth curve with accelerated growth early in life tapering as mature size was approached.

However, under practical grazing conditions this never occurs as animals experience interrupted growth, sometimes expressed as weight loss during periods of low nutrition (e.g., during the dry season), followed by ‘catch-up’ or compensatory growth when nutrition improves (e.g., the wet season). Although the phenomenon of compensatory growth is well recognised and has been documented to varying degrees (Ryan 1990; McLennan 1997) it is the quantification of these interactions between seasonal events and the impact on whole-of-life growth that is limiting. The effects of dry season supplement treatments are commonly partially or totally eroded by compensatory growth in the subsequent wet season which results in lost benefits of the improved nutrition and thus reduced cost-efficiency of feeding overall (Winks 1984).

The challenge from a practical point of view is how to construct a growth path which optimises the benefits of any nutritional treatment and provides the most cost-effective solution to achieving a particular production target, for instance a liveweight or carcass weight at given age. This has become even more important in recent years with the on-going cost-price squeeze on northern beef producers (McCosker *et al.* 2010) and the steep increases in the cost of supplements. Under far northern grazing conditions, cattle usually have to traverse at least 2 dry seasons and 2 wet seasons before reaching heavy slaughter weights typical of those required by northern Asian markets; without nutritional treatments it is often more. The question then is – what is the best time to impose nutritional intervention, and at what level, in order to optimise the benefits and cost-efficiencies? The options are to provide the extra nutrition either in early life (e.g., immediately post-weaning), late life (near marketing), or a combination of both? Another way of couching this is, if a producer had a tonne of supplement to feed to a steer when should it be fed to realise the best return for money spent? The feeding standards clearly elucidate that there are differences in the efficiency with which cattle of different ages use various nutrients (e.g., protein versus energy) and in the types and proportions of tissue (e.g., muscle versus fat) they deposit (CSIRO 2007), so different responses could be expected to providing a set amount of nutrients to cattle of different ages. At present these differences have not been quantified. The other consideration is that of compensatory growth, as discussed above. The further in time cattle are from market liveweight the greater the opportunity for compensatory growth to erode any responses to increased nutrition. Thus it is likely that cattle fed early in life as weaners will be affected more by compensatory growth than those fed closer to the target. These questions have been addressed in the current project.

A further consideration in maximising profitability is choosing the nutritional treatment which provides the greatest response per dollar spent. In terms of nutritional supplements tropical northern Australia has limited choice as there is no significant grain or cotton industry north of Rockhampton and the main energy source for north Queensland is molasses which is produced along the east coast of the state. Protein meals often have to be imported (e.g., copra meal) to make up a shortfall on the domestic scene. Previous research has indicated that molasses is inferior to grains as an energy source (Lofgreen 1965) and the cost advantage it previously held over grains has been diminished by increasing cost. Nevertheless, producers in northern Australia (mainly Queensland) have safely fed molasses-based supplements widely as both a drought and production ration and are comfortable in its use. It seems logical, in the absence of other practical alternatives, to continue to base supplement programs around its use. However, there has been limited work carried out to improve performance, against just cost, and profitable feeding strategies will require this.

The other main avenue for increasing growth rate of cattle is to provide access to an improved pasture species or fodder crop. One example is the use of leucaena in the growth path for finishing cattle, and this has been shown to significantly increase growth rates at relatively high stocking rates, and also appears a profitable option compared to other crops and native grass pastures (Bowen *et al.* 2010). Although the cost of establishment of these pastures and crops is often relatively high, savings are made in labour inputs and supplement costs relative to feeding supplements over the longer term. On the other hand, supplementation can be discontinued abruptly if climatic or economic conditions change. The benefit/cost relationship for using improved forage options needs to be assessed relative to that of nutritional supplements.

Sustainable use of native pastures underpins the longer-term profitability of the beef industry. It is receiving considerable attention from local and federal administrations and its importance has been generally accepted by the grazing industry. Responsible land management revolves around the use of realistic stocking rates which do not cause the pasture base to degrade over time. One of the problems associated with determining appropriate stocking rates lies in having a good estimate of the intake of grazing cattle. In recent times it has also become important for predicting environmental outcomes such as methane emissions and carbon balance (Gonzalez *et al.* 2012). In a previous project (McLennan 2005; McLennan and Poppi 2012), a simple spreadsheet calculator called ‘QuikIntake’ was developed by applying the energy balance principles of the feeding standards (SCA 1990; CSIRO 2007) to back-calculate intake from a description of the cattle, their liveweight gain and the digestibility of the forage selected using faecal near infrared reflectance spectroscopy (F.NIRS; Lyons and Stuth 1992; Dixon and Coates 2005). This decision support tool can also be used with pregnant and lactating cattle and the use of supplements can be accommodated. However, to have confidence in its use for these feed budgeting purposes QuikIntake needs to be validated under controlled conditions to ensure it is giving sufficiently accurate estimates of intake. This task was undertaken in the current project.

2 Project objectives

The project objectives were as set out below.

By February 2012:

1. Evaluated and compared (including a full economic assessment and sensitivity analysis) different feeding strategies for increasing growth rates of steers in the tropics of northern Australia to a common liveweight/age end-point.

2. Establish growth response relationships for mature-aged (finishing) cattle to supplements, based on high protein and/or high energy, and fed in conjunction with forages of low or medium quality and incorporate them into the ‘WhichSupp’ decision support spreadsheet.

3. Validate an existing intake prediction spreadsheet (‘QuikIntake’) for use in predicting intake of pasture by cattle grazing tropical or sub-tropical pastures.

4. Develop a supplementation optimisation model for use by producers and extension officers.

3 General project design

This project included several components as are alluded to in the Objectives. This section, and following ones, provide an overview of the methodology, results and discussion associated with the six components of the project. The full reporting of each component is provided in the final section of this report.
The various components of the project include:

A. A pasture-based study carried out at Swans Lagoon and Brian Pastures Research Stations, between 2008 and 2012.
Focus: Objective 1.
Report: Detailed Report 1.

B. An economic analysis of the growth paths provided by the trial described above.
Focus: Objective 1.
Report: Detailed Report 2.

C. Two pen feeding trials designed to compare the response curves for either weaner-aged or mature-aged steers to high-protein (cottonseed meal) or high-energy/protein (barley/urea or molasses/urea/protein) supplements.
Focus: Objective 2.
Report: Detailed Report 3.

D. A pen trial comparing different compositions of a molasses-based supplement for cattle.
Focus: Objective 2.
Report: Detailed Report 4.

E. Two pen feeding trials measuring the intake and digestibility of a range of tropical and temperate forages, and associated liveweight gains, by cattle in order to validate the QuikIntake spreadsheet for estimating pasture intake by grazing cattle.
Focus: Objective 3.
Report: Detailed Report 5.

F. A draft supplement optimisation spreadsheet calculator.
Focus: Objective 4.

4 Component A: Growth path grazing study (*see Detailed Report 1*)

4.1 Methodology

The pasture-based trial was carried out between August 2008 and June 2012 primarily at Swans Lagoon Research Station, Ayr but with 1 treatment partly located at Brian Pastures Research Station, Gayndah. Two drafts of Brahman crossbred (~75% *B. indicus*) steers were used, 12 months separated in time, covering the period between weaning and slaughter. The starting liveweights of the weaners were 212 and 209 kg thus representing the heavier end of the liveweight range for weaners in each year. The experimental design was a randomised block of 5 treatments with 3 replicates and 10 steers per replicate. Half the steers in each treatment group received several sequential implants of hormonal growth promotant (HGP) providing continuous pay-out from weaning through to slaughter; the other half received no HGP throughout.

The treatments comprised 5 growth paths spanning the period between weaning and slaughter at either ~30 mo or ~42 mo of age. Supplement treatments were applied at Swans Lagoon during the dry seasons when the steers were grazed in separate paddocks of mainly native pasture dominated by black speargrass (*Heteropogon contortus*). All groups grazed a common paddock during the wet seasons and did not receive any supplement. A summary of the growth paths is presented in Fig. 1.

The growth paths represented various combinations of treatment applied in the first and second dry seasons (DS1 and DS2) post-weaning. Three of the treatment groups received supplement inputs of low (L), medium (M) or high (H) order in DS1 followed by H in DS2, denoted as L-H, M-H and H-H, respectively. These groups were slaughtered at the end of the second wet season post-weaning (WS2) at about 30-33 months of age. A fourth treatment group, L-nil, received L input during DS1 but no subsequent supplementary feeding and were slaughtered at the end of the third wet season (WS3), 12 months older than the above groups at about 42-45 months of age. This treatment was considered to represent the ‘conventional’ nutritional management of male cattle grazing native pasture in tropical northern Australia. The fifth treatment, L-leuc, followed the L path in DS1 but was transferred to Brian Pastures at the end of the first wet season (WS1) and grazed leucaena-grass pastures throughout DS2 and for part of WS2 and, due to their rapid weight gains, were slaughtered about 3 months before the L-H, M-H and H-H groups at about 27-30 months of age. They received no supplement after transfer to Brian Pastures.

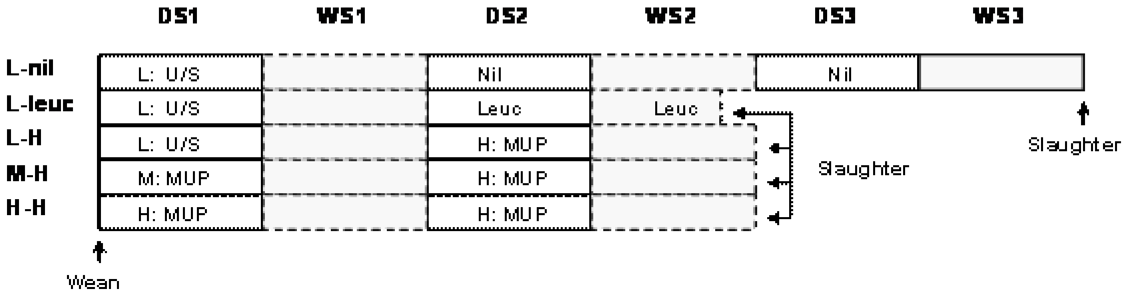

Fig. 1. Schematic representation of growth paths according to supplements provided, or leucaena access, during the dry seasons (DS) and wet seasons (WS; not fed) between weaning and slaughter. Except for the group grazing leucaena (Leuc), steers grazed native pasture throughout. Supplements were provided at low (L), medium (M) or high (H) nutritional input and were either based on a salt/urea/sulphur dry lick (U/S) or a liquid molasses/urea/copra meal mix (MUP). In DS2, intake of MUP supplement was varied between treatments to achieve similar liveweight by season end. Treatment details and supplement intakes are shown in the text.

The L supplement option used in DS1 was a proprietary dry loose mix including, w/w air dry, *ca.* 47% salt, 30% urea, 6% Gran-am (sulphate of ammonia; Incitec Pivot Ltd, Australia), 12% Kynafos21® and 5% palm kernel meal. Monensin was added at 0.3 kg of Rumensin®100 (active ingredient monensin at 100 g/kg; Elanco®, Eli Lilly Australia Pty Ltd)/100 kg of mix. This dry mix, hereafter referred to as US, was fed *ad libitum* from small covered troughs where the aim was to achieve urea intakes by individual steers of *ca.* 30 g/day or *ca.* 100 g/day of total mix. The H supplement from DS1 was a molasses-based mix, hereafter called MUP, comprising molasses (100 parts w/w, as fed), urea (3), copra meal (10), salt (1), di-calcium phosphate (1) and Rumensin®100 (0.05). In DS1, MUP was fed *ad libitum* throughout to steers on the H-H treatment but at a restricted rate with the M-H treatment to provide a growth rate intermediate between that of the L and H groups in DS1. The experimental target was for the L-H, M-H and H-H groups to reach the same liveweight by the end of the DS2 feeding period following different growth paths. Thus in DS2 the MUP supplement was fed *ad libitum* to L-H group but access was restricted slightly to the M-H and H-H treatments to reduce intakes.

Steers transferred to Brian Pastures (L-leuc) were given continuous access to mixed leucaena/grass paddocks and were kept within their original replicate groups except during the last 4 weeks when they were grazed together. They each received a rumen inoculant containing *Synergistes jonesii* to prevent mimosine toxicity. To maximise access to leucaena, the groups were rotated around paddocks about every 4-8 weeks depending on availability of leucaena leaf in the paddocks. No supplements were fed to this group whilst grazing leucaena.

The HGPs used were all of Compudose® origin (Elanco®, Eli Lilly Australia Pty Ltd) and for Draft 1 were implanted in the order: Compudose®-400 (C-400; oestradiol 17β; 400 day payout), Compudose®-100 (C-100; oestradiol 17β; 100 day), Compudose®-G (C-G; oestradiol 17β and trenbolone acetate; 90-100 day) and C-400 (14 July 2010). All treatments received the initial C-400 and the C-100 implants and all except the L-leuc treatment, which was ready for slaughter at the time, received the C-G. Only the L-nil group received the second C-400 implant. The same implant protocol was used for Draft 2 with the exception that Compudose®-200 (C-200; oestradiol 17β; 200 day) replaced C-100, due to the earlier start date of Draft 2.

Steers were mustered into cattle yards in the early morning, every 4-6 weeks. Measurements taken at every muster were liveweight (LW; un-fasted), body condition score (CS; 9-point scale) and hip height (HH; height at the peak of the sacrum), and measurements taken at every second muster and/or at the change of seasons were ultrasonically-scanned depth of fat at the rump P8 and 12/13th rib sites, and scanned depth of the eye muscle (EMD) at the 12/13th rib site.

Within treatments, all steers were slaughtered at the same time at 1 of 2 commercial abattoirs. Steers from L-H, M-H and H-H treatments were killed on the same day late in WS2, and L-nil steers about 12 months later, in an abattoir near Townsville, northern Queensland, about 120 km from Swans Lagoon. L-leuc steers were slaughtered in an abattoir at Beenleigh, south-eastern Queensland, about 350 km from Brian Pastures. Carcass measurements at each abattoir followed the AUS-MEAT® protocol and included hot carcass weight and P8 fat depth. In addition, a Meat Standards Australia (MSA) assessment was carried out on all eligible carcasses. In Draft 1 very few of the L-nil steers were assessed for MSA on the basis of excess permanent teeth. In Draft 2 all L-nil steers were assessed on request even those with more than 4 permanent teeth. A price premium was received for carcasses attaining MSA boning group score of 10 or less, in common with general industry practice at the time.

Faecal samples were collected every 2-4 weeks from a representative number of steers in each replicate (minimum 3 steers) of the L-nil treatment during the dry seasons and from the total trial herd (minimum 6 steers) during the wet seasons when common grazing occurred, to monitor changes in the quality of the pasture selected by the steers. After dry and milling the samples were scanned on a Foss 6500 Near Infrared Spectrometer spinning-cup system (FOSS NIRSystems Inc., Maryland USA). Diet quality in terms of crude protein content and dry matter digestibility were estimated using the methods described by Coates (2004) and Dixon and Coates (2005).

4.2 Results and discussion

A summary of the main findings (across drafts of steers) follows. More detailed discussion is provided in Detailed Report 1.

4.2.1 Seasonal conditions

- Different seasonal conditions were encountered with the 2 drafts of steers at Swans Lagoon which were characterised by the nature of the dry seasons (DS):
    - Draft 1: DS1 (2008) – Mild; DS2 (2009) – Harsh;
    - Draft 2: DS1 (2009) – Harsh; DS2 (2010) – Mild and short.

The combination of these dry seasons had a marked impact on the results obtained. With Draft 1 the experimental protocol of equalising LWs by the end of DS2 for the L-H, M-H and H-H treatments was achieved but in Draft 2 the second dry season was too short for the L-H group to catch up in LW with the other groups. In addition, the difference between the L-nil and L-H groups at the end of DS2 was not significant. These effects were reflected in the diet selected by the steers across seasons (see Detailed Report 1).

4.2.2 Supplement intakes

- Supplement intakes (g/day) varied with seasonal conditions and averaged:

Draft 1:	**DS1**	**DS2**
L-nil	67	nil
L-leuc	84	nil
L-H	88	6,008
M-H	2,234	5,412
H-H	3,904	5,326
Draft 2:		
L-nil	81	nil
L-leuc	76	nil
L-H	71	1,851
M-H	2,349	1,722
H-H	3,802	1,779

Low intakes of MUP in DS2 of Draft 2 reflected the short duration of the dry season and effects of intervening rainfall.

4.2.3 Liveweight change

- Feeding MUP to steers at high intakes increased growth rate when compared with that of others either fed US (as weaners; DS1) or no supplement (as yearlings; DS2) by 0.39-0.43 kg/day in weaners or 0.48 kg/day in yearlings;
- The conversion rate of MUP supplement to additional liveweight gain was between 7.9 and 9.9 kg/kg (as fed) for weaners (controls fed US) and 11.8 kg/kg for yearlings (controls not fed), with respective costs of $1.72, $2.16 and $2.57/kg extra gain;
- Compensatory gain in the wet seasons following feeding of MUP eroded between 34 and 52% of the LW advantage accrued by MUP-fed steers over their L counterparts during the dry season;

- Different results emerged depending on the type of dry seasons encountered in the second year:
    - Draft 1. A very dry second dry season was experienced resulting in high supplement intakes and the L-H group (H input year 2) 'caught up' to the H-H group (high input years 1 and 2) and reached suitable slaughter LW (527 kg) by the end of WS2 (*ca*. 30 mo of age); the L-nil group was only 464 kg at the same time and needed to be carried over an extra 12 mo.
    - Draft 2. A very short and intermittently wet second 'dry season' was experienced resulting in very low intakes of MUP supplement in DS2 with the result that the L-H group did not catch up in LW with its H-H counterpart (550 vs 585 kg) but it was also not different from the L-nil group (541 kg) at the end of the second wet season.

- Steers in the L-leuc treatment gained 0.79-0.82 kg/day on leucaena over 8-9 mo and were slaughtered at final LWs of 532-551 kg, 3.5 mo earlier than the L-H, M-H and H-H groups.

- The response to HGP to the end of WS2 averaged 7.7-8.3% for groups kept at Swans Lagoon, but when steers were retained for a third year (L-nil) before slaughter gains were slightly depressed with HGP in this final year.

- Steers grazing leucaena showed the highest response to HGP of 21.7-22.2% during the leucaena phase, emphasising the positive relationship between plane of nutrition and response to HGP.

These results showed that, given the right conditions, feeding in only one year, i.e., the second dry season post-weaning, can result in a similar LW gain to feeding in both dry seasons, but at a much reduced supplement intake and cost. The emphasis should then be on maintaining the animal in a healthy and strong state in the first dry season and concentrating high input feeding in the second year closer to the 'finish line'. Ironically, the conditions most suited to this result seem to require a dry second year which is suited to high supplement intakes (compare Drafts 1 and 2). However, if a short dry season is experienced in year 2 the improved growing conditions may result in the animals reaching slaughter weight without need for much supplement anyway. Delaying feeding also reduces the risk factor which increases the further the animals are from marketing. It should be emphasised that the above results apply to weaners starting at a relatively high LW (*ca*. 210 kg); starting at considerably lighter weights may not result in achievement of heavy enough animals for slaughter at 30 mo.

4.2.4 Skeletal growth (height)

- Steers grew skeletally even during periods of nutritional stress when liveweight change was only at maintenance, for instance during the prolonged, harsh 2009 dry season when both weaners and yearlings had zero LW gain but grew 39 and 32 mm/100 days, respectively.

- The effects of nutritional treatments on skeletal growth were expressed mainly during the dry seasons and especially during the first dry season post-weaning; there was no compensatory growth in height during the wet seasons.

- The increase in height for MUP-supplemented steers (H-H) in DS1 was 62 mm/100 days for both drafts compared with 35-39 mm/100 days for the L-nil group fed US.

- Steers from Draft 1 given the MUP supplement at some stage of their growth path grew 15% more in height to the end of WS2 than their L plane counterparts; trends were less defined in Draft 2 due to the mild second dry season but overall M-H and H-H groups grew faster than the L-nil group.

- Steers grazing leucaena grew at 44-47 mm/100 days.

- HGPs had a negative effect on skeletal growth, mainly expressed in the second (all treatments) and especially in the third (L-nil group) year post-weaning. Non-implanted L-nil steers grew 13-17% more than their HGP-implanted counterparts by time of slaughter at ca. 42 mo of age.

These results have shown that some priority for nutrient allocation by the animal is given to growth of the skeleton in that the steers continued to grow in height even when only maintaining LW. Nevertheless, there appears to exist an allometric relationship between skeletal and muscle growth so that after a period of nutritional stress LW increases faster than height as muscle responds to the increased frame size. There may be opportunities to exploit this relationship by increasing skeletal growth during the dry seasons (independent of LW) and benefiting from accelerated LW change during the wet seasons. The use of exogenous hormones impact on this relationship. The reduced skeletal growth with HGPs probably reflect earlier closure of the growth plates of longitudinal bones and this effect will be more pronounced as age of slaughter increases. It is likely that these variable effects of HGP on height and LW change also impact on fat content of the carcass.

4.2.5 Fat and eye-muscle depth

- Trends in the depth of rib or P8 fat cover and in eye-muscle depth (EMD), determined using ultrasound scanning, closely followed those of LW in that, where LW change was greater during the dry seasons for high plane treatments receiving MUP compared with those of steers on low plane nutrition (e.g., L-nil), the depth of rib fat, P8 fat and eye-muscle were also greater.

- In Draft 1, steers on the high plane of nutrition (MUP) were fatter and had greater EMD at the end of WS2 just before slaughter than those on the low plane nutrition (L-nil); in Draft 2 differences were not significant due to the mild and short DS2.

- HGPs had only small effects on body composition measurements, but implanted steers had lower P8 fat in Draft 1 and lower rib fat in Draft 2 and higher EMD in both drafts, at the end of WS2 just prior to slaughter.

4.2.6 Carcass characteristics and MSA chiller-assessed traits

Because treatment groups were slaughtered at different times and abattoirs, the only growth path treatment comparisons possible were for the 3 high plane treatments killed together (L-H, M-H and H-H). Otherwise, the comparisons discussed below were for HGP effects across treatments.

- For most measurements there were no differences between the 3 treatments slaughtered at the same time, the one exception being that the L-H group in Draft 2 had lower hot carcass weight than that of the H-H group.

- Within the high plane treatments, HGP use was associated with lower AUS-MEAT-assessed rib fat, lower MSA-rib fat depth and higher eye-muscle area in Draft 1.

- Ossification score was increased from 19 to 32% with HGP use for steers slaughtered at about 30 mo and by 88% for those slaughtered at about 42 mo.

- Use of HGPs increased the MSA boning group score by between 2.4 and 4.7 units, increasing with age at slaughter, and virtually none of the implanted steers were in boning groups 10 or less that qualified for the MSA price premium.

5 Component B: Economic assessment of growth paths (*see Detailed Report 2*)

5.1 Methodology

A full economic analysis of the growth paths generated in the grazing study described above (Component A) was carried out using 2 approaches. First, the treatments were assessed according to their effects on the increase in net value per head, i.e., the value-added method. This method calculated the final value achieved for individual steers and deducted the costs of achieving that value including cash and non-cash costs. These costs included indirect and opportunity costs which accounted for the amount of time taken for different treatments to reach sale weights (e.g., 12 mo difference between L-nil *vs.* L-H treatments). As a further test, a sensitivity analysis was carried out to assess the effects of reducing supplement costs by 25 and 50%, using the same steer value-added approach. A detailed description of the assumptions and values used in this analysis are provided in Detailed Report 2.

Second, the trial results were used in a model based on a breeding and fattening business in northern Australia where the base herd of 1000 cows turned off steers of average age 42 mo with minimal supplement inputs, i.e., representative of the L-nil treatment without HGP. Other treatments were then modelled as alternative finishing systems so that the herd size and structure was adjusted to maintain the same grazing pressure on the land (same adult equivalents; AEs); actual results from the grazing study were used as inputs into the model, e.g., liveweights, liveweight gains, supplement costs, etc. These herd models were constructed using the Breedcow and Dynama suite of programs (Holmes 2012). The grazing pressure applied by the whole herd was adjusted, where appropriate, to account for efficiency gains and substitution effects likely associated with feeding supplements. A herd gross margin for each production system was established and treatments ranked accordingly. It should be noted that the models assumed all steers from any calf drop had the same treatments whereas in practice it would possibly only be a proportion of the group targeted for earlier slaughter and fed supplement, probably the heavier steers at weaning. More details of the methodology are provided in Detailed Report 2.

5.2 Results and discussion

5.2.1 Steer value-added analysis

- In the absence of HGPs, the treatments ranked in descending order for net value added ($/steer): L-nil, 289; L-leuc, 213; L-H, 93; M-H, 35; and H-H, 1 for Draft 1 (No. 8s) and L-nil, 299; L-leuc, 231; L-H, 205; M-H, 157; and H-H, 120 for Draft 2 (No. 9s).

  Supplement costs were considerably lower for Draft 2 than Draft 1 due to the short and rain-interrupted nature of the second dry season of Draft 2, probably explaining the better economic results for the MUP-supplemented groups (L-H, M-

H and H-H) of the second draft compared with the first. The excellent growing conditions during this second year of Draft 2 meant that the steers still attained acceptable slaughter weights by 30 mo despite the low supplement intakes in dry season 2.

- The use of HGPs increased the net value added for every treatment in Draft 2 (range $13-79/steer) and for the L-leuc, M-H and H-H treatments (range $14-58/steer) but not the L-nil (-$14/steer) and L-H (-$14/steer) treatments in Draft 1.

- The effect of HGPs was greatest for the L-leuc treatment in both drafts at $58 and $79/head in Drafts 1 and 2, respectively, despite the failure of most of the implanted steers to achieve the MSA price premium.

5.2.2 Herd model analysis

- Analysis using this method provided similar rankings to that of the steer value-added method except that the L-leuc treatment with and without HGP ranked 1 and 2, above that of the respective L-nil treatments.

- In the presence of HGPs, the whole herd gross margins increased, relative to the L-nil plus HGP treatment, by: L-leuc, 13.6% and 16.3%; L-H, -18.9 and -1.6%; M-H, -21.9 and -10.2%; and H-H, -26.8 and -14.1% for Drafts 1 and 2, respectively. Thus only the L-leuc treatment increased gross margin.

- The HGP treatment effects were of the same order as for the above analysis, with only the L-nil and L-H treatments of Draft 1 showing a negative effect of HGP, and with the L-leuc treatment increasing herd gross margin by 7.6 and 9.5% in Drafts 1 and 2, respectively.

5.2.3 Sensitivity analysis

- Reducing the cost of the MUP supplement by 50% considerably improved the value added per steer but not by enough to overcome other feed associated costs, and the supplemented treatments remained less profitable than the low-input treatment of L-nil.

5.3 General conclusions

- In the current economic climate of costs and returns, the use of high-input, high-cost supplements to target a younger age of turn-off for slaughter cattle on a northern Australian beef breeding and fattening property is unlikely to improve profitability.

  Factors conspiring against a profitable outcome include the high cost of supplements required to attain the necessary growth rate increases, the slim premiums paid for young vs older steers at the abattoirs, the compensatory growth which erodes the response to supplementation and the changes in herd structure associated with slaughtering younger cattle, notably the higher numbers of cows and their associated higher drought risk.

- Transfer of steers to a leucaena pasture did improve profitability in our study and other forage-based options for increasing growth rates of cattle and reducing turn-off age are worthy of further investigation.

- Although the effects of HGP were variable, in most cases they increased profitability relative to respective non-implanted treatments despite virtually rendering them ineligible for MSA compliance; the effect of HGPs was greatest with steers grazing leucaena and growing rapidly for 8-9 months leading up to slaughter.

6 Component C: Stage of maturity of steers X supplement response pen trial (*see Detailed Report 3*)

One of the key questions asked in this project was: do cattle at different stages of maturity respond in a similar way to nutritional treatments based on increased protein, energy or combinations of both? The hypothesis was that because proportional tissue deposition changed between lean (muscle) and fat as cattle matured, different age groups would have different nutrient requirements and would respond variably to provision of different supplement types based on providing increased protein and/or energy. The answers to these questions have important practical implications especially in relation to the imposition of supplements into the growth paths. A brief description of the methodology and the results and their discussion are provided below, with more detail in Detailed Report 3.

6.1 Methodology

Two pen feeding experiments, hereafter Exp1 (carried out in 2008) and Exp2 (2010), of similar design and with similar objectives but using different supplement treatments, were carried out at Brian Pastures Research Station near Gayndah, Queensland. The methodology was similar for both experiments.

Brahman crossbred steers (*ca.* 5/8 *Bos indicus* content) of 2 age groups but of the same genetic origin were sourced from the commercial herd at Swans Lagoon Research Station, 120 km south-east of Townsville. The ages of the steers were *ca.* 10-12 months (Young) and *ca.* 33-36 months (Old). At the commencement of the studies the average liveweight of the steers was 195.5 (± 7.00; sd) and 424.6 (± 18.87), and 203.3 (± 7.43) and 440.1 (± 16.38) kg, for Young and Old steers in Exp1 and Exp2, respectively. A basal diet of low quality hay was fed *ad libitum* to all steers, this being pangola grass (*Digitaria eriantha* subspecies *pentzii*) in Exp1 and black speargrass (*Heteropogon contortus*) in Exp2. The experimental design was a randomised block incorporating response surfaces with 2 age groups x 2 supplement types x 4 levels of feeding with from 2 to 4 replicates per feeding level, plus unsupplemented Control steers. Steers were fed in individual pens with 42-44 pens used in total.

In Exp1, the 2 supplements used were barley grain mix plus urea-sulphur (Bar1) and cottonseed meal (CSM). The CSM was fed without additives. The barley mix was formulated by thoroughly mixing coarsely-cracked (roller-milled) barley (94.33%; w/w, as fed), salt (0.94%), limestone (0.94%), molasses (1.89%) and water (1.89%). Steers on the barley treatments also received 200 g (Young) or 440 g (Old) daily of a urea-ammonium sulphate solution (urea-S) which delivered, daily, 40.9 (Young) or 90.0 (Old) g urea. The barley mix was offered at 0.5, 1.0, 1.5 and 2.0% liveweight (W)/day whilst the CSM was offered at 0.25, 0.5, 0.75 and 1.0%W/day. There were 4 unsupplemented Controls for each age group.

In Exp2, the 2 supplements used were a barley-based treatment (Bar2) similar to the Bar1 described for Exp1 and a molasses-based mix containing urea and protein meal (MUP), similar to that used in the grazing study. The Bar2 supplement differed slightly to that used in Exp 1 in that Rumensin®100 (active ingredient monensin at 100 g/kg) was added in order to be consistent in this respect with the MUP mix. Thus the barley mix comprised coarsely-cracked (roller-milled) barley (94.30%; w/w, as fed), salt (0.94%), limestone (0.94%), molasses (1.89%), water (1.89%) and Rumensin® 100 (0.05%). Steers on the Bar2 treatments also received the urea-S solution, as described above. The MUP mix contained molasses (86.9%; w/w, as fed), urea (2.6%), copra meal (8.7%), salt (0.87%), dicalcium phosphate (0.87%) and Rumensin®100 (0.04%). Both the barley mix and the MUP were offered at 0.5, 1.0, 1.5 and 2.0%W/day.

Each experiment consisted of a 6 day initial equilibration, a 70 day experimental and a 4 day final equilibration period. The steers were allocated to treatments by stratified randomisation on fasted liveweight. The hay was fed once daily (0800 h) and residues of hay and supplement were collected once weekly. The urea-S solution was sprinkled on and mixed into the hay once daily soon after the hay was fed out. It was fed separate from the barley mix to reduce the possibility of urea toxicity in the event of rapid grain intake. The other supplements were fed out in separate feeders from the hay to allow the intake of both dietary components to be accurately determined. Each week the steers were weighed full before feeding and the amount of supplement fed daily was adjusted, on an individual steer basis, on these new weights to maintain a constant intake on a LW basis.

During week 7 a total collection of the faeces from the concrete floor of each pen was undertaken at least 3 times daily for 7 days. Total faecal DM output and the digestibility of DM (DMD) were determined from these collections. Rumen fluid samples and blood were collected from each steer on Day 58, 3 h after feeding the hay and supplements. The rumen fluid samples were later analysed for concentrations and proportions of volatile fatty acids (VFAs) and the blood plasma for urea-N concentration.

6.2 Results and discussion

6.2.1 Liveweight response

Exp1 (CSM and Bar1 comparison)

- When intake of supplement was expressed as %W/day, the growth response (kg/day) to CSM was greater than to Bar1 across the range of comparable supplement intakes (to 1%W/day) for both age groups of steers and, within supplement types, the Old steers had higher responses than their Young counterparts.

- When intake of supplement was expressed in absolute terms, as kg/day, the growth response within supplement types was similar for Young and Old steers but with the CSM response still greater than that of Bar1 for both age groups.

- The higher response to CSM compared with Bar1 seems related to correction of a deficiency of rumen degradable protein in the rumen (rumen degradable protein/digestible organic matter; RDP/DOM) from using the protein meal at even the lowest intake level, a deficiency which was corrected with Bar1 only when the highest rate was fed.

Exp2 (Bar2 and MUP comparison)

- When intake of supplement was expressed as %W/day, the growth response (kg/day) to Bar2 was greater than to MUP across the range of supplement intakes for both age groups of steers and, within supplement types, the Old steers had higher responses than their Young counterparts.

The lower performance with MUP compared with Bar2 reflects the lower net energy of molasses compared to the grain source, as previously detailed. This occurred despite the inclusion of a protein meal source in the molasses (*ca.* 9% of DM).

- As above (Exp 1), Young and Old steers responded similarly within supplement type when supplement intake was expressed in kg/day, but Bar2 still provided greater response than MUP.

Thus despite expectations that Young steers would use the supplement more efficiently than Old steers, both Young and Old steers showed the same growth response to a given intake (kg) of supplement of either type in both experiments. This has important practical implications for ration formulation and for economic forecasting of supplement responses.

6.2.2 Intake and digestibility

Both experiments

- Unsupplemented, Old steers had markedly lower intake than Young steers (1.3 vs 1.7%W/day in Exp1 and 1.3 vs 1.5%W/day in Exp2).

- Intake of hay declined with increasing intake of all types of supplement fed, demonstrating a typical substitution effect, but the effect tended to be greater for barley compared with protein meal in Exp1 and with no difference between barley and the molasses-based supplement in Exp2.

7 Component D: Composition of molasses-based mix pen trial (*see Detailed Report 4*)

The growth path grazing study above (*Detailed Report 1*) has quantified the growth responses by cattle to a molasses-based mix colloquially called MUP which includes, as well as molasses, a source of protein meal, non-protein nitrogen, some minerals that are limiting in molasses, and a rumen modifier. This supplement has been used quite widely in northern Australia either for survival feeding during dry years or for increased production of mainly male cattle. Molasses-based supplements were first used in northern Australia because, relative to grains growth mainly in southern Queensland, molasses was locally available, less expensive and considered safer to feed due to problems with grain feeding associated with acidosis. Protein meals are a relatively safe option but costly and often difficult to distribute through the herd when fed in small amounts. Producers are comfortable with feeding molasses-based supplements. However, the cost of molasses has risen sharply in recent years which has challenged the cost-efficacy of feeding. This study examined several options for increasing efficacy of molasses-based mixes without concomitant increases in cost. Inclusions of either a grain or whole cottonseed (WCS) in the MUP mix were investigated. A brief description of the methodology and the findings are provided below but the reader is directed to Detailed Report 4 for more detailed discussion of the main findings.

This experiment was not part of the original project objectives but was added later to answer some applied questions about ways of improving efficacy of molasses-based supplements.

7.1 Methodology

Commercial Brahman crossbred weaner steers (*ca.* 5/8 *Bos indicus*) were sourced from Swans Lagoon Research Station. They were approximately 9-10 months of age and averaged 190.2±7.03 (s.d.) kg liveweight at the commencement of the trial.

The steers were individually fed in pens a basal diet of *Heteropogon contortus* (speargrass) hay *ad libitum* with or without supplement. The experimental design was a randomised block incorporating a response surface with 5 supplement types x 4 levels of feeding x 2 replications (steers), plus 4 Control (unsupplemented) steers, equalling 44 steers in total. The supplements fed were (i) barely grain mix (Bar); (ii) molasses, urea, protein meal mix (MUP); (iii) MUP mix plus added barley (MUP-B); (iv) MUP mix plus added WCS (MUP-W); and (v) MUP mix plus added barley and WCS (MUP-BW). The Bar mix contained, w/w as fed, rolled barely (100 parts), molasses (2), water (2), limestone (1), salt (1) and Rumensin (0.05). The MUP mix contained molasses (100 parts), urea (3), copra meal (10), salt (1), dicalcium phosphate (1) and Rumensin (0.05) and was thus similar in composition to that used in the Growth Path Optimisation (GPO) grazing study (Detailed Report 1). The MUP-B, MUP-W and MUP-BW mixes were formulated by adding an additional 8.75 parts barley, 17.5 parts WCS or 8.75 parts barley and 8.75 parts WCS, respectively, to 100 parts MUP mix, w/w as fed. Steers on the Bar treatment also received 200 g/day of a urea-ammonium sulphate solution (urea/S) containing, by weight as fed, 20.45% urea, 4.55% ammonium sulphate (GranAm) and 75% water, so the steers received 40.9 g urea daily.

The experimental procedures were similar to those described for the pen trials in Component C above and only differences in procedure are highlighted here. A full description is given in Detailed Report 4. The trial period was 70 days. Hay was fed *ad libitum*, as described above, except in the first 2 weeks when the amount fed was slightly restricted to encourage the steers to consume all of their supplements. The urea/S solution for the Bar groups was sprinkled on and mixed into the hay once daily soon after the hay was fed out. To reduce the risk of acidosis, the Bar mix was fed out in a separate feeder to the hay in approximately equal portions twice daily at 0800 h and 1600 h. The molasses-based mixes were prepared by first thoroughly mixing the molasses/urea/copra meal/salt/DCP/Rumensin, i.e., the MUP mix for about 20 min after which it was weighed out and fed once daily at 0800 h to the steers from feeders separate from the hay trough. At the same time, the additives of barley and WCS for the MUP-B, MUP-W and MUP-BW treatments, which had been weighed out separately, were sprinkled on top of the above MUP mix. The steers tended to consume these additives from the top of the MUP mix soon after feeding. Residues of hay and supplement were collected weekly and dried to constant weight to determine DM content. During Week 9 the total faeces output was collected from the concrete floor of each pen of the 4 Control steers, 3 times daily. From this total faecal DM output was calculated and the digestibility of DM (DMD) was determined.

7.2 Results and discussion

- Unsupplemented Control steers made small losses in liveweight for the trial but the growth rate of the steers was linearly increased with increasing intake of all supplement types.

- The growth responses can be arranged (statistically) into 3 groupings, in increasing order of response: (i) MUP and MUP-B; (ii) MUP-W and MUP-BW; and (iii) Bar, where the increase in growth rate was 0.48, 0.58 and 0.75 kg liveweight gain per %W fed as supplement, respectively.

- The effects of supplements on hay intake were variable but all depressed hay intake as supplement intakes increased, i.e., a substitution effect, with the effect being greater with Bar compared to the molasses-based mixes at higher supplement intakes.

These results indicate that there is no benefit from adding a small amount of grain in the form of barley to the MUP mix but the addition of WCS either alone or with barley does increase growth response per unit of supplement intake. Nevertheless, none of the molasses-based supplements increased growth rate to the same extent as a barley-based supplement alone. The lack of response to adding Bar alone to MUP is probably a function of the small amount included and its correspondingly small effect on energy intake. Although barley has been shown to have a higher net energy value than molasses, the difference in total energy intake of effectively replacing 10% molasses with 10% barley will be small. With the other treatments the additions were about double, i.e., *ca.* 20% in the form of WCS alone or with barley, and the WCS is considerably higher in energy than molasses by virtue of its high lipid content (*ca.* 20% of DM). It is possible that even higher inclusions of WCS could be made which will further improve animal performance on a molasses-based supplement.

8 Component E: Validation of an intake prediction spreadsheet decision support tool (QuikIntake; see *Detailed Report 5*)

The reasons for wanting to predict the intake of grazing cattle have been outlined above (Background) but in most cases intake prediction will be used in practice to derive an estimate that can be used for feed budgeting purposes. In addition, it is a useful research tool to evaluate likely effects of nutritional or other treatments on intake of animals, or for formulating rations. There are a large number of factors of both animal and forage origin that impact on intake so prediction in the field is open to large errors which limit its application. One approach which has been used previously is to back-calculate intake from animal production, e.g., from liveweight gain, using knowledge of the energy balance relationships encapsulated in the feeding standards. It is logical that if the feeding standards can be relied upon to give a reasonably accurate estimate of animal production from known energy intake, they should similarly be able to be used in reverse to predict intake from known or estimated animal production where such an estimate may be based on past history for the area in question. In a previous project McLennan (2005) showed that the Australian feeding standards (SCA 1990; CSIRO 2007) gave a reasonable prediction of liveweight gain of cattle confined in pens from known intake of forage and supplement, thereby providing confidence that intake could also be calculated accurately from known liveweight gain. Consequently, a spreadsheet calculator was developed (QuikIntake (QI); McLennan and Poppi, unpublished) for intake prediction purposes using equations from the feeding standards. The purpose of this study was to validate QI for intake prediction. A full description of the equations used in QI and of the methodology and results of the validation study, is given in Detailed Report 5.

8.1 Methodology

In order to validate the QI spreadsheet for use in predicting intakes of grazing cattle data was used from controlled experiments with confined cattle where exercise was restricted and where intake and digestibility of the diets and growth rate of the cattle were measured. These data were derived from several sources: Source A - pen feeding experiments conducted as part of this current project, using a wide range of C3 and C4 forages of varying nutritive value; Source B – previous pen feeding experiments of our own research group using mainly low-quality C4 forages; and Source C – recent and current studies of our research group using mainly higher-quality C3 species. From these studies, observed intakes were compared with those predicted using QI.

8.1.1 Data used in validations

Source A studies. Two runs of a forage evaluation experiment were carried out at Brian Pastures Research Station between May and October 2009. Commercial Brahman crossbred weaner steers (50-75% *B. indicus*) approximately 6-8 months of age at the start of the experiments, were used. The intended experimental design was 2 runs of a randomised complete block each involving 7 forage treatments with 6 steer replicates. In fact, the number of replicates varied for treatments from the intended 6 to between 3 and 7 where some forages were rejected by steers leading to low replicate numbers for those treatments whilst other forages were allocated an additional replicate. The forages used in Run 1 included 2 lots of Rhodes grass (*Chloris gayana*; A and B) at slightly different stages of maturity, Bisset bluegrass (*Bothriochloa inscupta cv.* Bisset), wheat straw (*Triticum aestivum*), lucerne A (*Medicago sativa;* source A), forage sorghum (*Sorghum spp.* hybrid) and peanut hay (*Arachis hypogaea*). Those used in Run 2 included Dolicos (*Lablab purpureus*), 2 lots of Mitchell grass (*Astrebla* spp*.,* A and B) cut at different stages of maturity, millet (*Pennisetum glaucum*), barley (*Hordeum vulgare*) and lucerne A and B, where A was the same as used in Run 1 and B was from another source. All forages were fed *ad libitum* apart from lucerne A in Run 2 which was fed at a restricted intake of 1.4%W/day, calculated on an ‘as fed’ basis. Steers were housed in individual pens.

Runs 1 and 2 of the experiment each consisted of a 42 day growth study, which included a 7 day faecal collection period. During the growth study the various forages were fed once daily. Prior to feeding the forages were chaffed, mostly using a tub grinder but the millet and lucerne were chaffed using a feed wagon fitted with horizontal blades and Dolicos lablab and peanut hay were fed un-chaffed due to the woody nature of their stem material and the risk of losing leaf material during chaffing. Residues were generally collected once weekly. The forages were fed *ad libitum*, with the exception of lucerne B in Run 2 (see above) for which steers were fed at 1.4%W/day. Steers were weighed un-fasted once weekly. During Week 5 of each study total faeces was collected from each steer from the concrete floor of the pen for 7 days and the total faecal DM output was recorded and DMD calculated.

Source B studies. Data from unsupplemented steers of 6 other pen feeding studies established in a similar way to that described above but with growth periods of 70 days duration, were included in the test group. These studies all used C4 forages of relatively low quality (<6% CP). The steers in each trial were Brahman crossbreds (50-75% *B. indicus*) which were mostly aged *ca.* 10-12 mo (range 177-242 kg liveweight) but some mature steers *ca.* 36 mo old (range 420-433 kg liveweight) were included in 2 experiments. The procedures used in determining intake, DMD and liveweight change were similar to those described above.

Source C studies. Data were obtained from 3 other pen feeding experiments which used higher quality rations than most of those above, mainly based on temperate species. The first used either Friesian (average 15 mo, 293 kg) or *B. indicus* crossbred (average 10 mo, 231 kg) steers which were given lucerne chaff either *ad libitum* or at a restricted intake over 3.5 mo. In the second experiment *B. indicus* crossbred steers of average age either 12 or 36 mo and liveweight 224 and 496 kg, respectively, were given ryegrass haylage either *ad libitum* or at restricted intakes which, over a 75 day feeding period, averaged (DM) 1.08, 1.49, 1.82 and 2.15%W/day for the young steers and 0.97, 1.29, 1.62 and 1.76%W/day for the older steers. In the third experiment, pellets containing varying concentrations of P were fed *ad libitum* to *B. indicus* crossbred steers (15 mo, 339 kg), supplemented with 0.5 kg/day of Mitchell grass hay to maintain rumen motility, over 122 days. Intake in these studies was determined in a similar manner to that described above but DMD was measured by confining the steers in metabolism cages and determining total faecal DM output.

8.1.2 Validations

Validations were carried out using QI in its original format (Model_O), which used the equations as outlined in SCA (1990), and in revised format (Model_R) after the equations were modified slightly in accordance with the updated feeding standards (CSIRO 2007) and with other discretionary changes. The main changes from Model_O to Model_R were in some of the parameters relating to differences between *B. taurus* and *B. indicus* cattle. These changes are described in Detailed Report 5.

The validations are based on the precision of the regression defining the relationship between the observed intake and that predicted using the various models of QI. Usually the regression is defined by an R^2 value which describes the proportion of variation explained by the regression line and a residual standard deviation (RSD) which is the standard deviation of points around that fitted line. However, a better measure for this purpose is the model efficiency (EF) which is a similar measure to R^2 above but measures the variation in relation to the line of best fit, i.e., Y=X, where the predicted and observed intakes correspond totally. In the words of Mayer and Butler (1993) model efficiency gives an indication of goodness of fit and a model giving a negative value for efficiency cannot be recommended.

Validations with Model_O used data from Sources A and B; those with Model_R used all 3 sources of data.

8.2 Results and discussion

8.2.1 Model_O predictions (using Source A and B data)

- Comparing observed (Y) with predicted (X) intakes ($R^2 = 0.38$), QI markedly over-predicted intake, the model efficiency (EF) was equal to -1.33, meaning it was of little use for predictions, and the slope of the regression line was different to 1 and intercept different to zero.

The majority of the data for these simulations were from lower quality diets where animal performance was around maintenance although there were some notable exceptions, e.g., lucerne and barley. The predictions seem to be better for the low intake forages and deviated widely from observed values with the higher quality forages. The reasons are not clear. Over-prediction of intake could be for a variety of reasons but suggest that metabolisable energy (ME) intake is being over-predicted, perhaps through over-prediction of the maintenance requirements of the animal or its energy value of gain. .

8.2.2 Model_R predictions (using Source A and B data)

- The regression for the predicted *vs* observed intake using Model_R explained slightly more of the variation (R^2 = 0.47) than Model_O above and the EF was a positive but small value (0.21) which need not be discarded, but this model still over-predicted intake and the slope of the regression line was different to 1 and intercept different to zero.

8.2.3 Model_R predictions (using Source C data)

- Predictions using the Source C data (higher quality forages) were excellent, with an R^2 of 0.94 and the slope (0.99) not different to 1 and intercept (-0.05 kg/day) not different from zero suggesting almost complete agreement between predicted and observed values.

The reason for the differences in precision of the predictions using Source C data relative to Source A and B combined are not obvious. Although the Source C data included mainly higher quality C3 forages (or pellets) there were some high quality forages included in the Source A set and these deviated markedly from the line of best fit. This validation study has shown that in some cases QI can provide excellent, accurate estimates of intake based on the liveweight gain of cattle and a measure of the DMD of the selected diet. Thus at this stage it should not be discarded. However, in other cases the predictions were less than satisfactory. The problem is that it is currently not possible to determine which set of circumstances apply. Solving this dilemma may also provide the solution to better application of the feeding standards in tropical production systems, perhaps including the development of a tropical version of GrazFeed for northern beef producers and their advisors.

9 Component F: Develop a supplement optimisation model (*GroCosta*)

The objective for this aspect of the project was to develop a supplement optimisation tool that could be used by producers and their advisors to assist in the decision making process in relation to supplementary feeding of cattle for accelerated growth to finishing. It builds on the preceding components of the project concerned with defining the production responses to feeding either in the grazing or pen feeding situation. It is also prefaced by the economic analysis of the grazing study which showed a negative impact of high level feeding on profitability thereby demonstrating the challenges associated currently with any feeding program aimed at markedly increasing growth of cattle. A simple (draft) spreadsheet calculator called 'GroCosta' has been developed.

9.1 Description of the supplement optimiser (GroCosta)

GroCosta is an Excel-based spreadsheet calculator for comparing different feeding options for production feeding of cattle, from weaning onwards, to meet target markets. It is not an economic model. Ideally, GroCosta will be used in conjunction with an economic model which will define the economic parameters for feeding, for instance, the 'break-even' cost. Other programs are currently available to do this, including BreedCow Dynama, and are set up to incorporate the broad spectrum of factors affecting whole-farm profitability. We could see no reason to duplicate these models here.

For GroCosta to be practical and useful several aspects need to be included, viz., 1. growth response curves to different supplement types likely to be fed in northern Australia; 2. an estimate of the likely wet season compensatory growth following supplementation in the previous dry season; and 3. a break-even cost for feeding as provided by an accompanying economic model (see above).

9.1.1 Structure of GroCosta:

- Aimed at the accelerated growth of non-reproductive cattle, principally steers as the main target of production feeding, from weaning through to marketing (although a start at any age is possible).
- Allows a maximum of 3 years post-weaning growth, to an age of about 42-45 months.

  Production feeding is unlikely to involve cattle finished older than this age.
- Separates annual growth into Dry and Wet season phases which, although treated separately, are linked in terms of the starting and finishing weights and the extent of compensatory growth in the Wet season (which is related to the previous Dry season response to feeding).
- Focus is on Dry season feeding only.

  Wet season feeding, e.g., of phosphorus, could be included later if required but can also be accommodated in the current structure by incorporating a response in the baseline Wet season growth rate.
- An option is provided for the Dry season to be divided into periods of supplementation and non-supplementation to accommodate a delayed start or early suspension of feeding, for instance with changing seasonal conditions.
- Provides the option to use a HGP during the Wet season, on the assumption that the response to the HGP will mainly occur during this season.

  Dry season HGP options could be included if desired but the assumption is that the response occurs primarily during the Wet season.
- Allows for up to 6 comparisons at a time (6 rows) which could include different groups of cattle (e.g., weaners starting at different weaning weights), the same group with different feeding options at any time, one group with different stages of growth represented on different rows, etc.
- As well as the predicted liveweight and date for the end of any season, the option is provided to include an 'actual' date and liveweight so that the spreadsheet can be progressively updated as time progresses and new information becomes available.

  The starting date and liveweight for any season is taken from the 'actual' finishing date and liveweight of the preceding season.
- Summary data on the cumulative liveweight and costs are presented in tabular form on a separate worksheet ('Summary') and the predicted/actual growth path (liveweight) is plotted in a graph which is updated as actual data replaces predicted values as time progresses.

- The costs of supplements, according to local landed prices, can be entered by the user in the 'Constants' sheet.

9.1.2 Inputs by user

- Age and LW at weaning – average.

  The animals can be stratified into different age or weight groups (on different rows) if required.
- Number of cattle in the group – if total cost as well as individual animal cost is to be calculated.
- Predicted season end date.
- Predicted base-line (unsupplemented) growth rate for the season (this can be a historical value which is updated during the season based on observations or actual weighings)
- Intake of supplement – intended or measured (where measured replaces intended over time).
- Presence or absence of a HGP.
- Cost of supplement – landed on property and including a labour cost for feeding.

9.1.3 Assumptions:

- HGP response is equivalent to 10% extra growth during the Wet season.
- Compensatory growth during the Wet season is equal to 35% of the previous Dry season response with most supplements, but 50% with the urea/S supplement.

9.1.4 Limitations

- Supplement responses are based on a base-line of low quality tropical pasture which would normally support only maintenance or low rates of loss in cattle, e.g., base-line growth of -0.2 to +0.2 kg/day.

  No provision is given at this stage for medium quality pastures where lower rates of response to supplement could be expected. This could be included later if suitable response information became available.
- For some supplement types there is a dearth of information to support the response relationships, and these will need to be continually updated as new information becomes available.
- The user needs some knowledge, or an educated estimate, of the likely performance of cattle without supplement (or HGP) input.

  Users will become better at estimating this over time and the estimate within any season can be continually updated with actual data.
- The compensatory growth effect is set at a constant value (35 or 50%, depending on supplement type).

  Compensatory growth effects are known to vary widely according to a range of factors including the stage of growth of the animals but in this spreadsheet a single value, based on the results of the growth path project (Component A), is given to cater for all situations. A review of compensatory growth for varying feeding scenarios is required to provide the necessary information to modify this component.

9.2 Discussion

This calculator is open to the same criticisms as any such decision support tool – it is only as good as the information that is entered by the user and quality of the incorporated equations used to predict cattle performance within any season. The latter are unfortunately based on limited data sets, mainly our own, from a limited range of regions and base-line pasture quality categories. In many cases this information is not available, especially not in response surface format. We have had to use data from not only grazing studies but also from pen feeding experiments where cattle are confined and restricted from exercise. The responses under field conditions will usually be lower than in pens because of the ability of grazing cattle to select a higher quality diet, even when pasture quality appears very low, than those consuming low-quality chaffed hay in pens. Thus best-bet predictive equations are included in the model, which may lack accuracy in some circumstances.

Nevertheless, the purpose of this support tool is not to provide extremely accurate predictions of cattle growth rates and liveweights over the longer term; that is not possible without knowledge of seasonal conditions into the future. The spreadsheet calculator does, however, allow the user to look at best and worst case scenarios and gauge whether a profitable outcome is likely in the broader context. In so doing the level of risk associated with a supplementation program can be assessed at any point of the growth path between weaning and marketing. The further the cattle are from sale the greater the level of unknowns and associated risk. Thus predictions made at the time of weaning on the final liveweight of steers 2 years down-track will be highly speculative but as time progresses the estimate of final outcomes will improve. The risk reduces the closer the cattle are to the market end-point and the precision of the predictions will also improve. A user can continually update their predictions as time progresses and the cattle approach market end-point. By replacing estimated liveweights with actual values along the growth path, as they become available, performance can be continually monitored, risk continually assessed and, where necessary, management or marketing decisions changed. If nothing else a tool like GroCosta will cause the user to consider the likely costs of a feeding program and the likely effects on profitability and retreat from it if necessary. It would be fair to say that this does not always happen.

10 Conclusions and recommendations

10.1 Growth path grazing study

The grazing trial included the study of a small number of growth paths of cattle between weaning and slaughter at various ages, including supplementation and forage strategies for reducing the age at slaughter of cattle post-weaning. The main conclusions from the grazing study, and the associated economic analysis, of this project were that:

(i) the turn-off age of steers grazing tropical native pastures in the intermediate zone of northern Australia can be successfully reduced by at least 12 months (to about 30 months of age) using high-input supplementation;

(ii) efficiencies in the use of supplements, and reductions in cost, can be realised by restricting high-input feeding of steers to only the second dry season post-weaning instead of feeding in both years, without jeopardising attainment of target final carcass weight;

(iii) high-input supplementation of cattle to reduce age at slaughter is unlikely to be profitable in the present economic climate due to the high costs of supplements, the low conversion of supplement (e.g., MUP) to additional liveweight gain, the low and unpredictable price premium for cattle killed at a younger age, the negative effects of compensatory growth on overall responses to supplements, and the likely effect of a younger slaughter age on herd dynamics, notably the increased proportion of (drought-susceptible) cows in the herd;

(iv) in contrast to the findings with supplements, use of leucaena as a component of the growth path resulted in profitable increases in growth rate and markedly reduced the age at slaughter (by about 15 months);

(v) there were unexpected, and previously un-documented, trends in the relationship between liveweight and hip height (skeletal growth) whereby steers continued to grow skeletally even during very dry periods when they were only maintaining or even losing weight, but failed to fully compensate in height during the wet seasons relative to cattle not receiving the same growth setback.

The following recommendations are made:

Recommendation 1

That further growth path studies be carried out to gain a better understanding of the progressive relationships over time in the deposition of, and proportional body composition of, bone, lean tissue and fat in *indicus*-type cattle in northern Australia, as affected by seasonal fluctuations, with the aim of identifying efficiencies in the growth path from weaning to marketing at various ages, of exploiting compensatory growth effects, and of timing the incursion (and type) of improved nutrition provided either by strategic nutrients (supplements) or improved forages.

Such studies might involve artificially manufacturing extreme growth paths in cattle and measuring changes in body composition in the live animal (e.g., ultrasound scanning) and in the carcass by sequential slaughters, coupled with detailed studies in bone and muscle metabolism and histology, gene expression of bone and muscle growth, endocrinology and meat science. We believe that a better understanding of these processes will lead to improvements in the efficiency of growth of cattle in this seasonal northern environment with limited but optimal use of additional nutrient as supplement or improved forage at critical points in the growth path. The skeletal elongation project (B.NBP.0692) led by Dr L. Kidd is a first step in this process. Further discussion is required around this topic.

Recommendation 2

Following from Recommendation 1, that specific studies be undertaken to identify the most efficient and strategic use by cattle of areas of improved forage such as leucaena, in terms of the age at which it is most effectively utilised and the optimum proportion of access area of improved to native forage for most cost-effective utilisation of both resources.

The areas of improved forage are a limited resource on most properties and a better understanding of the growth patterns of tropical cattle from Recommendation 1 may lead to transformational changes in associated cattle management to optimise its profitable use.

Recommendation 3
That a detailed study be carried out towards better quantifying the extent of compensatory growth in cattle under different growing conditions experienced in northern Australia, and identifying the factors affecting it (e.g., age of animal, duration and extent of growth limitations, etc.), towards gaining better predictability of its effect and perhaps a better understanding of how it might be best exploited or ameliorated under practical grazing conditions.

Compensatory growth is a highly significant factor in determining the growth efficiency of cattle in northern Australia. The first stage of this work would be a detailed desk-top audit, perhaps a meta-analysis, of published and otherwise reported quantified examples and the conditions pertaining to those cases to identify likely contributing factors. This analysis should first be restricted to cases reported in northern Australia where seasonal conditions dictate large fluctuations in the quality of nutrition and the growth of cattle. These desk-top studies might be followed up with specifically designed experiments to investigate key treatments. Being able to predict the extent of compensatory growth, with reasonable accuracy, would vastly enhance the predictions of likely outcomes, including economic, from any nutritional intervention in the growth of cattle.

Recommendation 4
That the benefits of using HGPs in cattle grazing improved pastures which promote high growth rates be compellingly publicised to beef producers with access to these pasture types, as a highly profitable undertaking.

Recommendation 5
That further investigation be undertaken to confirm possible negative effects of using HGPs in older cattle (say older than 2 years) and if confirmed, a management plan be implemented for whole-of-life use of the implants.

Recommendation 6
That a wide range of potential growth paths of cattle from weaning to marketing at different ages be simulated and economically modelled, with sensitivity analyses, to identify potentially profitable options, to identify animal growth (seasonal) and cost thresholds and also the factors which are having the major impact on profitability, and to isolate aspects requiring further research attention.

It is suggested that there is reasonable knowledge available to simulate a wide range of growth paths involving various treatments such as seasonal variability, access to improved forages and the use of supplements, the use of HGPs etc. without further research and that the sensitivity of these growth paths to manipulation could be challenged using economic models such as Breedcow Dynama.

10.2 Supplement response pen feeding studies

A series of pen feeding studies were carried out using cattle of different ages to establish the response curves to various supplement types and to investigate how the supplement responses might be improved by manipulation of its composition. It is envisaged that this information will be used for formulation of supplements to optimise growth responses and the cost-efficacy of feeding. The main conclusions drawn from these studies include:

(i) although young cattle (weaners) appear to have a higher relative growth response (average daily gain per kg liveweight) than older cattle (yearlings or older), particularly with protein meals, the absolute growth responses (kg) per kg supplement fed are very similar for the different age groups indicating that cattle from different age groups will increase in liveweight to the same extent with a given intake of supplement, at least to the point where they reach mature size and start to fatten;

(ii) the supplement conversion efficiency (kg supplement/kg additional liveweight gain) is considerably lower for the molasses-based supplements (MUP) compared to protein meals e.g., cottonseed meal, or barley plus urea fed to cattle;

(iii) small additions of whole cottonseed but not barley alone to a molasses-based supplement (MUP) will improve the growth response and the supplement conversion efficiency by cattle although this finding is probably partly dose related as whole cottonseed was included at a higher rate than the barley.

The following recommendations are made:

Recommendation 7
That given the high responsiveness by cattle in growth to protein supplementation, research priority be given to identifying ways of increasing protein supply to cattle under practical feeding conditions, which might include devising practical ways of feeding existing protein meals ensuring good distribution through the herd, identifying and testing new and novel supplementary protein sources and developing systems to provide small areas of a property to high-protein forages such as legumes for reducing weight losses in the dry season or increasing gains for various purposes.

This research might include identifying and testing new forages or devising the most cost-effective way of using existing forages in small areas as a protein bank for use during the dry season for weaners or for finishing cattle for sale. A current project (B.NBP.0695) led by Dr P. Schenk investigating the use of on-farm algal ponds to provide protein to cattle is consistent with this recommendation, but further options are required.

Recommendation 8
That further investigation is undertaken to determine the optimum inclusion of whole cottonseed, and other nutrient sources, into the molasses-based supplement to improve its efficacy and cost-effectiveness as a source of both energy and protein for cattle for production feeding.

10.3 Validation of intake predictions

A decision support tool called QuikIntake, constructed using the Microsoft Excel framework and based on using the energy balance equations from the Australian feeding standards, has been set up to provide predictions of intake of forage by grazing ruminants from knowledge of the liveweight change of the animals. In this project studies were carried out to validate this intake calculator. The main conclusions were:

(i) the predictions of intake of forage for steers confined in pens (known intake, digestibility and liveweight gain) using QuikIntake were highly variable, being relatively accurate for some data sets but poor with others;

(ii) minor modification of the equations from the feeding standards improved the accuracy of the predictions with QuikIntake but not sufficiently to provide confidence in its use under all circumstances;

The following recommendations are made:

Recommendation 9
That further research be undertaken to understand why the QuikIntake calculator, and therefore the feeding standards, provide good predictions in some circumstances but not in others and to make the necessary changes to improve predictions overall.

Understanding the reasons the feeding standards are not providing accurate predictions of intake based on growth rate of cattle, or vice versa, is fundamental to being able to apply the standards to practical growth and nutrition of cattle in tropical northern Australia. Anecdotal evidence is that the standards work well in the temperate regions of Australia, as evidenced by the much wider use of GrazFeed in southern regions, and the same basic principles and equations should apply in the tropics. Currently there is no confidence in the use of GrazFeed or the feeding standards in northern Australia. Improving the precision of the standards for northern use would also provide for their use in other programs such as Grasp for predicting animal performance from simulated pasture growth and quality.

10.4 Development of a supplement optimisation tool

As part of the project an Excel-based supplement optimisation calculator (GroCosta) has been created to compare supplement options for cattle from weaning through to eventual marketing as live animals or carcasses, or part thereof of the growth path, to be used in conjunction with an economic model. The program includes response equations derived from pen studies such as those described above, with modifications based on responses achieved under practical grazing conditions.

The following recommendation is made:

Recommendation 10
That the GroCosta calculator be distributed to a few key extension staff for ‘road-testing’ and feedback on potential improvements and that it be continually ‘upgraded’ as new information on the growth responses to supplements becomes available.

The main limitation of the calculator will always be the supplement response equations which are based on studies from confined cattle and are limited to circumstances where the base production is only liveweight maintenance or thereabouts. Considerable modification may be needed for a range of feeding scenarios. Regardless, GroCosta should provide the producer or his advisor a ‘rough’ first look assessment of whether a feeding program is likely to be profitable and under what seasonal and cost/price circumstances. Putting a realistic stop to a feeding program because of questionable economic outcome might be its best use.

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12 Reference list

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005a) The northern Australian beef industry, a snapshot. 1. Regional enterprise activity and structure. *Australian Journal of Experimental Agriculture* **45**, 1057-1073.

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

Bowen MK, Buck SR, Gowen RL (2010) High-output forage systems for meeting beef markets – Phase 1. Final Report of Project B.NBP.0496 to Meat and Livestock Australia, Sydney.

Cafe LM, Hearnshaw H, Hennessy DW, Greenwood PL (2006) Growth and carcass characteristics of Wagu-sired steers at heavy market weights following slow or rapid growth to weaning. *Australian Journal of Experimental Agriculture* **46**, 951-955.

Cafe LM, Hennessy DW, Hearnshaw H, Morris SG, Greenwood PL (2009) Consequences of prenatal and preweaning growth for feedlot growth, intake and efficiency of Piedmontese- and Wagu-sired cattle. *Animal Production Science* **49**, 461-467.

Coates DB (2004) Faecal NIRS - technology for improving nutritional management of grazing cattle. Final Report of Project NAP3.121. Meat and Livestock Australia, Sydney.

CSIRO (2007) ‘Nutrient requirements of domesticated ruminants.’ (CSIRO Publishing: Melbourne, Australia)

Dixon RM, Coates DB (2005) The use of faecal NIRS to improve nutritional management of cattle in northern Australia. In ‘Recent advances in animal nutrition in Australia’. **15**, 65-75

Gonzalez LA, Ramirez-Restrepo C, Coates D, Charmley E (2012) Prediction of feed intake in growing beef cattle fed tropical forages. In, ‘Proceedings of the Australian Rangelands Society Biennial Conference’. Poster 4-2. (Australian Rangelands Society: Australia)

Graham JF, Byron J, Clark AJ, Kearney G, Orchard B (2009) Effect of postweaning growth and bulls selected for extremes in retail beef yield and intramuscular fat on progeny liveweight and carcass traits. *Animal Production Science* **49**, 493-503.

Greenwood PL, Cafe LM, Hearnshaw H, Hennessy DW, Thompson JM, Morris SG (2006) Long-term consequences of birth weight and growth to weaning on carcass, yield and beef quality characteristics of Piedmontese- and Wagu-sired cattle. *Australian Journal of Experimental Agriculture* **46**, 257-269.

Holmes WE (2012) ‘Breedcow and Dynama Herd Budgeting Software Package, Version 6.0 for Windows 95, 98, Me, NT, 2000, XP and 7’. Training Series QE99002. (Queensland Department of Agriculture, Fisheries and Forestry: Townsville)

Lofgreen GP (1965) Net energy of fat and molasses for beef heifers with observations on the method for net energy determination. *Journal of Animal Science* **24**, 480-487.

Lyons RK, Stuth JW (1992) Fecal NIRS equations for predicting diet quality of free-ranging cattle. *Journal of Range Management* **45**, 238-244.

McCosker T, McLean D, Holmes P (2010) ‘Northern beef situation analysis 2009’. Project B.NBP.0518, Report to Meat and Livestock Australia, North Sydney, NSW

McIntyre BL, Tudor GD, Read D, Smart W, Della Bosca TJ, Speijers EJ, Orchard B (2009) Effect of growth path, sire type, calving time and sex on growth and carcass characteristics of beef cattle in the agricultural area of Western Australia. *Animal Production Science* **49**, 514-514.

McKiernan WA, Wilkins JF, Irwin J, Orchard B, Barwick SA (2009) Performance of steer progeny of sires differing in genetic potential for fatness and meat yield following post-weaning growth at different rates. 2. Carcass traits. *Animal Production Science* **49**, 525-534.

McLennan SR (1997) Implications of compensatory growth for efficient beef production in Australia. In, 'Growth and development of cattle'. (Eds DW Hennessey, SR McLennan, VH Oddy) pp.81-91. Proceedings of the Growth and Development Workshop. (Meat Quality CRC: Armidale, NSW).

McLennan SR (2005) Improved prediction of the performance of cattle in the tropics. Final Report to Meat and Livestock Australia Ltd - Project NBP.331.

McLennan, SR, Poppi DP (2012) Application of nutrient requirement systems to grazing cattle, with and without supplements. In 'VIII SIMCORTE, 4th International symposium of beef cattle production, Vicosa, Brazil'. pp. 95-122.

Robinson DL, Oddy VH, Dicker RW, McPhee MJ (2001) Post-weaning growth of cattle in northern New South Wales 3. Carry-over effects on finishing, carcass characteristics and intramuscular fat. *Australian Journal of Experimental Agriculture* **41**, 1041-1049.

Ryan WJ (1990) Compensatory growth in sheep and cattle. *Nutrition Abstracts and Reviews* **60**, 653-664.

SCA (1990) 'Feeding standards for Australian livestock. Ruminants. (Standing Committee for Agriculture, CSIRO: Melbourne)

Wilkins JF, McKiernan WA, Irwin J, Orchard B, Barwick SA (2009) Performance of steer progeny of sires differing in genetic potential for fatness and meat yield following post-weaning growth at different rates. 1. Growth and live-animal composition. *Animal Production Science* **49**, 515-524.

Winks L (1984) 'Cattle growth in the dry tropics of Australia'. (Australian Meat Research Committee Review no. 45)

13 Detailed reports

13.1 Detailed Report 1: Growth path grazing study

Consequences of changes to post-weaning growth path due to supplements and leucaena on growth and carcass characteristics of steers in the seasonally-dry tropics of Australia

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Introduction

Cattle production on native pastures in northern Australia follows a distinctly seasonal pattern, analogous to that of rainfall and pasture growth, with low or nil growth during the dry winter/spring months followed by high growth rates early and then moderate growth during the remainder of the wet summer/autumn months (Winks 1984; McCown 1980-81; Bortolussi *et al.* 2005b). Annual liveweight gains are generally low by comparison with those from the temperate regions of Australia, and are highly variable and thus unpredictable on a year by year basis (Winks 1984; Bortolussi *et al.* 2005b). Consequently, the time to finishing cattle for slaughter in this environment is prolonged and the likelihood of producing meat of high and consistent eating quality is low. For instance, Bortolussi *et al.* (2005b) in a survey of the northern Australian beef industry, reported an average annual liveweight gain of steers for the black speargrass (*Heteropogon contortus*) community of northern Queensland of 116 kg, well short of the projected gains of 180 kg/year required for higher value markets such as Japan and Korea or to reliably comply with the Meat Standards Australia (MSA; Anon. 2003) grading system (Bortolussi *et al.* 2005b; English *et al.* 2009). Increasing annual liveweight gains not only improves the chance of meeting these high value market specifications, but also increases the flexibility to take advantage of changing market opportunities. Cattle producers in the region, when surveyed on future goals for their herds (Bortolussi et al. 2005a), listed increasing turn-off weight and reducing turn-off age of their cattle to increase profitability, as major priorities. To ensure higher meat quality, a realistic goal would be to target a final steer liveweight in excess of 500 kg at about 2.5 years of age.

Over the last decade or so a considerable body of research has been carried out in other states and regions with a more temperate environment, into the effects of either pre-weaning (Cafe *et al.* 2006, 2009; Greenwood *et al.* 2006) or post-weaning (Robinson *et al.* 2001; Graham *et al.* 2009; Wilkins *et al.* 2009; McIntyre *et al.* 2009; McKiernan *et al.* 2009) backgrounding growth of cattle on the efficiency of production, final carcass composition and meat quality for cattle finished on either pasture or in feedlots. Often a breed interaction with growth rate was incorporated into the experimental design. Whilst the general principles will still apply to the northern Australian situation, the application of their results is limited by their use of *Bos taurus* breeds of cattle compared with *B. indicus* in northern regions, by the much higher base growth rates usually achieved in the backgrounding phase which allowed earlier finishing ages than normally achieved in northern Australia, and by the practice of regularly finishing the steers in feedlots compared to total grass-fed systems predominating in the northern region.

Various strategies have been used to reduce turn-off age of steers in northern Australia, including both pasture improvement and supplementary feeding options. A major expansion in the area of land improved to leucaena (*Leucaena leucocephala*), and the high quality of leucaena/grass pastures for growing cattle especially in central Queensland (Quirk *et al.* 1990; Dixon and Coates 2008), has led to its much wider use for growing and finishing cattle for premium markets. Bowen *et al.* (2010) calculated average annual growth rates of *ca.* 240 kg for steers on leucaena pastures when reviewing available published and un-published reports from the literature. Consequently, it offers a potential finishing option and is one that was investigated in the present study as an alternative to supplementation. Lindsay *et al.* (2006) showed that by using a molasses-based production supplement in each of 3 years post-weaning the age of turn-off of steers could be reduced by 16 months (from 4.5 to 3.1 years) compared with an unsupplemented control group. In a similar environment and using a similar supplement, steers fed over 2 dry seasons reached a finishing weight of *ca.* 550 kg at 2.5 years of age (Fordyce *et al.* 2010). Whilst these supplementation approaches undeniably achieved the stated goal of reducing age of turn-off without sacrificing final carcass weight, the need to feed in each dry season coupled with the likely reduction in liveweight response to compensatory growth (Ryan 1990) increases the cost of feeding and reduces the likelihood of a profitable outcome, especially with the escalation of feeding costs in recent years. One alternative is to reduce the period of high-input feeding to a single dry season but the effect of this approach on overall weight gains and achievement of target carcass weight and quality is unknown. Furthermore, there is the question of which dry season to target; viz. that immediately post-weaning or the following one when steers are 12 mo older. Theoretically, feeding steers at the younger age should increase efficiency of supplement use for liveweight gain as younger steers deposit a higher proportion of protein to fat compared with older ones and liveweight gain is greater per unit weight of protein deposited compared with fat (CSIRO 2007). On the other hand, liveweight responses to supplement made early in life may be eroded in part by compensatory growth in the ensuing period leading up to slaughter (Ryan 1990), and delayed feeding might then be the more cost-effective option. The study reported here examined the effects of different supplementation strategies, and the different growth paths they generated, on liveweight, height and body composition in the live animal and on carcass composition, for steers grazing native pastures in north Queensland. Hormonal growth promotants (HGP) are also extensively used in northern Australia (Bortolussi *et al.* 2005b; Hunter 2010) so a growth path x HGP interaction has also been included in the study.

Materials and methods

Animal ethics

The experiment was carried out under the endorsement of the Queensland Dept. of Primary Industries and Fisheries Animal Ethics Committee, with permission references SA 2007-05-195 and SA 2010-05-317.

Locations

The main part of the grazing experiment was carried out at Swans Lagoon Research Station, near Ayr (northern Queensland; 20.05S, 147.13E) but one treatment was partly located at Brian Pastures Research Station, near Gayndah (south-eastern Queensland; 25.39S, 151.45E). The land types for the two sites are described on the FutureBeef site (futurebeef.com.au) as poplar gum woodland and on duplex and loam, respectively, with a predominant native grass species being *Heteropogon contortus* (black speargrass) in both regions.

Animals and experimental design

Two drafts of steers were used, 12 months separated in time. The first, hereafter Draft 1, comprised commercial Brahman crossbred (about 3/4 *Bos indicus*) calves weaned at about 6-9 months of age in mid-2008, purchased from a property near Maxwelton, central northern Queensland. The second draft (Draft 2) were commercial Brahman crossbred calves (about 5/8 *Bos indicus*) from the Swans Lagoon herd, weaned at between 6 and 8 months of age in June 2009. The liveweights of the calves at allocation were 212.4 (± 22.69, sd) and 208.8 (± 18.09) kg for Drafts 1 and 2, respectively. Both drafts of calves were vaccinated to prevent major clostridial diseases (Ultravac® 7-in-1; Pfizer Animal Health Pty Ltd), tick fever (trivalent tick fever vaccine; Biosecurity Queensland), botulism (Singvac® 3-year bivalent botulism vaccine; Virbac Australia Pty Ltd) and bovine ephemeral fever (BEF; Websters BEF vaccine, Fort Dodge Australia Pty Ltd). Annual booster vaccinations for BEF prevention were carried out in September-October for all groups remaining in the trial.

The experimental design was a randomised block of 5 treatments (growth paths) with 3 replicates and with 10 steers per replicate. Within the original blocking, half of the steers in each group were implanted with hormonal growth promotants (HGPs) to pay-out continuously from allocation through to eventual slaughter (+H); the others were not implanted (nil).

Growth paths and supplements

At allocation, steers were weighed un-fasted and initially divided into 3 liveweight classes of heavy, medium and light, representing the 3 replicates. Within weight classes, they were then assigned to treatments by stratified randomisation on this initial liveweight so that each treatment comprised one replicate of 10 steers from each weight class. Within replicates, steers were then paired on liveweight, within original blocking, and the HGP treatment was randomly allocated within these pairs.

At the Swans Lagoon site, steers grazed as separate replicate groups during the ‘dry’ seasons but as a common group during the ‘wet’ seasons. The start of the wet, and thus end of dry, was delineated by falls of rain in 1 or more episode in spring/summer sufficient to promote sustained new growth of pasture whereas the dry season start corresponded with the last weighing or slaughter of the steers in June. The dry season trial paddocks were blocked on proximity and apparent similarity of soil and pasture type and each treatment allocated to each of the 3 blocks, with treatments randomly allocated to paddocks within blocks. The pastures comprised mainly native tropical medium grass species, with *Heteropogon contortus* (black speargrass) a predominant species, but in some areas there was a natural spread of legume of the *Stylosanthes* spp. Separate nearby paddock blocks were used for dry season grazing so that the 2 drafts used the same paddocks during DS1 and DS2, but 12 months apart. These areas were spelled from grazing for most of the intervening wet seasons. Within drafts, the steers were grazed as a single mob in 1 of several large station paddocks during the wet seasons and during the 2010-11 wet season the remaining steers from Draft 1 (L-nil treatment) grazed the same area as the Draft 2 steers. The stocking rates for both drafts were 0.67, 0.42 and 0.33 steers/ha in DS1, DS2 and DS3, respectively. Variable stocking rates were used during the wet seasons (0.25-0.31 steers/ha), depending on paddock size, but care was taken to ensure pasture was not limiting at any time. Steers transferred to Brian Pastures remained in original replicates and grazed separate paddocks throughout (see below) at a stocking rate of ca. 0.67 steers/ha, depending on paddock size. The steers were rotated between paddocks about every 3-6 weeks or when pasture became limiting.

A summary of the 5 growth paths, common for both drafts of steers, is illustrated in Fig. 1. The growth paths represented various combinations of treatment applied in the first and second dry seasons (DS1 and DS2) post-weaning. No supplements were fed during the wet seasons. Three of the treatment groups received supplement inputs of low (L), medium (M) or high (H) order in DS1 followed by H in DS2, denoted as L-H, M-H and H-H, respectively. These groups were slaughtered at the end of the second wet season post-weaning (WS2) at about 30-33 months of age. A fourth treatment group, L-nil, received L input during DS1 but no subsequent supplementary feeding and were slaughtered at the end of the third wet season (WS3), 12 months older than the above groups at about 42-45 months of age. This treatment was considered to represent the ‘conventional’ nutritional management of male cattle for the beef industry in northern Australia. The fifth treatment, L-leuc, followed the L path in DS1 but was transferred to Brian Pastures at the end of the first wet season (WS1) and grazed leucaena-grass pastures throughout DS2 and for part of WS2 and, due to their rapid weight gains, were slaughtered about 3 months before the L-H, M-H and H-H groups at about 27-30 months of age. They received no supplement after transfer to Brian Pastures.

The L supplement option used in DS1 involved feeding a proprietary dry loose mix including, w/w air dry, *ca.* 47% salt, 30% urea, 6% Gran-am (sulphate of ammonia; Incitec Pivot Ltd, Australia), 12% Kynafos21® (*ca.* 3:1, mono-calcium phosphate and di-calcium phosphate dihydrate; KK Animal Nutrition, South Africa) and 5% palm kernel meal. Monensin was added at 0.3 kg of Rumensin®100 (active ingredient monensin at 100 g/kg; Elanco®, Eli Lilly Australia Pty Ltd)/100 kg of mix. This dry mix, hereafter referred to as US, was fed *ad libitum* from small covered troughs where the aim was to achieve urea intakes by individual steers of *ca.* 30 g/day or *ca.* 100 g/day of total mix. Additional flossy fine salt was added at times in an effort to regulate urea intake. The H supplement from DS1 was a molasses-based mix, hereafter called MUP, comprising molasses (100 parts w/w, as fed), urea (3), copra meal (10), salt (NaCl; 1), di-calcium phosphate (1) and Rumensin®100 (0.05). It was mechanically mixed for 20-30 min in a tank fitted with motor-driven paddles and mounted on the back of a truck and was fed out in open troughs in the paddocks. In DS1, MUP was fed *ad libitum* throughout to steers on the H-H treatment and also initially to those on the M-H treatment but, for this group, the composition of the mix was gradually changed over the course of the feeding period to include more urea and less copra meal. This was done to restrict supplement intake and achieve a growth rate for the M steers intermediate between that of the L and H groups in DS1. The experimental target was for the L-H, M-H and H-H groups to reach the same liveweight by the end of the DS2 feeding period, albeit by different growth paths. Thus the MUP supplement was fed *ad libitum* to L-H group in DS2 but access was restricted slightly to the M-H and H-H treatments to reduce intake.

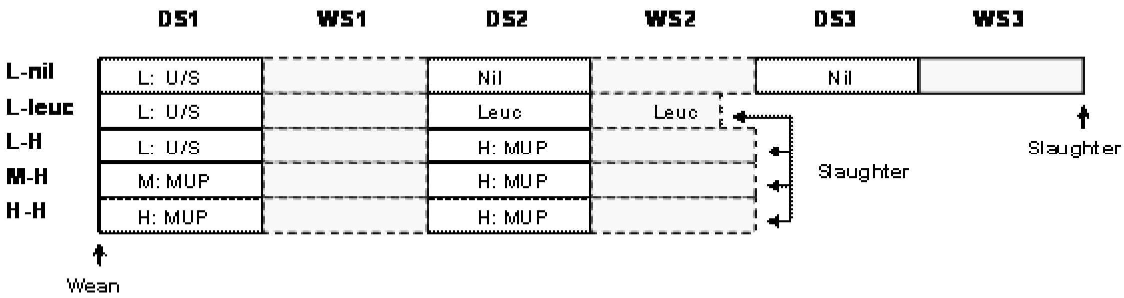

Fig. 1. Schematic representation of growth paths according to supplements provided, or leucaena access, during the dry seasons (DS) and wet seasons (WS; not fed) between weaning and slaughter. Except for the group grazing leucaena (Leuc), steers grazed native pasture throughout. Supplements were provided at low (L), medium (M) or high (H) nutritional input and were either based on a salt/urea/sulphur dry lick (U/S) or a liquid molasses/urea/copra meal mix (MUP). In DS2, intake of MUP supplement was varied between treatments to achieve similar liveweight by season end. Treatment details and supplement intakes are shown in the text.

Steers transferred to Brian Pastures (L-leuc) were given continuous access to mixed leucaena/grass paddocks and were kept within their original replicate groups except during the last 4 weeks when they were grazed together to avoid social behavioural problems and potential bruising around slaughter. Upon first access, the steers were each drenched with 100 mL of a rumen inoculant containing *Synergistes jonesii* to prevent mimosine toxicity (Klieve *et al.* 2002). To maximise access to leucaena, the groups were rotated around paddocks about every 4-8 weeks depending on availability of leucaena leaf in the paddocks. No supplements were fed to this group whilst grazing leucaena.

The HGPs used were all of Compudose® origin (Elanco®, Eli Lilly Australia Pty Ltd) and for Draft 1 were implanted in the order: Compudose®-400 (C-400; oestradiol 17β; 400 day payout; implanted on 18 August 2008), Compudose®-100 (C-100; oestradiol 17β; 100 day; 14 October 2009), Compudose®-G (C-G; oestradiol 17β and trenbolone acetate; 90-100 day; 25 February 2010) and C-400 (14 July 2010). All treatments received the initial C-400 and the C-100 implants and all except the L-leuc treatment, which was ready for slaughter at the time, received the C-G. Only the L-nil group received the second C-400 implant. The same implant protocol was used for Draft 2 with the exception that Compudose®-200 (C-200; oestradiol 17β; 200 day) replaced C-100, due to the earlier start date of Draft 2. The implant dates for Draft 2 were 25 June 2009 (C-400), 10 August 2010 (C-200), 28 February 2011 (C-G) and 15 June 2011 (C-400).

Procedures

Steers were mustered into cattle yards in the early morning, every 4-6 weeks. Measurements taken at every muster were liveweight (LW; un-fasted), body condition score (CS; 9-point scale) and hip height (HH; height at the peak of the sacrum), and measurements at every second muster and/or at the change of seasons were ultrasonically-scanned (linear array real-time ultrasound) depth of fat at the rump P8 (rump site adjacent to the sacral crest) and 12/13th rib sites, and scanned depth of the eye muscle (EMD; *M. longissimus thoracis et lumborum*) at the 12/13th rib site.

Within treatments, all steers were slaughtered at the same time in 1 of 2 commercial abattoirs. Steers from L-H, M-H and H-H treatments were killed on the same day late in WS2, and L-nil steers about 12 months later, in an abattoir near Townsville, northern Queensland, about 120 km from Swans Lagoon. In Draft 2, the designated experimental protocol was followed despite the L-nil group being almost the same weight as the L-H steers by the end of WS2 due to favourable growing conditions. L-leuc steers were slaughtered in an abattoir at Beenleigh, south-eastern Queensland, about 350 km from Brian Pastures. Carcass measurements at each abattoir followed the AUS-MEAT® protocol and included hot carcass weight and P8 fat depth. In addition, a Meat Standards Australia (MSA) assessment was carried out on all eligible carcasses providing information on cold carcass weight, hump height, ossification score, marbling score, rib fat depth, fat colour, meat colour, pH and eye muscle area, and an MSA boning group score between 1 and 15 was allocated (Anon. 2007). Ineligibility for MSA assessment was on the basis of dentition (more than four permanent teeth), low fat depth, dark meat or yellow fat colour and high meat pH (greater than 5.7). In Draft 1 very few of the L-nil steers were assessed for MSA on the basis of excess permanent teeth. In Draft 2 all L-nil steers were assessed on request even those with more than 4 permanent teeth. A price premium was received for carcasses attaining MSA boning group score of 10 or less, in common with industry practice.

Steers from Draft 2 receiving the L treatments in DS1 carried heavy cattle tick burdens late in the dry season, so all trial steers including those receiving the M and H treatments which were relatively unaffected, were treated with Cydectin Pour-On (Moxidectin 5 g/L; Fort Dodge Australia Pty Ltd). No other parasite treatments were applied during the experiment.

Faecal samples were collected every 2-4 weeks from a representative number of steers in each replicate (minimum 3 steers) of the L-nil treatment during the dry seasons and from the total trial herd (minimum 6 steers) during the wet seasons when common grazing occurred, to monitor changes in the quality of the pasture selected by the steers. Both drafts of steers were sampled separately except during the 2010-11 wet season when the remaining steers from Draft 1 (L-nil group) and all from Draft 2 were grazed on a common area, and diet quality estimates represented the combined drafts. Samples were taken per rectum from the steers during weighing musters or, between musters, freshly voided faeces was collected from the ground where the cattle were camped. Samples were bulked across replicates (dry season) and for the whole herd (wet season), dried soon after collection at 60°C, milled on a Foss Tecator Cyclotec mill using a 1 mm screen and then re-dried overnight at 60°C. After cooling in a desiccator the samples were scanned on a Foss 6500 Near Infrared Spectrometer spinning-cup system (FOSS NIRSystems Inc., Maryland USA). Diet quality in terms of crude protein content and dry matter digestibility and the proportion of non-grass (C3 pathway) components were estimated using the methods described by Coates (2004) and Dixon and Coates (2005).

Statistical analyses

Statistical analyses were performed using residual maximum likelihood (REML) methods in GenStat (2011). For selected time points each variable (liveweight, body condition score, hip height etc.) was analysed with treatment, HGP and their interaction included as fixed effects and paddock allocation as the random effect. Where the interaction was found to be non-significant it was omitted from the model. For some time-points not all treatments had measurements and so only comparable treatments were included in the model. In cases where only 1 treatment was recorded (e.g., L-nil in year 3) only the HGP effect was included. Where there were significant differences ($P<0.05$) found between treatments, pair-wise comparisons were performed using Fishers protected least significant differences to determine where those differences lay. Paddock, the random effect, was found to have little or no effect on the results. Carcass variables were tested using the same methods. Where deaths of steers occurred (see below), spare steers were used to maintain even stocking rates in dry season paddocks.

Results

Animal health and welfare

The steers from both drafts were generally in good health throughout the trial. There were 5 deaths in total from Draft 2, across treatment groups, but none were considered treatment-related. Botulism was suspected, but not confirmed, in most cases despite vaccinations of all steers against this disease. There were no signs of molasses toxicity in any of the supplemented steers.

Seasons

At Swans Lagoon, the long term average annual rainfall between 1966-2007 was 840 mm of which 81% was received between November and March. Of this total rainfall, it can be estimated that 744 mm on average occurred during the wet season period, which excluded falls during the usually ‘dry’ winter months of the year. Furthermore, the predicted average start to the wet (defined by at least 50 mm of rainfall with a further 50 mm within 1 month) was 20 November. By comparison, the annual rainfalls (July – June) for 2008/09, 2009/10, 2010/11 and 2011/12 were 1155, 781, 1583 and 1059 mm and the estimated wet season breaks occurred on 11 December 2008, 30 December 2009, 10 August 2010 and 2 December 2011, respectively. The monthly rainfall for the period is shown in Fig. 2. In summary, grazing conditions during the 2008 dry season were well above average due to heavy, unseasonal rainfall in July (111 mm) and precipitation for the 2008/09 wet season was 40% above average. Very dry conditions were experienced during the 2009 dry season with no rainfall between June and mid-November but the following wet season rainfall was similar to the long-term average. The duration of the 2010 dry season was only about 6 weeks following late rainfall in June and with heavy, season-breaking rain in mid-August (77 mm) and follow-up falls in September. Consequently, the 2010/11 wet season was prolonged and total rainfall exceeded the long-term average by 161%. Another long dry season was experienced in 2011 during which there was almost no rain between May and November, but the 2011/12 wet season had 42% higher than average rainfall.

At Brian Pastures, annual rainfall from 1956 to 2008 averaged 692 mm but this rainfall was better distributed than at Swans Lagoon as only 63% occurred between November and March. Conditions were relatively dry between July and October 2009 when Draft 1 steers first grazed the leucaena but rainfall between October 2009 and March 2010 was just above average for the station. By contrast, rainfall was much higher in the equivalent periods of 2010/11 for Draft 2 steers with good falls from August onwards and the October-March rainfall was double the long-term average.

Diet quality

Changes in the estimated quality of the forage selected by grazing steers are illustrated in Fig. 2. These estimated values for crude protein (CP) content and dry matter digestibility (DMD) represent the quality of the forage only component of the diet as the steers were either non-supplemented or, in DS1, received only a US supplement which does not interfere with quality estimates of the forage component (Dixon and Coates 2005; Coates and Dixon 2008). On native pasture at Swans Lagoon, in 3 of the 4 wet seasons (except 2010-11), both CP content and DMD of the diet increased steeply with the onset of the wet seasons and peak values of about 13% CP and 63-64% DMD were rapidly attained. These high values were relatively short-lived though and both quality attributes tended to also decline steeply between the mid- and late-wet season. Sustained low values for both CP content, generally less than 6%, and DMD, less than 52%, were recorded during the 2008 and 2009 dry seasons, the duration of low values being much longer (*ca.* 5-6 mo. duration) in 2009. Even small falls of rain in the late dry seasons promoted a marked increase in both CP content and DMD in the diet. A similar trend was evident during the 2011 dry season but both CP content and DMD were slightly higher than for 2008 and 2009. There was a less pronounced increase in quality in the early 2010-11 wet season than described above but this followed a dry season (2010) which, in response to substantial falls of rain, was both short in duration and associated with higher diet quality than the other dry seasons. During the 2009 dry season diet quality trends were similar for both drafts but CP content and DMD were slightly higher for Draft 1 compared to Draft 2 reflecting the higher quality of the pastures in the area used for DS2 grazing.

Estimates of the quality of the diet selected by steers in the L-leuc group at Brian Pastures are also shown in Fig. 2 for comparative reasons although these obviously have no relationship with the rainfall measurements shown for Swans Lagoon. With Draft 1 the DMD and CP content of the diet remained moderately high from August until slaughter, exceeding 60% and 9% respectively throughout, despite the apparent low availability of leucaena leaf during the winter months. Initial diet quality was lower in Draft 2 compared to Draft 1 but from September onwards DMD averaged 60% and CP content averaged 11.8% in the selected diet.

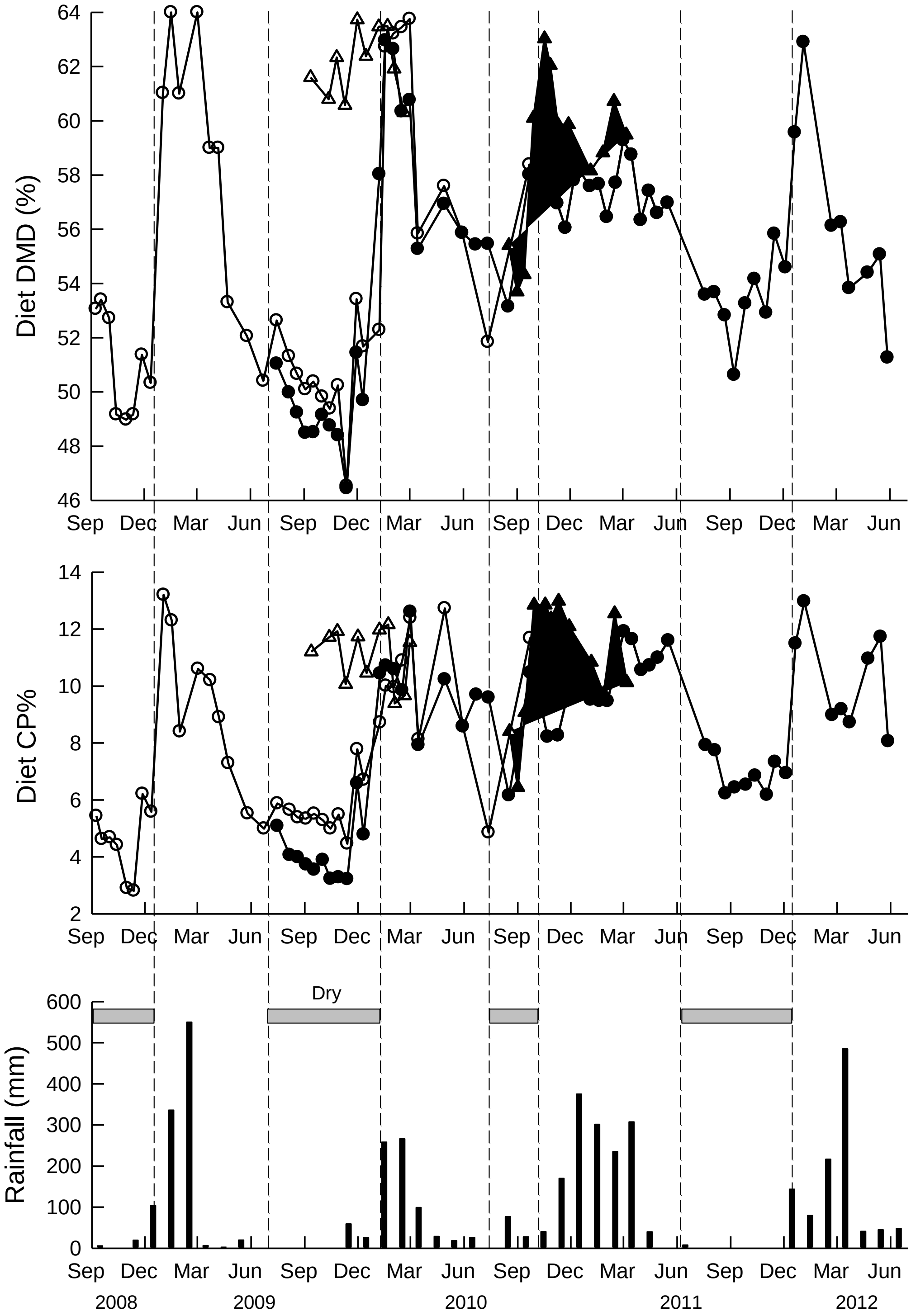

Fig. 2. Monthly rainfall at Swans Lagoon and changes in the dry matter digestibility (DMD) and crude protein (CP) content of the diet selected by steers in the L-nil group at Swans Lagoon (circles) and L-leuc group at Brian Pastures (triangles), for Drafts 1 (open symbols) and 2 (filled symbols). During the 2010-11 wet season both drafts at Swans Lagoon were grazed together and a common estimate of diet quality is given (closed circles). An arbitrary delineation between dry (shaded) and wet (unshaded) seasons is indicated by the dashed vertical lines.

Supplement intake

The final composition of the supplements fed and the average intakes during the dry seasons are shown in Table 1. For Draft 1, intakes of US during the 2008 dry season (DS1) were lower on average than 100 g/day, and tended to be consistently so across months, meaning that average urea intakes (20.0-26.3 g/day) were also less than the intended 30 g/day. During the same period, *ad libitum* intake of MUP by the H-H group was 3.9 kg/day but this was reduced by 47% for the M-H group through increases in urea and reductions in copra meal concentrations in the mix. Thus intakes averaged 0.93 and 1.59%W/day on an 'as fed' basis or *ca.* 0.71 and 1.21%W/day (DM) for the M-H and H-H groups, respectively. Unrestricted intake of MUP by the L-H group during the 2009 dry season (DS2) was *ca.* 6.0 kg/day but intake restriction procedures used for the M-H and H-H groups reduced intake by 10-13%, respectively. These intakes corresponded with 1.57, 1.38 and 1.34%W/day, as fed, or *ca.* 1.19, 1.05 and 1.02%W/day DM for the L-H, M-H and H-H groups, respectively.

For Draft 2, urea intakes averaged 21.3-24.3 g/day during the 2009 dry season (DS1) but the intended intake of 30 g/day was achieved during the dry period between August and the first rain episode in mid-November. Average intakes of MUP were similar to those of Draft 1 for the first dry season, although the feeding period was much longer (184 vs. 115 days), and the reduction in intake of the M-H compared with H-H group was about 38%. On a liveweight basis, intakes averaged 1.00 and 1.54%/day as fed or *ca.* 0.76 and 1.17%/day DM for the M-H and H-H groups, respectively. The feeding period was relatively short and interrupted by rain for the 2010 dry season (DS2) and intakes were on average nearly 70% lower than for Draft 1 for the comparable period. Average intakes were 0.50, 0.43 and 0.43%W/day, as fed, or 0.38, 0.33 and 0.32%W/day DM for the L-H, M-H and H-H groups, respectively.

Animal performance

Across all measurements, the performance of steers from the 3 groups receiving US in the first dry season post-weaning (L-nil, L-leuc and L-H) was not different ($P>0.05$) during DS1, WS1 and for the combined Year 1 and these groups are hereafter collectively referred to as either the L groups or L(low)-plane groups during these periods. Groups receiving the MUP supplement during DS2 (L-H, M-H and H-H) are collectively referred to as the H groups or H(high)-plane groups from the start of DS2 until slaughter at the end of WS2. Thus the L-H group changes from a L to a H group from the start of DS2, as its acronym suggests. There were only 2 isolated measurements (see Tables 3 and 4) for which there was a significant interaction between growth path and HGP treatment so trends discussed below are for main effects only.

Growth rate

The average liveweights and growth rates of different treatment groups are shown in Table 2 (Draft 1) and Table 5 (Draft 2) and changes in liveweight are illustrated in Fig. 3.

Draft 1. The L groups receiving US gained at well above maintenance during DS1, averaging 0.24 kg/day and thereby considerably higher than average based on long-term observations. Nevertheless, there were step-wise, significant increases in growth rate ($P<0.05$) with M-H and H-H supplements so that by the end of DS1 the M-H and H-H groups were *ca.* 31 and 47 kg heavier, respectively, than their L counterparts (Table 2). The associated conversion rates of supplement intake to additional LW gain, over and above that of the L group, during DS1 averaged 8.7 and 9.9 kg/kg for the M-H and H-H treatments, respectively. Growth rate trends were reversed during WS1 decreasing significantly in the order L to M-H to H-H so that the previous LW advantages of the M-H and H-H over the L groups were eroded by 52% during this season. The LW of the H-H group was greater ($P<0.05$) than that for the L groups at the end of WS1, but neither was different to M-H. During the prolonged DS2 the unsupplemented L-nil group only maintained LW whilst the L-H, M-H and H-H groups receiving MUP gained at 0.48 kg/day, on average. Gains increased incrementally in order of H-H, M-H and L-H, consistent with the order of supplement intakes (Table 1), the differences being significant between L-H and H-H but not between M-H and other treatments (Table 2). At the end of DS2, LWs were not different between these 3 groups and on average they were *ca.* 109 kg heavier than the L-nil group.

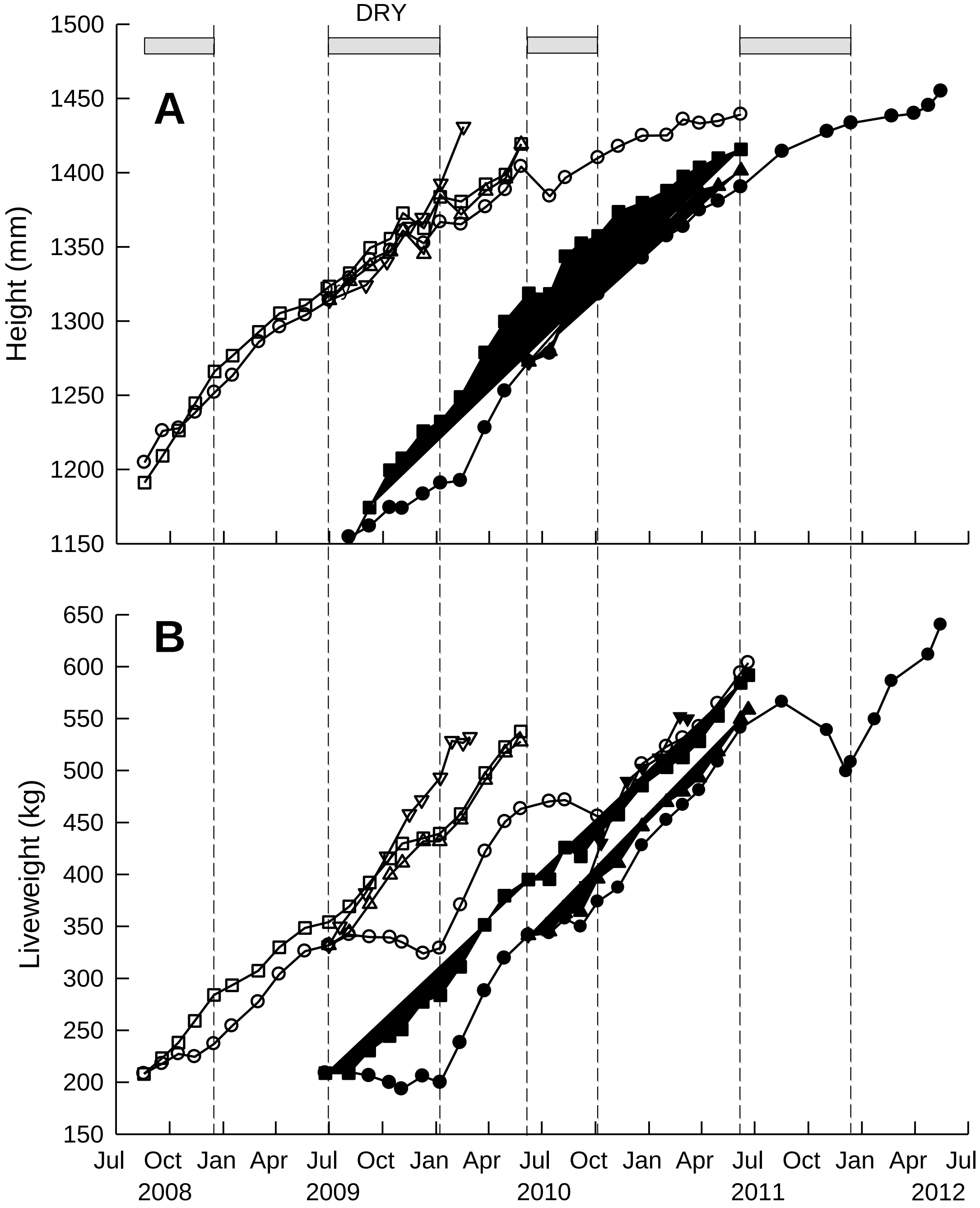

Fig. 3. Changes in (A) the height and (B) the liveweight of steers from Drafts 1 (open symbols) and 2 (filled symbols) following the L-nil (circle), L-H (upright triangle) and H-H (square) growth paths at Swans Lagoon and the L-leuc (inverted triangles) growth path at Brian Pastures. Data are averaged and represented by a single plot (same symbol as L-nil group) for treatments L-nil, L-leuc and L-H for the first dry and wet season post-weaning and individual plots are shown thereafter. Values are pooled across HGP treatments. An arbitrary delineation between dry (shaded) and wet (unshaded) seasons is indicated by the dashed vertical lines. Treatment details are given in the text.

This LW advantage was reduced by 34% (to 71 kg) during WS2 resulting from the higher growth rate by L-nil steers compared to the others ($P<0.05$), which gained at a similar rate. Final pre-slaughter LWs for the L-H, M-H and H-H groups at the end of WS2 were similar and averaged 533 kg. Overall gains over 24 mo from weaning for these 3 groups exceeded that for the L-nil group by 43%. The L-leuc steers gained at the very high rate of 0.82 kg/day over about 8 mo on leucaena at Brian Pastures and were considered ready for slaughter at similar LW but about 3.5 mo younger than their MUP-supplemented counterparts at Swans Lagoon. Although DS3 was relatively short and interrupted by rain events, the L-nil steers only maintained LW during this season but then made excellent gains over the prolonged WS3 and final LW at 604 kg exceeded that for the groups killed the previous year by about 70 kg.

Growth rate was increased with the use of HGPs in DS1, WS1 and DS2 and not affected in WS2. Over the 2 years post-weaning leading up to slaughter of the main group of steers the growth response to HGP, excluding the L-leuc group, averaged 7.7% and the implanted steers were *ca.* 23 kg heavier than non-implanted steers by the end of WS2. By contrast, there was a small (12%) but significant depression in growth rate with the use of HGPs on the L-nil steers over the next 12 months, diminishing the previous response and resulting in similar LW for treated and untreated steers by the end of WS3 (Table 2). Steers in the L-leuc treatment gained 21.7% more during the leucaena grazing phase at Brian Pastures, and 14.9% more over the total post-weaning period to slaughter (both $P<0.001$), with the use of HGPs. At their final weighing prior to slaughter the implanted steers were *ca.* 44 kg heavier than untreated steers ($P<0.05$).

Draft 2. Despite the use of US supplement, the L groups only maintained LW during the prolonged DS1. These steers were losing weight until a small fall of rain in November provided some new green growth in the pasture (see Fig. 2). Growth rates were increased with MUP supplements, more so with the H-H supplement compared with that for M-H (P<0.05), so that at the end of DS1 the M-H and H-H groups were *ca.* 58 and 84 kg heavier, respectively, than their L counterparts (Table 5). Conversion rates of supplement to additional LW gain, relative to the L groups, were 7.9 and 8.9 kg/kg for the M-H and H-H treatments, respectively. Growth rates in WS1 were in the opposite order to those in DS1 with the result that the previous LW advantage of the M-H and H-H over the L treatments were reduced in both cases by *ca.* 37% to 36 and 54 kg, respectively. Growth rates were highly variable during the short feeding period of DS2 and there were no treatment differences (Table 5). Similarly, there were no differences in growth rates between groups in WS2 and by the end of this season (pre-slaughter) LWs were similar for L-nil and L-H groups, and heavier but similar for M-H and H-H groups, and the LW advantage of the latter groups over the L-nil treatment was ca. 33 and 44 kg, respectively. The pre-slaughter LW of the L-H, M-H and H-H steers averaged 569 kg. Despite being close to this weight (541 kg) the L-nil group were carried on at Swans Lagoon, as the trial design required, and maintained LW during a short DS3 and then gained at a high rate over the prolonged WS3 season to achieve a final LW of 665 kg just prior to slaughter. Steers transferred to leucaena pasture gained at the high rate of 0.79 kg/day over nearly 9 mo and reached a pre-slaughter LW of 551 kg.

Steers implanted with HGPs grew faster during WS1 and WS2 but not during the respective dry seasons (Table 5). Consequently, the overall growth rate to the end of WS2 was 8.3% higher, and final LW 29 kg heavier, in favour of the implanted steers. However, implanted steers from the L-nil group had lower growth rate in DS3 and similar growth rate in WS3, to untreated steers so that performance in the third year post-weaning was inferior with HGP implants. Nevertheless, overall performance for the 3 years favoured implanted steers from the L-nil treatment over their non-implanted counterparts by 9%.

Steers in the L-leuc treatment gained 22.2% more during the leucaena grazing phase at Brian Pastures, and 17.6% more over the total post-weaning period to slaughter (both $P<0.001$), through the application of HGPs. At their final weighing prior to slaughter the implanted steers were *ca.* 54 kg heavier than their untreated counterparts (*P*<0.05).

Height

The changes in height of the steers are shown in Table 3 (Draft 1) and Table 6 (Draft 2) and are illustrated in Fig. 3.

Draft 1. There were significant effects of growth path treatments on height change in DS1 and DS2, but not during the associated wet seasons (Table 3). In DS1, groups H-H and M-H increased in height more than the L groups with the exception that the difference between M-H and L-H was not significant (Table 3). During the prolonged DS2, height change was not significantly different between the unsupplemented L-nil group and the M-H and H-H groups receiving high intakes of MUP but the L-H steers increased height more than all other treatments. Thus the L-nil group grew 51 mm in height despite only maintaining weight during this dry season. When estimated in terms of mm/100 days, height change for DS1, WS1, DS2 and WS2 equated to *ca.* 35, 34, 27 and 27 for steers on the low plane of nutrition (L-nil) and 62, 30, 32 and 26 for those on a high nutritional plane throughout (H-H), respectively, indicating that much of the difference between treatments occurred in the first dry season post-weaning. Over the total 2 year period, height change was greater by *ca.* 15% on average for groups L-H, M-H and H-H, which were not significantly different, than for the L-nil group (*P*<0.01). Nevertheless, there were no significant differences in height of the steers from different treatments at the end of WS2 when the majority were slaughtered. Growth slowed after Year 2 and increases for the L-nil group were only 2 and 13 mm/100 days during DS3 and WS3, respectively. The height of steers in this group immediately pre-slaughter was only 1.7 cm greater than for those at the equivalent time slaughtered 12 mo earlier. Steers grazing leucaena pastures increased in height at the rate of 47 mm/100 days on leucaena pasture or 40 mm/100 days for the total post-weaning period.

There was a negative association between HGP use and growth of steers during DS2 and this was expressed in reduced total height change during Year 2. Height change for L-nil steers was also lower in WS3 with HGP implantation and, combined for the 3 years post-weaning, untreated steers grew 13% more in height than their implanted counterparts (Table 3).

Draft 2. During the prolonged DS1, height of the L groups increased by *ca.* 74 mm despite the steers only maintaining weight, but progressive increases (*P*<0.05) in height occurred with the M-H and H-H treatments (Table 6). Consequently, height at the end of DS1 was greater for the M-H and H-H treatments compared to the L groups. However, there were no further differences in height increase between groups for WS1, DS2 and WS2. Although there were indications of compensatory height increases by L groups relative to the H-H group, over the total 2 year period to the end of WS2 the height increases were greater for the M-H and H-H treatments than for the L-nil and L-H treatments. Expressed in terms of mm/100 days, height changes for the L-nil group were 39, 55, 35 and 30 and for the H-H group were 62, 57, 33 and 23 over DS1, WS1, DS2 and WS2, respectively. Over the combined 2 years, the respective height changes for the L-nil and H-H treatments averaged 39 and 43 mm/100 days. The L-nil steers continued to grow during the following year (by 18 mm/100 days) and were about 37 mm taller at slaughter than their counterparts killed 12 mo earlier. Steers in the L-leuc treatment increased in height by 44 mm/100 days both during the leucaena grazing period and over the total post-weaning phase.

As for Draft 2, the use of HGPs was associated with reduced growth during WS2 across all treatments and also for the L-nil group in WS3. Consequently, the increase in height was greater by 9% after 2 years and by 17% after 3 years for untreated compared with HGP-implanted steers.

Liveweight/height ratio

Draft 1. Providing steers with a higher plane of nutrition based on MUP supplement in DS1 (M-H and H-H) and DS2 (L-H, M-H and H-H) resulted in a higher LW/height ratio at the end of those seasons compared with those groups maintained on lower planes of nutrition. This trend was still apparent at the end of WS2 when the L-nil group had lower LW/height ratio than other groups previously fed MUP. Steers from the L-nil group had a LW/height ratio *ca.* 11% greater than those from the H-H group at the time of slaughter of both groups. Across most seasons, HGP-implanted steers had a greater LW/height ratio than their untreated counterparts. This effect was significant at the end of WS2, when some groups were slaughtered, and was a trend (P=0.09) at the end of WS3 when the L-nil group were slaughtered. It also applied to the L-leuc steers.

Draft 2. The LW/height ratio was higher at the end of DS1 and WS1 for the M-H group compared with the L groups and higher again for the H-H group (all P<0.05). At the end of WS2 the ratio was higher for the H-H group than others, which were not different from each other. Steers from the L-nil group slaughtered at the end of WS3 had a LW/height ratio about 11% higher than that of the H-H group when slaughtered 12 mo earlier. From WS1 onwards, steers without HGP implants had a higher ratio of LW/height than those implanted.

Fat and eye-muscle depth

Draft 1. The effects of growth path treatments over time were similar for all measurements of body composition, i.e., rib fat, P8 fat and eye-muscle depth. Fat and eye-muscle depths were greater at the end of DS1, DS2 and WS2, but not WS1, for groups fed the higher input supplements based on MUP compared with those on low plane treatments. At the end of DS1, P8fat depth was greater for the H-H compared with the M-H treatment (P<0.05) but at other times and for other measurements, these treatments were not different. Rib and P8 fat depth averaged 5.9 and 11.1 mm and eye-muscle depth averaged 64.8 mm for steers slaughtered at the end of WS2 and appeared of similar order to measurements for the L-nil group when slaughtered 12 mo later, although this was not analysed. The L-leuc steers seemed (not analysed) to have more fat cover and eye-muscle depth than the other groups. At most stages of the growth path the effect of HGPs was non-significant but at the end of WS2 implanted steers had higher eye-muscle depth and lower P8 fat depth than untreated steers.

Draft 2. Fat cover and eye-muscle depth at the end of DS1 followed the order of supplement input with higher values for the H-H compared to the M-H, and for M-H compared with L groups (Table 7). However there were variable effects after this. P8 fat depth was not different between treatments at any other stage whilst with rib fat depth the main effect was that the H-H group had higher values than for other treatments at all stages except at the end of WS2 when there no significant differences between treatments. Eye-muscle depth was also greater for the H-H group than the L groups at the end of WS2 but after that there were no treatment differences. Rib and P8 fat depth averaged 4.5 and 9.1 mm and eye-muscle depth averaged 63.6 mm for steers slaughtered at the end of WS2 and appeared (not analysed) lower than respective values for the L-leuc steers killed at approximately the same age and for the L-nil group slaughtered 12 mo older. Similar to Draft 1 there was little effect of HGP treatment on fat or muscle depth until the end of WS2 when HGP-implanted steers had lower depth of rib fat ($P<0.05$) and P8 fat (trend only; P=0.07) but increased eye-muscle depth ($P<0.05$) relative to their non-implanted counterparts (Table 7).

Carcass characteristics and Meat Standards Australia chiller-assessed traits

The carcass traits and MSA chiller assessment results are presented in Table 8. Growth path treatment comparisons are only valid between groups slaughtered at the same time and abattoir, i.e., groups L-H, M-H and H-H (referred to here as H-plane groups); groups L-leuc and L-nil were slaughtered at different times (and hence ages) and/or abattoirs. However, as there no differences between the H-plane groups for nearly all traits examined, results for these treatments are pooled in Table 8. The exception was that the L-H group had lower ($P<0.05$) hot carcass weight (HCW) than the H-H group in Draft 2 (284.7 vs 305.1 kg), with the M-H group intermediate (296.8 kg) and not different to the other treatments. There were no treatment differences in HSCW in Draft 1.

The analysis presented in Table 8 represents the main effect of HGP across growth path treatments, as there were no significant growth path x HGP interactions ($P>0.05$). In the case of treatments L-nil and L-leuc, steers numbers were small within each HGP treatment sub-group (n=~15) thereby reducing chances of attaining significance of treatment effects. No MSA chiller assessment results are presented for the L-nil treatment in Draft 1 as most steers were not graded by the abattoir due to having more than 4 permanent teeth at time of slaughter. Compared to their non-implanted counterparts, HGP-treated steers from H-plane groups had lower AUS-MEAT-assessed P8 fat depth, significantly so in Draft 1, and trending to be in Draft 2 ($P=0.08$), and lower MSA-rib fat depth and higher eye-muscle area in Draft 1 but not Draft 2. Of these traits, most effects of HGP were non-significant for the other 2 treatments, the exception being that for the L-nil treatment in Draft 2 implanted steers had lower rib fat depth than for non-treated steers. The effects of HGP on marbling were variable, with significant reductions in the H-plane groups in Draft 2 with implantation, by both measures of marbling, but increases with the L-leuc treatment in Draft 1. Marbling was not affected by HGP with the L-nil group in Draft 2. Results were also variable for meat and fat colour. The trend was for higher meat colour with use of HGP in H-plane steers in both drafts and in L-leuc steers in Draft 2 but not in Draft 1 when it was reduced. Fat colour was significantly higher in implanted H-plane steers in Draft 1 compared to for non-implanted steers but there were no other significant effects.

Treatment with HGP was associated with large and highly significant effects on ossification score of the carcasses. With steers slaughtered at the younger ages the increase in ossification score ranged from 19 to 32% across drafts whereas with the L-nil steers killed *ca.* 12 months older, the increase was 88% in Draft 2. The average boning group assigned ranged from 2.4 to 4.7 units higher for implanted steers relative to those not treated and whereas most untreated steers were in boning groups 10 or less, which attracted an MSA premium price from the abattoirs, almost none of the implanted steers achieved these lower boning groups. The average boning group of non-implanted steers from the L-leuc treatment in Draft 1 was relatively high, and the proportion in boning group ≤10 was low especially when compared with respective values for Draft 2. The MSA price premium was not always reflected in the final price/kg paid though as it varied between higher, lower and not changed for implanted relative to non-implanted steers (Table 8).

Discussion

Liveweight performance

Most market signals point to an increasing demand in the future for carcases derived from young cattle but which still exceed lower thresholds for weight and fat cover. The indirect link between age at slaughter and meat quality is incontestable, and limits already apply to age for various markets, as determined by dentition of the animal or ossification in the carcass. Our study has shown that the post-weaning growth path of steers grazing low-quality native pastures in the seasonally-dry tropics of northern Australia can be practically modified, through the use of high-input supplements or high-quality pasture systems, to improve compliance with these higher value markets. Lindsay *et al.* (1996) and Fordyce *et al.* (2009) had earlier demonstrated that by using a high-input feeding and management system in a similar environment to ours, steer growth rates could be increased and age at slaughter reduced compared with the low input systems commonly employed by the grazing industry. In the latter study steers fed supplements based on molasses over 2 dry seasons achieved final LWs of at least 500 kg at 30 mo of age. Our study builds on their work, with some additional objectives around exploring cost-efficiencies to offset increasing cost/price challenges. We similarly achieved final LWs of between 527 and 585 kg at about 30 mo of age with steers given the H plane of nutrition during some part of their growth path. By comparison, for Draft 1 of the trial, steers offered the minimalist nutritional intervention (L-nil) typical of ‘normal’ industry practice, were only 456 kg LW at the same age and had considerably lower fat cover (8.4 vs. 11.1 mm P8 fat). Commercial practice in northern Australia for steers weaned at a similar age and LW (200 kg) to those we used tends to involve feeding a urea-based supplement in the first dry season post-weaning but then no further supplement, except in P-deficient regions where wet season P-feeding sometimes occurs.

The present study focused on one main strategy to reduce the costs of feeding, that of reducing the period over which high input supplements (MUP) were fed to steers from 2 to only 1 dry season post-weaning. The dry season is the main period targeted for feeding in northern Australia as paddocks are then easily accessible and responses to additional nutrients by cattle are greatest. Thus for steers slaughtered at 30 mo there are 2 main opportunities for nutritional intervention, feeding them either as weaners or 12 mo older as yearling steers. The studies of Lindsay *et al.* (1996) and Fordyce *et al.* (2009) involved feeding steers across both dry seasons to achieve the heavier LWs they reported. However, our results for Draft 1 steers showed that feeding in only the second dry season (L-H group) achieved the same final LW as feeding in both (H-H), with a 23% reduction in supplement intake and cost. The alternative approach investigated was to feed over both years but at a restricted rate, i.e., the M-H treatment, so that total supplement intake was reduced by 12% relative to the H-H treatment without compromising final LW and condition. It is apparent that efficiencies in supplementation leading to reduced costs can be achieved by manipulating both the duration and level of supplementation, and this aspect deserves further attention.

The vagaries of season contributed to the failure to reproduce the above results with Draft 2 steers. Following the harsh dry season of 2009 (DS1) during which a LW advantage of 84 kg was achieved by H-H steers over the combined L groups, the 2010 dry season (DS2) was short in duration and interrupted by heavy falls of rain in August with the result that even unsupplemented steers (L-nil) gained weight over the total dry season. Conditions were not conducive to feeding supplements as evidenced by unseasonally high diet CP and DMD values, low intakes of MUP and the absence of any LW response to feeding. Consequently, the early LW disparity between treatments L-H, M-H and H-H was not eliminated by the end of DS2 as designed and at the time of slaughter the L-H group had lower final LW than both the M-H and H-H groups and was not different to the L-nil group. Nevertheless, because of the very prolonged wet season (WS2) all steers in Draft 2 had LWs at 30 mo of age that exceeded 540 kg and they also had similar P8 fat cover (*ca.* 9 mm). Such seasonal conditions are atypical, but not unprecedented, and highlight the risks associated with undertaking long-term feeding programmes involving decisions taken when the cattle are a long time from marketing.

Ironically, eventual elimination of the LW disparity established between L and H pathways in the first dry season seems to rely on a medium to long second dry season favouring high intakes of supplement. This seasonal uncertainty further supports the case for L-plane treatments in early post-weaning life of the steers thereby allowing the cattle producer later opportunity to better assess seasonal conditions and the likelihood of cost-effective responses to feeding.

A key factor determining the cost-efficacy of feeding is the growth response by cattle relative to supplement intake. Before our experiment we could find no documentation of the responses to MUP supplements by cattle grazing low quality dry season pasture, despite their regular use in production feeding situations in coastal regions of northern Australia. In the studies of Lindsay *et al.* (1996, 1998) supplement intakes was not reported whilst Fordyce *et al.* (2009) did not compare the growth rates of steers with and without supplements. Liveweight responses to feeding MUP in our study were relatively consistent across years and age groups, as were the *ad libitum* intakes of the supplement. Based on growth rate differences between the H-H and L-nil groups, responses averaged 0.40 and 0.43 kg/day with weaner steers from Drafts 1 and 2 and 0.44 kg/day with yearling steers from Draft 1, achieved with supplement DM intakes of 1.21, 1.17 and 1.02%W/day for the H-H group, respectively. The latter value was based on a slight restriction of MUP intake by the yearling H-H group; the corresponding L-H group fed *ad libitum* consumed 1.19%W/day for a LW response of 0.51 kg/day. No estimate of response is given for the yearling steers of Draft 2 as the 2010 dry season (DS2) was relatively short in duration, supplement intakes were low and there was no significant LW responses to feeding.

The above intakes and responses translate to conversion rates (kg MUP DM/kg additional gain) of *ca.* 6.7-7.4 for weaner steers and 9.0-9.2 for yearling steers. However, this may be an overestimation of the true conversion rate for weaner steers as the L-nil group upon which the response was based received a US supplement. From the author’s experience of feeding this supplement under similar conditions (McLennan *et al.* 1981, 1991) and associated reports from the same area (Winks *et al.* 1976, 1979), the response to US would have been small or nil in 2008 due to heavy unseasonal rainfall early in the dry season (July), with associated positive weight gains by steers on the L treatments, but may have been close to the maximum usually recorded (*ca*. 0.25 kg/day) during the very harsh 2009 dry season. Assuming an average response of 0.15 kg/day for the total 2009 dry season, on the basis that the steers would not have been responding for the whole period, the calculated conversion rate would be *ca.* 5.0 kg MUP DM/kg additional gain relative to unsupplemented steers. These conversion rates can be compared with values recorded for pen-fed steers of similar breed and age of about 4.0-4.4 kg/kg (McLennan *et al.* 2013), the better conversion of confined steers presumably attributable to their very low or nil energy expenditure for walking and grazing and the lower quality of the hay fed relative to the diet selected by the grazing steers.

Compensatory growth during the wet seasons consistently eroded the responses to supplement achieved in the preceding dry season feeding periods. Comparing the extreme nutritional treatments of H-H and L-nil, dry season LW advantages to the H plane of nutrition were reduced by 47% and 33% in WS1 and WS2 of Draft 1 and 36% and 33% in WS1 and WS2 of Draft 2, resulting from 31, 35, 27 and 15% higher wet season growth rates by the L-nil group, respectively. The results for WS2 of Draft 2 were interesting in that the H-H steers only gained 12 kg more than the L-nil group during DS2 ($P>0.05$), less than the apparent compensation by the L-nil group of 22 kg in WS2 ($P>0.05$), which suggests that some of the compensatory effect may relate to the earlier feeding effects and that compensatory growth can extend over several years. The compensatory effect was greatest during the early part of the wet season and declined as the wet season progressed, as illustrated in Fig. 4. where the proportional change in LW advantage to the H-H over the L-nil treatment is plotted against days of wet season. In fact, by further plotting the proportion of the total compensatory growth that occurred in any season against time (not shown) we calculated that 84, 100 and 77% of the total occurred in the first 100 days of wet seasons WS1 and WS2 of Draft 1 and WS1 of Draft 2, respectively.

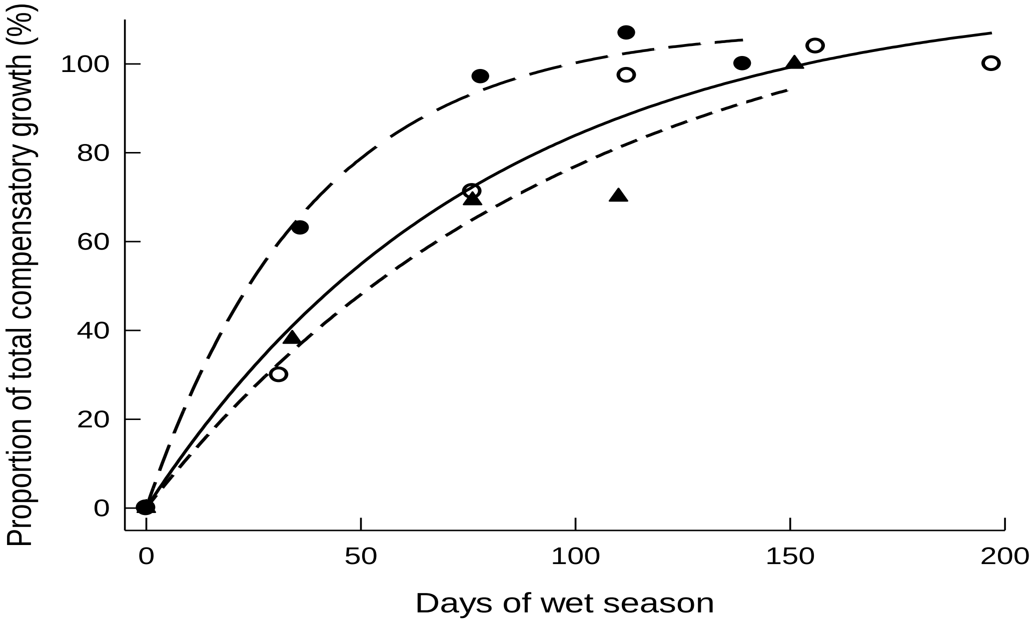

Fig. 4. Relationship between days of wet season and the proportion of the total compensatory growth by steers in the L-nil group, relative to the H-H group, that occurs during that wet season, for Draft 1 wet season 1 (WS1; open circles, solid line), Draft 1 WS2 (closed circles, long-dashed line) and Draft 2 WS1 (triangles, short-dashed line). The respective exponential regression lines were: $Y = 116.36\ (1-e^{(-0.0128\ X)})$, $R^2=0.98$, RSD=7.17, $P<0.001$; $Y = 108.32\ (1-e^{(-0.0259\ X)})$, $R^2=0.99$, RSD=4.69, $P<0.001$; and $Y = 120.16\ (1-e^{(-0.0102\ X)})$, $R^2=0.97$, RSD=7.73, $P<0.01$).

Winks (1984) reported that compensatory growth by unsupplemented cattle during the wet season accounted for 0-100% of the response supplemented cattle had accumulated during the previous dry season, with an average of 50%. However, these values related to cattle given urea-based supplements where the dry season responses were considerably smaller than those achieved here with high-intake MUP supplements. In his review on the subject, Ryan (1990) identifies several factors which influenced the extent of compensatory growth and are of relevance here. He alludes to the importance of the duration of the recovery period in allowing time for the restricted animals to make up the previous difference in weight. However, in our study the compensatory growth of Draft 1 steers in both wet seasons seemed to have stalled towards the end of the wet season period, perhaps due to the diminished quality of the diet available for total recovery to occur. By contrast, with steers from Draft 2 the short duration of WS1 may have limited the extent of the compensatory growth (Fig. 3). Ryan (1990) also concluded that compensatory growth was likely to decline as animals approached maturity. Our failure to record any obvious difference between the compensatory effects in WS1 and WS2 of Draft 1 probably reflects the fact that even our yearling steers were still some way from reaching mature size, as is also illustrated by the height curves (Fig. 3) where L-nil steers did not reach mature body size until at least the end of WS3. From an economic point of view, the importance of compensatory growth is demonstrated by the fact that the estimated costs of supplement only per kg additional gain were $2.85 and $2.68 at the end of DS2 for Drafts 1 and 2, and $4.10 and $4.00 at the end of WS2, respectively, due to the erosion of LW responses without changing costs of feeding. Marketing the cattle at the end of the feeding period may appear an obvious solution but cattle grown in northern Australia usually require the final wet season growth period to reach market specifications for weight and fatness.

Despite the highly divergent growth paths generated through the use of high-input supplements, there was no statistically significant evidence of any interaction between growth path treatment and the use of HGPs on liveweight change, (although a trend was indicated at the end of WS2 for Draft 2). This was notwithstanding the fact that during the dry seasons there was a wide range in liveweight performance from weight gains at moderate rates (0.3-0.6 kg/day) down to weight maintenance. In his comprehensive review of HGP use, Hunter (2010) summarised that growth rate responses to implants were greater when cattle were in positive energy balance and gaining weight than during periods of weight stasis or weight loss when effects were often non-existent. For the Draft 1 cohorts, the overall growth rate response to HGP was significant during the first and second dry seasons post-weaning presumably because the positive effects with groups consuming high amounts of MUP and gaining weight masked any low or negligible effect of those growing slowly (DS1) or merely maintaining weight (DS2). For instance, during DS2 both implanted and non-implanted L-nil steers had zero weight change. Most other responses to HGP across both cohorts of steers occurred during the wet seasons, in agreement with the summation of Hunter (2010).

Based on a compilation of data from experiments in northern Australia of average duration 364 days and thus spanning both a wet and dry season, Hunter (2010) predicted a growth response to Compudose-400 of 0.06 kg/day when the base growth rate was 0.3 kg/day. By comparison, and under similar conditions of measurement, the response to the first implant of Compudose-400 over the combined DS1 and WS1 of Drafts 1 (317 days) and 2 (348 days) averaged 0.03 kg/day, or 8%, across treatments with both cohorts when the average base growth rates were 0.41 kg/day and 0.44 kg/day, respectively. Further evaluations of individual HGP treatments and comparisons with the predicted values of Hunter (2010) are not valid as the data presented by Hunter relates only to cases where cattle were treated for the first time with a single implant whereas responses to re-implants in our study were possibly compromised by compensatory or carryover effects from previous implants.

The whole-of-life (post-weaning) effects from multiple implants of HGP of both oestrogenic and androgenic hormones (Compudose-G; trenbolone acetate) indicate an average LW response (excluding L-leuc) to the end of WS2 when H-plane steers were slaughtered, of 22.7 kg (0.04 kg/day; 7.7%) and 28.4 kg (0.04 kg/day; 8.4%) for Drafts 1 and 2, respectively. Direct comparisons with other published values from northern Australia are difficult as implant strategies and the grazing and seasonal conditions vary widely between studies, and Hunter (2010) alluded to the direct link between the nutritional status of the animal and its response to HGP. Overall responses to multiple implant treatments in central Queensland, across seasons of alternating high and low steer growth, varied from 0.06-0.12 kg/day (10-21%) when the average base growth rate ranged from 0.49-0.56 kg/day in the studies of Mason *et al.* (1984) and Hunter *et al.* (2000; 2001), but responses as low as 0.02 kg/day (2%) at base growth rate 0.46 kg/day have also been reported (Tudor *et al.* 1992). Under conditions supporting continuous, medium-high growth rates, steers grazing leucaena/grass pastures at Brian Pastures in our study gained 0.71-0.74 kg/day over 242-260 days (across drafts) without implants but this increased by 0.16 kg/day, or 21.7 and 22.2%, in response to HGP implants for successive drafts. Consequently, implanted steers were ca. 44 kg heavier than untreated steers just prior to slaughter. These improvements in liveweight performance were much higher than for steers on native pasture at Swans Lagoon, although this could not be tested statistically, despite using only oestrogenic hormones of C-400 at weaning followed by either C-100 (Draft 1) or C-200 (Draft 2); the steers were considered ready for slaughter when those at Swans Lagoon were receiving the androgenic implant, trenbolone acetate (C-G).

An unexpected finding was the depression in growth rate of the L-nil steers with HGP implantation in the period leading up to slaughter, the extent of growth reduction being 0.04-0.05 kg/day over about 12 mo when the base growth rate was 0.33-0.34 kg/day across drafts. This resulted in the overall effect of the HGP being non-significant by the end of Draft 1. We can find no other reports of such an effect with cattle on a positive plane of nutrition. This may be related to the long duration of the implant treatment as while there are published results relating to cattle finished at similar or heavier weights, e.g., Hunter *et al.* (2001), most did not implant for 3 years as we did with the L-nil treatment. The reason for this effect is not clear. Theoretically, the there would be a shift in the composition of gain during this period to more fat and less muscle deposition but similar changes should have occurred with the steers killed 12 mo earlier. The difference may lie in the fact that the older steers were closer to reaching skeletal maturity, especially those implanted (see below), and with the associated reduced muscle deposition the anabolic effects of the HGP would be diminished and weight gain associated with muscle growth also reduced. Irrespective of the reason, our results do suggest caution with the long-term use of HGP and warrant further examination of such implantation practices.

Height

Previously, there was no detailed description of the skeletal development of cattle grown under commercial conditions in northern Australia. Our results have documented the progressive changes in the height of steers from weaning through to turn-off at about 42 months of age, incorporating seasonal variability and the effects of varying supplement and HGP use. Skeletal development is a major driver of animal production. Growth of muscle is integrally related to that of the skeleton which supports it, the lengthening of bones providing the passive stretch to which the muscle responds (Holly *et al.* 1980; Always *et al.* 1990). Brody and Ragsdale (1924) described the growth of Jersey cows in terms of an exponential function such that the theoretical growth in height, in the absence of nutritional constraints, increased in any year at about 34% of that in the preceding year, until mature size was attained. This general pattern of declining rate of height change with increasing age appeared consistent with present results with steers from the H-H treatment of our study, which were least limited in growth by poor nutrition but still growing well below their theoretical potential (see Fig. 3). These steers though had still not attained mature size by time of slaughter at 30 mo of age when hip height was *ca.* 1420 mm. Instead, steers from the L-nil group which were retained for another 12 months continued to grow skeletally beyond 30 mo and achieved heights at *ca.* 42 mo of

1440-1460 mm which, on visual examination of the time sequence, may have still been slightly below mature size.

One of the most surprising observations was that even when L-plane steers were nutritionally challenged during the dry season to the extent of only maintaining weight or showing slight losses, the skeleton continued to grow albeit at a slower rate than for those given H-plane supplements. This effect was especially evident during the 2009 dry season when L-nil steers from Drafts 1 and 2 grew in height at 27 and 39 mm/100 days respectively. On the other hand, providing a much higher quality diet as achieved with the leucaena pasture (L-leuc) increased height at a faster rate than achieved with the MUP-supplemented treatments in Draft 1, indicating that the growth path of the H-H treatment was below the theoretical maximum described by the equations of Brody and Ragsdale (1924).

The highest seasonal increase in hip height was 62 mm/100 days achieved with both drafts of H-H steers fed during their first dry season post-weaning, which exceeded the increases achieved in the following wet seasons in both cases (30 and 57 mm/100 days, respectively). Achieving this peak height increase during the first dry season, albeit with high-input supplementation, demonstrates the strong influence of age on the growth in linear dimensions of the animal, a product of being on the steep part of the theoretical growth curve. It also suggests that this early phase of the animal’s life may be the most sensitive to manipulation. Matthews *et al.* (2008) reported a similar high value of 72 mm/100 days for weaner steers fed a MUP-type supplement at Swans Lagoon during the first dry season post-weaning whilst a recent study with weaner steers from the same source as ours has recorded height changes of 86 mm/100 days on a high-quality diet of lucerne *ad libitum* (L. Kidd, pers. comm.).

Unlike the trends with LW change across seasons, there was no apparent compensatory effect on height during the various wet seasons following periods of low performance during the preceding dry seasons. In fact, the trends with the LW/height ratio were very similar to those for LW change showing that this index was far more sensitive to LW than height changes. Matthews *et al.* (2008) similarly found no wet season compensatory effects on height, but LW compensation, following one dry season when both LW and height were depressed in steers receiving US compared with a MUP-based supplement.

These relationships between height and liveweight are best demonstrated by their graphical presentation, as illustrated in Fig. 5. There was a close quadratic relationship between height and LW for the H-H groups of both drafts and these are plotted in the figure without individual data points presented, for clarity of presentation. The corresponding data for the L-nil groups of each draft are also plotted but as individual measurements over time. Within drafts, these data for L-nil groups tend to generally follow a similar pattern to that of their high-plane counterparts except during the harsh dry seasons encountered, when height increased while LW remained relatively stable (maintenance). These occurrences are shown by the series of vertical data points within a narrow range of LWs. The critical point though is that as LW increased after these dry season events, the tendency was for the relationship to be re-established so that at any LW the height was similar for the extreme treatments of L-nil and H-H. This suggests a general strong allometric relationship between height and LW which is open to perturbations from extremes of nutritional stress but endures over the course of the growth path. The critical question is: can height be manipulated during phases of the growth path to stimulate subsequent LW gain by virtue of the response by muscle to the stretch stimulus of elongated bones, as discussed above.

Conflicting reports have been published on the effects of HGP on skeletal growth, some of which apparently stem from the type of compounds used and the final age of the animals at slaughter. The HGP implants we used primarily supplied oestrogenic compounds although all treated steers except those in the L-leuc group also received a short-acting (claimed functional life of 100 days) Compudose-G implant containing trenbolone acetate, a synthetic androgen, in the lead-up to the slaughter of the high-plane steers at 30 mo. Our results indicating a reduction with HGP implants in height of steers at time of slaughter at 42 mo for both drafts and at 30 mo for Draft 2, are opposed to the conclusions of Hunter (2010) and conflict with other findings that the length of the metacarpal bones of sheep was not affected when oestrogenic implants were used (Field *et al.* 1990; Hutcheson *et al.* 1992); it was increased with the use of testosterone (Peralta *et al.* 1994). Furthermore, increases in skeletal growth of cattle have been recorded by Loy *et al.* (1988) using oestradiol compounds, by Preston (1978) using diethylstilbestrol (a synthetic non-steroidal oestrogen) and by Schlegel *et al.* (2006) using bovine somatotropin (a peptide hormone). Conversely, calves implanted with oestrogenic compounds at birth had shorter metacarpal lengths and height at the hip at 4 mo and 9 mo of age (weaning) despite gaining weight faster, than non-implanted calves (Bagley *et al.* 1989).

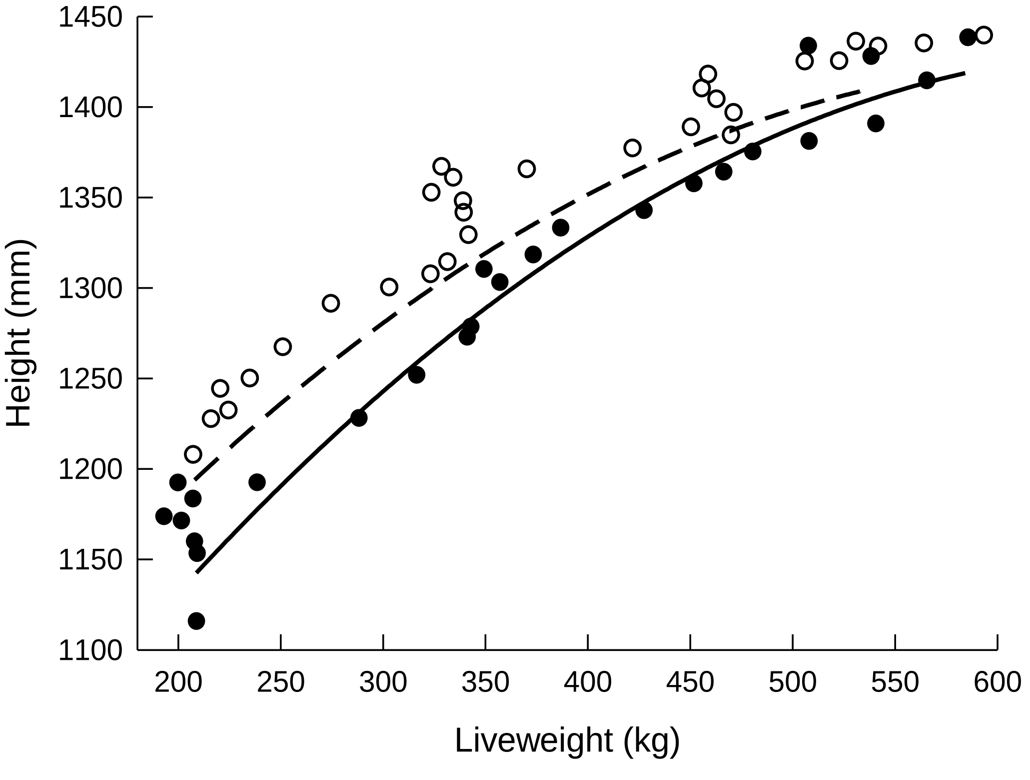

Fig. 5. Relationships between height and liveweight of steers from the L-nil groups in Drafts 1 (open circles) and 2 (closed circles) and from the H-H group of Drafts 1 (dashed line; no symbols) and 2 (solid line; no symbols). The plotted relationships for the H-H groups were: Draft 1: $Y = 922.62 + 1.556 X – 0.0012 X^2$, $R^2 = 0.99$, RSD = 5.50, $P<0.0001$; and Draft 2: $Y = 832.53 + 1.752 X – 0.0013 X^2$, $R^2 = 0.99$, RSD = 11.09, $P<0.0001$.

The effects of exogenous oestrogen on the length of the longitudinal bones and on final height are mediated through effects on ossification of the growth plates. In reviewing the endocrine regulation of the growth plate Nilsson *et al.* (2005) provided evidence that oestrogen advances growth path senescence and fusion, thereby inhibiting longitudinal bone growth. This is consistent with the results of Bagley *et al.*

(1989) reported above albeit with very young cattle. However, Field *et al.* (1990) found that implanting lambs with oestrdiol-17β hastened the ossification of the metacarpal bone growth plate relative to non-implanted lambs but because complete ossification of the growth plate in implanted lambs was not complete until 570 days of age and bone length had stopped increasing at 408 days, mature size of the lambs was not affected. The age of slaughter of animals in experiments relative to time of implantation seems central to understanding these analogous results. Often reported studies involve the slaughter of cattle at a relatively young age (< 2 years) following a period on high-energy diets, e.g., Loy *et al.* (1992), and the effects of oestrogenic compounds on skeletal development may not have been fully expressed. Our growth paths, especially those of the L-nil treatment, were the antithesis of that production system in that growth followed cyclical periods of low and moderate gains and slaughter was delayed until the steers were approaching their mature size at nearly 4 years of age. It is possible that ossification of growth plates in longitudinal bones was completed between the 2 slaughter ages, thus having a larger effect on the L-nil steers, and occurred earlier in implanted than non-implanted steers thereby leading to earlier attainment of mature size in the former. The much higher ossification scores for the skeletal column in carcasses of implanted compared with untreated steers supports this supposition. The earlier maturity with implants is also consistent with the negative effect of HGPs on liveweight during this 12 mo before slaughter of L-nil steers. We found no published reports of the effects of HGP on height of steers grown under similar longer-term production systems. These impacts of long-term implantation on skeletal maturity need to be considered in relation to final body composition and market requirements.

Body composition and final carcass effects

Recent advancements in the development of portable, robust ultrasound scanners has allowed regular monitoring, with acceptable precision, of changes in various measures of fat and muscle composition in grazing cattle and here provided for the first time detailed, sequential measurements in *Bos indicus* crossbred cattle grazing in the relatively harsh environment of northern Australia. Changes in fat cover and eye-muscle depth followed a distinct seasonal pattern analogous to the general trends in LW change, particularly so in steers from the L-nil treatment. The major divergence in composition traits between the L- and H-plane treatments occurred, as expected, during the dry seasons when low-plane groups experienced marked reductions in fat cover, presumably through mobilisation of the fat to support body energy requirements thereby limiting bodyweight loss, and the reduction in eye-muscle depth reflected the inadequacy of nutrient intake for maintaining muscle mass. By contrast, steers on high-level nutrition throughout displayed an almost linear increase in fat depth from weaning through to slaughter at 30 mo of age. Thus on these higher-plane treatments, fat deposition tended to be cumulative and by time of slaughter at the end of WS2, rib- and P8-fat cover in steers averaged 5.9 and 11.1 mm for Draft 1 and 4.5 and 9.1 mm for Draft 2 steers, respectively, exceeding lower thresholds for fat cover for most markets.

Despite these treatment differences in fat metabolism for the dry season, compensatory gains by L-plane steers during the following wet season tended to erode the deficit in fat cover relative to that of H-plane counterparts, sometimes to the extent of completely nullifying any previous difference. This was not always the case though and in Draft 1, at the end of WS2 when the early slaughter was carried out, there remained a deficit in fat cover in the L-nil group relative to those receiving enhanced nutrition. Quite apart from the obvious energy costs of this cyclical pattern of fat accretion and depletion by low-plane groups, from a commercial viewpoint the lower fat cover is likely to jeopardise compliance with market requirements for rib- or P8-fat cover on carcasses at slaughter, particularly for slaughter at younger ages.

Results from the harsh 2009 dry season provide an interesting contrast in the performance of 2 ages of steers, i.e., weaners and yearlings. Given a similar high-plane feeding regime (H-H), weaner steers (Draft 2) declined in fat cover during the 2009 dry season whilst their 12-month older cohorts (Draft 1) made substantial increases in both rib- and P8-fat cover, reflecting the effect of stage of maturity and in particular the higher fat to protein composition of body weight gain in the older steers (CSIRO 2007).

Various recent studies, predominantly with *Bos taurus* breeds of cattle in temperate regions of Australia, have reported a direct relationship between fat deposition and either post-natal or post-weaning rate of growth of cattle (references). For instance, when Wilkins *et al.* (2009) backgrounded steers of various *B. taurus* breeds from weaning to similar feedlot entry weight (*ca.* 405 kg) at growth rates of either *ca.* 0.5 or 0.7 kg/day, the faster backgrounding growth was associated with increased subcutaneous fatness of steers at feedlot entry. However, the faster growing steers were also younger than their ‘slow’ growth counterparts at this point of comparison. The comparative growth rates to slaughter for the H-H and L-nil groups in our study were lower at *ca.* 0.5 kg/day for the H-H group in both drafts and *ca.* 0.38 and 0.43 kg/day for the L-nil group in successive drafts, but with extreme fluctuations in growth rate across the total post-weaning phase for the latter group. Because of the widely varying age x LW structure within the different growth paths it is difficult to make direct point-of-time comparisons between treatments. Accordingly, we have plotted the P8 fat depth against LW at all measurement points for the extreme treatments L-nil and H-H of Draft 1, where growth paths were most widely spread (see Fig. 6). Distinctly different relationships seem to exist for the 2 treatments in that the H-H steers carried more fat cover than their low-plane counterparts at any LW other than the starting point. For instance, at LW 500 kg the predicted fat cover at the P8 site for the 2 treatments averaged 10.3 and 8.0 mm, respectively. Thus steers grown over the longer time-span need to reach higher LWs to achieve the same degree of fat cover as their faster growth counterparts. Although not large, these differences have commercial implications where the price grid for carcasses at abattoirs is usually based on both fat depth and weight. The reason for these treatment differences is not clear but in CSIRO (2007) the calculation of fat content of empty body gain, according to Equation 1.30, is adjusted upwards with increasing rate of gain so that steers attaining a certain LW at young age (e.g., H-H) will have a proportionately higher fat content in gain that those taking longer to achieve the same LW (e.g., L-nil). Age differed by as much as 8 mo for steers at the same LW on the 2 treatments.

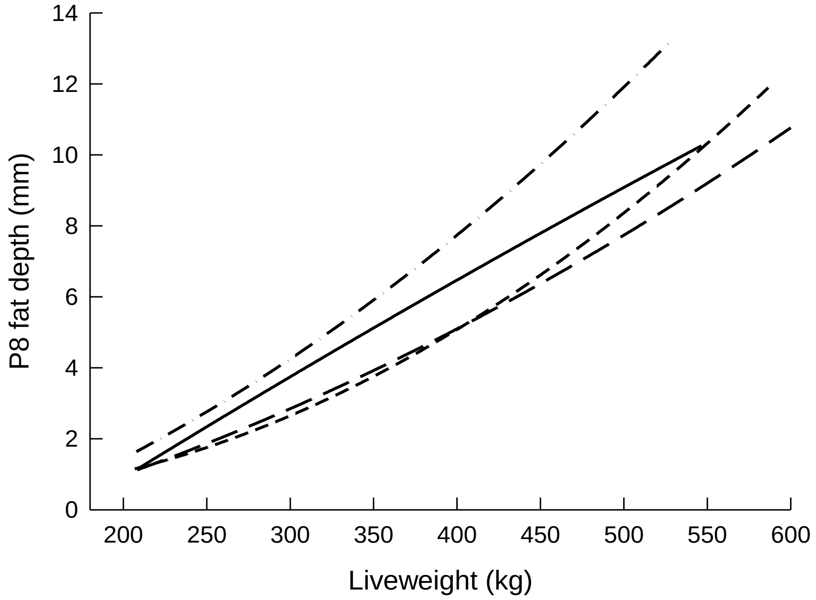

Fig. 6. Relationships between depth of fat at the P8 site and liveweight of steers of Draft 1 from the L-nil group without (short dash line) and with (long dash) HGP and the H-H group without (dash-dot) and with (solid) HGP. The plotted relationships are: L-nil without HGP: Y = 0.480 –0.0056 X + 0.00004 X^2, R^2 = 0.94, RSD = 0.98, P<0.0001; L-nil with HGP: Y = –1.584 + 0.0090 X + 0.00002 X^2, R^2 = 0.95, RSD = 0.71, P<0.0001; H-H group without HGP: Y = –2.118 + 0.0110 X + 0.00003 X^2, R^2 = 0.98, RSD = 0.56, P<0.0001; H-H group with HGP: Y = –5.128 + 0.0313 X – 0.000006 X^2, R^2 = 0.96, RSD = 0.70, P<0.0001.

Other studies have highlighted the variable effects of both pre-weaning and post-weaning growth rate on the fatness of the live animal or carcass. Greenwood and Cafe (2007) reported that cattle grown slowly pre-weaning had similar or leaner carcasses than those grown more rapidly, at equivalent carcass weights. Several studies from southern and Western Australia using *B. taurus* cattle and temperate grazing systems have reported the higher subcutaneous fat cover in steers grown rapidly post-weaning compared to those grown more slowly (Graham *et al.* 2009; McIntyre *et al.* 2009; Wilkins *et al.* 2009) but, although compared at about the same liveweight, age varied for the different post-weaning groups. Robinson *et al.* (2001) compared groups with different post-weaning growth rate to the end of a pasture backgrounding phase where the age was similar but liveweight different for the 2 groups, and found that steers with fast growth post-weaning were fatter than their slow growth counterparts when adjusted to the same liveweight. Our results indicated no difference in fat depth in the live animal or in the carcasses of steers from the L-H, M-H and H-H groups which, at the same age, attained similar final liveweight in Draft 1 despite the widely divergent growth paths followed by the different groups post-weaning. Carcass weight was slightly lower in the L-H compared with the H-H group in Draft 2 due to the short second dry season which restricted the period of feeding, but the results mirrored those of Draft 1. This finding is of considerable commercial relevance as it indicates that that there was no apparent penalty from restricting steer growth early, compared to fast growth throughout, when steers were killed later at a common weight and age. This provides further evidence of the benefits of exploiting compensatory growth at key times in the growth path in order to reduce input costs without sacrificing productivity.

Previous reviews (e.g., Preston 1975; Hunter 2010) have concluded that HGP use increases muscle deposition relative to fat so that HGP-treated cattle are generally leaner at any given LW than their non-implanted cohorts. Our results from live animal scans are consistent with this general conclusion although the effects were most noticeable, and statistically significant, when the steers were approaching mature size and weight. For instance, by the end of WS2 implanted steers had greater depth of eye-muscle in both drafts and lower fat cover at the P8 (Draft 1) or rib site (Draft 2) than non-treated steers. However, LW varied quite markedly between extreme treatments at this point and the extent to which these findings are a result of the HGP *per se* or the indirect effect of HGP increasing LW, needs further examination. Accordingly, the liveweight and scanned P8 fat depth data were plotted for the extreme treatments of L-nil and H-H in Draft 1, for different HGP treatments (Fig. 6). Either quadratic or linear functions were arbitrarily fitted to describe these relationships. They suggest that fat depth is lower for HGP-treated compared with untreated steers, that the effect increases as LW increases and that it is most pronounced for steers with a fast compared to a slow growth rate to finishing. Hunter (2010) attributed this effect partly to the delayed maturity of implanted cattle and the fact that at any given intermediate weight, implanted cattle were at a less mature stage of growth compared with non-implanted cattle and thus had a lower fat content in body composition. However, as indicated earlier, our results contradict this proposition suggesting instead that HGP use, at least in the longer term, hastens skeletal maturity.

Not surprisingly, the carcass data provided similar trends to those described above for live animal measurements but HGP effects were significant mainly for the H-plane group of treatments, perhaps because of the larger numbers of steers in the analysis (n = ~45 steers per HGP treatment) compared with the L-nil and L-leuc treatments (n = 15) which were assessed separately. Consistent with live animal assessments, carcasses from HGP-implanted steers in the H-plane treatments generally had lower AUS-MEAT-assessed P8- and MSA rib-fat depth, significantly so for both sites in Draft 1 and a trend in Draft 2 ($P = 0.08$) for the P8 site, and higher eye-muscle area in Draft 1 only relative to non-implanted steers. The lack of significant effects in the other 2 treatments, except that rib-fat depth was lower in implanted compared to untreated steers in the L-nil group of Draft 2 is, as indicated above, probably partly a product of the low animal numbers involved. Relative to the marbling scores reported by McKiernan *et al.* (2009) with *B. taurus* steers (average MSA USDA score 347), those in our study from *B. indicus* crossbred steers were low and were variably affected by HGP. Marbling was reduced in the H-plane steers with the use of HGP, either significantly in Draft 2 ($P < 0.01$) or as a trend in Draft 1 ($P = 0.07$ for USDA score), similar to the findings of Reiling and Johnson (2003) and Watson *et al.* (2008), but this result was reversed for the L-leuc steers in Draft 1 so that implanted steers displayed more marbling that untreated steers. Hunter (2010) concluded that the negative effects of HGP were most likely when trenbolone acetate was included in the implant, not just oestrogen, and that oestrogens were likely to have minimal effect on marbling. This is consistent with our results especially as the L-leuc steers did not receive the C-G implant, although with the H-plane steers it was implanted late in life and thus less likely to impact on marbling. The increase in marbling with HGP in L-leuc steers, which is not usually reported, may be a function of the heavier weights, more advanced maturity status and greater general fatness of implanted compared with untreated steers in this draft. These anomalies, whilst difficult to explain, are commercially important as marbling has a profound effect on MSA boning group score as determined using the MSA calculator (Anon. 2007). Further investigation is required to verify the effects seen on the 2 different pasture systems.

By far the greatest effect of HGP on carcass traits was the increased ossification scores of carcasses from implanted compared with non-implanted steers, consistent with other reports on skeletal maturity effects (Scheffler *et al.* 2003; Watson *et al.*

2008; Hunter 2010). The magnitude of this effect appeared related to the period of implantation so that for L-nil steers killed at about 42 mo of age, implanted steers had 88% higher ossification score than their non-implanted counterparts of the same chronological age. As ossification is used to estimate physiological maturity in cattle for MSA grading, these effects of HGP have serious implications in the final assessment of meat quality, as is discussed further below.

HGP had an acute effect on the MSA assessment, the Australian quality assurance scheme predicting meat quality of the final carcasses (Thompson 2002). The assigned boning group, as determined by skilled assessors combined with the use of the MSA calculator (Anon. 2007), increased by up to 4.7 units with the use of HGP and hardly any of the carcasses from HGP-implanted steers were allocated into boning groups 10 or less which secured a price premium from the abattoirs. The reasons for this were several fold. There is automatic penalty built into the MSA calculations of boning group for the use of HGP, recognising the adverse effect of HGP on meat eating quality (Thompson 2002; Watson *et al.* 2008), and boning group increases directly with ossification score and inversely with marbling score (Thompson 2002; Anon. 2007). Consequently, based on the results discussed above, HGP-implanted steers had very limited chance of achieving boning groups below the upper threshold of 10, especially those slaughtered at older ages, e.g., L-nil, due to the higher ossification scores coupled with the possibility of exclusion from MSA grading on the basis of excessive dentition (>4 permanent teeth). Nevertheless, the price differential in $/kg was very small between HGP treatments primarily because implanted steers, despite not receiving the MSA premium, often achieved a higher position on the price grid for the abattoir than their untreated counterparts due to their heavier carcass weights.

Conclusions

Our study has demonstrated that in the seasonally-dry environment of northern Australia provision of high-input supplements or specialised high quality forages to steers can reduce the post-weaning time to slaughter by at least 12 months, compared with conventional practice, and still produce carcasses suitable for the higher quality and higher value markets such as MSA. Furthermore, the cost of supplement inputs can be substantially reduced without impacting on carcass weight or quality by restricting high-input feeding to just one dry season post-weaning, rather than two, and exploiting compensatory growth to assist in meeting market targets. However, seasonal conditions with their high unpredictability impact in a major way on the outcomes of these nutritional interventionist practices, and the risks associated with making decisions on long-term feeding strategies a long time before marketing were highlighted in the variable results achieved in this study.

The detailed description of seasonal changes in height and body composition of *B. indicus*-derived steers in northern Australia, for up to 2.5 years post-weaning, has not previously been available but now provides an insight into the inefficiencies mediated by seasonal variability and also the opportunities for improvements by strategic nutritional inputs. One example is the possibility of exploiting increased height change during the dry season to enhance the compensatory growth effect on growth in the following wet season, without major inputs.

Although well researched and reviewed in the past (e.g., Hunter 2010) some effects of HGP in our study were not anticipated, especially with longer-term use. It was apparent though that HGP had an overarching effect on all aspects of production, from a positive effect on LW and HCW, a negative impact on fat cover and a variable effect on skeletal growth which interacted with these other factors. Where meat quality was measured by compliance of carcasses with MSA, HGP had a major negative effect as few carcasses from implanted steers graded below the MSA boning group threshold attracting a price premium. Nevertheless, the increased production attributable to HGP seemed to more than compensate for any reduction in price per unit weight. Until price more positively rewards meat quality HGP will remain one of the most cost-effective management practices available to northern cattle producers.

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References

Alway SE, Gonyea WJ, Davis ME (1990) Muscle fiber formation and fiber hypertrophy during the onset of stretch-overload. *American Journal of Physiology - Cell Physiology* **259**, C92-C102.

Anon. (2007) Meat Standards Australia. Available at http://www.msagrading.com.au [Verified March 2013]

Bagley CP, Morrison DG, Feazel JI, Saxton AM (1989) Growth and sexual characteristics of suckling beef calves as influenced by age at castration and growth implants. *Journal of Animal Science* **67**, 1258-1264.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005a) The northern Australian beef industry, a snapshot. 1. Regional enterprise activity and structure. *Australian Journal of Experimental Agriculture* **45**, 1057-1073.

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

Bowen MK, Buck SR, Gowen RL (2010) High-output forage systems for meeting beef markets – Phase 1. Final Report of Project B.NBP.0496 to Meat and Livestock Australia, Sydney.

Brody S, Ragsdale AC (1924) The rate of growth of the dairy cow. V. Extrauterine growth in linear dimension. *Journal of General Physiology* **6**, 329-336.

Cafe LM, Hearnshaw H, Hennessy DW, Greenwood PL (2006) Growth and carcass characteristics of Wagu-sired steers at heavy market weights following slow or rapid growth to weaning. *Australian Journal of Experimental Agriculture* **46**, 951-955.

Cafe LM, Hennessy DW, Hearnshaw H, Morris SG, Greenwood PL (2009) Consequences of prenatal and preweaning growth for feedlot growth, intake and efficiency of Piedmontese- and Wagu-sired cattle. *Animal Production Science* **49**, 461-467.

Coates DB (2004) Faecal NIRS - technology for improving nutritional management of grazing cattle. Final Report of Project NAP3.121. Meat and Livestock Australia, Sydney.

Coates DB, Dixon RM (2008) Faecal near infrared reflectance spectroscopy estimates of diet quality and responses to nitrogen supplements by cattle grazing *Bothriochloa pertusa* pastures. *Australian Journal of Experimental Agriculture* **48**, 829-834.

CSIRO (2007) 'Nutrient requirements of domesticated ruminants.' (CSIRO Publishing: Melbourne, Australia)

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.

Dixon RM, Coates DB (2008) Diet quality and liveweight gain of steers grazing *Leucaena*-grass pasture estimated with faecal near infrared reflectance spectroscopy (F.NIRS). *Australian Journal of Experimental Agriculture* **48**, 835-842.

English BH, Shaw KA, Matthews RA, Rolfe JW, Kernot JC (2009) Pasture-fed beef from tropical pasture systems. *Tropical Grasslands* **43**, 253-254.

Field RA, Maiorano G, Hinds FC, Murdoch WJ, Riley ML (1990) Bone ossification and carcass characteristics of wethers given silastic implants containing estradiol. *Journal of Animal Science* **68**, 3663-3668.

Fordyce G, Coates R, Debney M, Haselton S, Rebgetz R, Laing AR, Cooper NJ, Hall R, Holmes WE, Doogan V (2009) A systems evaluation of high-input management using fortified molasses for beef production in Australia's dry tropics. *Animal Production Science* **49**, 177-191.

GenStat (2011) 'GenStat for Windows, Release 14.1.' (VSN International Ltd: Oxford)

Graham JF, Byron J, Clark AJ, Kearney G, Orchard B (2009) Effect of postweaning growth and bulls selected for extremes in retail beef yield and intramuscular fat on progeny liveweight and carcass traits. *Animal Production Science* **49**, 493-503.

Greenwood PL, Cafe LM (2007) Prenatal and pre-weaning growth and nutrition of cattle: long-term consequences for beef production. *Animal* **1**, 1283-1296.

Greenwood PL, Cafe LM, Hearnshaw H, Hennessy DW, Thompson JM, Morris SG (2006) Long-term consequences of birth weight and growth to weaning on carcass, yield and beef quality characteristics of Piedmontese- and Wagu-sired cattle. *Australian Journal of Experimental Agriculture* **46**, 257-269.

Holly RG, Barnett JG, Ashmore CR, Taylor RG, Mole PA (1980) Stretch-induced growth in chicken wing muscles: a new model of stretch hypertrophy. *American Journal of Physiology* **238**, C62-C71.

Hunter RA (2010) Hormonal growth promotant use in the Australian beef industry. *Animal Production Science* **50**, 637-659.

Hunter RA, Burrow HM, McCrabb GJ (2001) Sustained growth promotion, carcass and meat quality of steers slaughtered at three liveweights. *Australian Journal of Experimental Agriculture* **41**, 1033-1040.

Hunter RA, Magner T, Allingham PG (2000) Sustained growth promotion, carcass characteristics, and meat quality of steers treated with oestradiol-17B. *Australian Journal of Agricultural Research* **51**, 133-138.

Hutcheson JP, Greene LW, Carstens GE, Byers FM (1992) Effects of zeranol and two dietary levels of calcium and phosphorus on performance, carcass and bone characteristics, and calcium status in growing lambs. *Journal of Animal Science* **70**, 1346-1351.

Klieve AV, Ouwerkerk D, Turner A, Roberton R (2002) The production and storage of a fermentor-grown bacterial culture containing *Synergistes jonesii*, for protecting cattle against mimosine and 3-hydroxy-4(1H)-pyridone toxicity from feeding on *Leucaena leucocephala*. *Australian Journal of Agricultural Research* **53**, 1-5.

Lindsay JA, Dyer RM, Gelling BA, Laing AR (1996) Finishing *Bos indicus* crossbred cattle on northern speargrass pastures using molasses or grain based supplements. *Proceedings of the Australian Society of Animal Production* **21**, 89-91.

Lindsay JA, Cooper NJ, Batterham I. (1998) A molasses based production feeding system for Brahman cattle. *Animal Production in Australia* **22**, 119-121.

Loy DD, Harpster HW, Cash EH (1988) Rate, composition and efficiency of growth in feedlot steers reimplanted with growth stimulants. *Journal of Animal Science* **66**, 2668-2677.

Mason GW, Blight GW, Rudder TH (1984) Effects of frequency of zeranol implantation on liveweight gain of steers grazing improved pastures in central Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **24**, 460-463.

Matthews RA, Fordyce G, Poppi DP (2008) Nutritional management of skeletal bone growth in cattle in the dry tropics. *Proceedings of the Australian Society of Animal Production* **27**, 57.

McCown RL (1980-81) The climatic potential for beef cattle production in tropical Australia: Part 1 – simulating the annual cycle of liveweight change. *Agricultural Systems* **6**, 303-317.

McIntyre BL, Tudor GD, Read D, Smart W, Della Bosca TJ, Speijers EJ, Orchard B (2009) Effect of growth path, sire type, calving time and sex on growth and carcass characteristics of beef cattle in the agricultural area of Western Australia. *Animal Production Science* **49**, 514-514.

McLennan SR, Dunster, PJ, O'Rourke PK, Murphy GM (1981) Comparison of dry season urea supplements containing salt, sulfur or molasses for steers grazing native pasture in the dry tropics of northern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **21**, 457-463.

McLennan SR, Hirst DJ, Shepherd RK, McGuigan KR (1991) A comparison of various methods of feeding supplements of urea, sulfur and molasses to weaner heifers during the dry season in northern Queensland. *Australian Journal of Experimental Agriculture* **31**, 153-158.

McLennan SR, Campbell J, Poppi DP, Dawson K, Kidd JF (2013) Effect of stage of maturity of cattle on responses to supplements fed with low quality forages. In 'Optimising the growth paths of cattle for increased profitability'. Project B.NBP.0391 Final Report to Meat and Livestock Australia (this report, in preparation)

McKiernan WA, Wilkins JF, Irwin J, Orchard B, Barwick SA (2009) Performance of steer progeny of sires differing in genetic potential for fatness and meat yield following post-weaning growth at different rates. 2. Carcass traits. *Animal Production Science* **49**, 525-534.

Nilsson O, Marino R, De Luca F, Phillip M, Baron J (2005) Endocrine regulation of the growth plate. *Hormone Research* **64**, 157-165.

Peralta JM, Arnold AM, Currie WB, Thonney ML (1994) Effects of testosterone on skeletal growth in lambs as assessed by labelling index of chondrocytes in metacarpal bone growth plate. *Journal of Animal Science* **72**, 2629-2634.

Preston RL (1975) Biological responses to estrogen additives in meat producing cattle and lambs. *Journal of Animal Science* **41**, 1414-1430.

Preston RL (1978) Possible role of DES on mature size of steers. *Journal of Animal Science* **47 (Suppl. 1)**, 436.

Quirk MF, Paton CJ, Bushell JJ (1990) Increasing the amount of leucaena on offer gives faster growth rates of grazing cattle in South East Queensland. *Australian Journal of Experimental Agriculture* **30**, 51-54.

Reiling BA, Johnson DD (2003) Effects of implant regimens (trenbolone acetate-estradiol administered alone or in combination with zeranol) and vitamin D3 on fresh beef color and quality. *Journal of Animal Science* **81**, 135-142.

Robinson DL, Oddy VH, Dicker RW, McPhee MJ (2001) Post-weaning growth of cattle in northern New South Wales 3. Carry-over effects on finishing, carcass characteristics and intramuscular fat. *Australian Journal of Experimental Agriculture* **41**, 1041-1049.

Ryan WJ (1990) Compensatory growth in sheep and cattle. *Nutrition Abstracts and Reviews* **60**, 653-664.

Scheffler JM, Buskirk DD, Rust SR, Cowley JD, Doumit ME (2003) Effect of repeated administration of combination trenbolone acetate and estradiol implants on growth, carcass traits, and beef quality of long-fed Holstein steers. *Journal of Animal Science* **81**, 2395-2400.

Schlegel ML, Bergen WG, Schroeder AL, VandeHaar MJ, Rust SR (2006) Use of bovine somatotropin for increased skeletal and lean tissue growth of Holstein steers. *Journal of Animal Science* **84**, 1176-1187.

Thompson J (2002) Managing meat tenderness. *Meat Science* **62**, 295-308.

Tudor GD, James T, Hunter RA (1992) Seasonal growth and carcass characteristics of grazing steers implanted with trenbolone acetate and oestradiol. *Australian Journal of Experimental Agriculture* **32**, 687-687.

Watson R, Polkinhorne R, Gee A, Porter M, Thompson JM, Ferguson D, Pethick D, McIntyre B (2008) Effect of hormonal growth promotants on palatability and carcass traits of various muscles from steer and heifer carcasses from a *Bos indicus Bos taurus* composite cross. *Australian Journal of Experimental Agriculture* **48**, 1415-1424.

Wilkins JF, McKiernan WA, Irwin J, Orchard B, Barwick SA (2009) Performance of steer progeny of sires differing in genetic potential for fatness and meat yield following post-weaning growth at different rates. 1. Growth and live-animal composition. *Animal Production Science* **49**, 515-524.

Winks L (1984) ‘Cattle growth in the dry tropics of Australia’. (Australian Meat Research Committee Review no. 45)

Winks L, Laing AR, O’Rourke PK, Wright GS (1979) Factors affecting response to urea-molasses supplements by yearling cattle in tropical Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**, 522-529.

Winks L, Laing AR, Wright GS, Stokoe J (1976) Effect of nitrogen, phosphorus and molasses supplements on the performance of weaner cattle during the dry season in north Queensland. *Journal of the Australian Institute of Agricultural Science* **42**, 246-251.

Table 1. Composition and intake (as fed) of supplements during the dry seasons

DS, dry season; US, salt-urea-sulphur dry lick; MUP, molasses with added urea and protein meal; treatments described in the text

Draft (dry season/year)	Treatment	Supplement	Days	Average intake (g/day)	Supplement composition (g/kg, air dry)								
					Molasses	Urea	Copra meal	Salt	DCP	Gran-am[A]	Kynafos[A]	PKE [A]	Rumensin® 100
Draft 1 (DS1; 2008)	L-nil	US	115	67		299		469		60	120	50	3.0
	L-leuc[B]	US		84									
	L-H[B]	US		88									
	M-H	MUP[C]		2,234	888	56	38	9	9				0.4
	H-H	MUP		3,904	869	26	87	9	9				0.4
Draft 1 (DS2; 2009)	L-H	MUP	184	6,008	869	26	87	9	9				0.4
	M-H[B]	MUP		5,412									
	H-H[B]	MUP		5,326									
Draft 2 (DS1; 2009)	L-nil	US	184	81		300		467		60	120	50	3.0
	L-leuc[B]	US		76									
	L-H[B]	US		71									
	M-H	MUP		2,349	887	39	56	9	9				0.4
	H-H	MUP		3,802	869	26	87	9	9				0.4
Draft 2 (DS2; 2010)	L-H	MUP	88	1,851	869	26	87	9	9				0.4
	M-H[B]	MUP		1,722									
	H-H[B]	MUP		1,779									

[A] Gran-am, ammonium sulphate; Kynafos, mono-calcium phosphate and di-calcium phosphate di-hydrate; PKE, palm kernel expeller meal.

[B] Same supplement composition as group above

[C] 76.11%DM, on average.

Table 2. *Draft 1*: effects of growth path (GP) and hormonal growth promotant (HGP) treatment on steer liveweight performance
LW, liveweight; ADG, average daily gain; DS, dry season; WS, wet season; Leuc, leucaena phase; Nil, no HGP implanted; +H, Compudose implants administered; *, ** and ***, *P*<0.05, *P*<0.01 and *P*<0.001; ns, not significant; sem, standard error of mean

		Growth path (GP)						HGP			*P*-value		
		L-nil	L-leuc	L-H	M-H	H-H	sem	Nil	+H	sem	GP	HGP	GP.HGP
LW (kg)	start	207.6	208.2	208.8	209.2	207.9	4.10	208.4	208.2	2.59	ns	ns	ns
	end DS1	235.3a	236.9a	238.5a	268.7b	284.0c	4.83	250.5	254.9	3.05	***	ns	ns
	end WS1	328.2a	333.3ab	334.0ab	347.7bc	354.1c	5.68	334.5	344.4	3.59	**	0.05	ns
	end DS2	328.9a		431.7b	438.6b	439.2b	6.79	398.7a	420.5b	4.80	***	**	ns
	end WS2	463.6a		527.3b	535.1b	537.5b	7.49	504.4a	527.4b	5.29	***	**	ns
	end Leuc		532.4				8.68	510.5a	554.3b	12.28		*	
	end DS3	456.3					6.01	443.8a	468.9b	8.50		*	
	end WS3	604.0					8.66	599.5	608.6	12.25		ns	
ADG (kg)	DS1 [120 days] [A]	0.23a	0.24a	0.25a	0.50b	0.63c	0.033	0.35a	0.39b	0.016	***	**	ns
	WS1 [197 days]	0.47a	0.49a	0.48a	0.40b	0.36c	0.023	0.43a	0.45b	0.012	**	*	ns
	Year 1 (DS1+WS1)	0.38a	0.39a	0.39a	0.44b	0.46b	0.014	0.40a	0.43b	0.008	*	***	ns
	DS2 [190 days]	0.0a		0.51b	0.48bc	0.45c	0.022	0.33a	0.39b	0.015	***	**	ns
	WS2 [139 days]	0.96a		0.69b	0.69b	0.71b	0.039	0.76	0.77	0.023	**	ns	ns
	Year 2 (DS2+WS2)	0.41a		0.59b	0.57b	0.56b	0.014	0.51a	0.55b	0.010	***	*	ns
	Years 1+ 2	0.40a		0.49b	0.50b	0.51b	0.010	0.46a	0.49b	0.007	***	***	ns
	DS3 [132 days]	-0.06					0.019	-0.05	-0.07	0.027		ns	
	WS3 [258 days]	0.57					0.017	0.60	0.54	0.024		0.08	
	Year 3 (DS3+WS3)	0.36					0.012	0.38a	0.34b	0.016		*	
	Years 1+2+3	0.38					0.007	0.38	0.39	0.010		ns	
	Leuc - BP only [B] [242 days]		0.82				0.019	0.74a	0.90b	0.026		***	
	Leuc total (DS1+WS1+BP) [B]		0.58				0.014	0.54a	0.62b	0.017		***	

[A] Duration of each season

[B] The leucaena phase at Brian Pastures (BP) is shown for the period at BP only and for the total period from the start of the trial (DS1+WS1+BP)

Table 3. *Draft 1*: effects of growth path (GP) and hormonal growth promotant (HGP) treatment on steer height measurements

DS, dry season; WS, wet season; Leuc, leucaena phase; Nil, no HGP implanted; +H, Compudose implants administered; LW, liveweight; *, ** and ***, $P<0.05$, $P<0.01$ and $P<0.001$; ns, not significant; sem, standard error of mean

		Growth path (GP)						HGP			*P*-value		
		L-nil	L-leuc	L-H	M-H	H-H	sem	Nil	+H	sem	GP	HGP	GP.HGP
Height (mm)	start	1208	1209	1197	1202	1191	7.41	1203	1200	4.68	ns	ns	ns
	end DS1	1250	1257	1249	1267	1266	7.15	1255	1260	4.53	ns	ns	ns
	end WS1	1316	1318	1308	1325	1323	7.09	1316	1320	4.49	ns	ns	ns
	end DS2	1367		1385	1386	1384	9.58	1385	1376	6.38	ns	ns	ns
	end WS2	1404		1419	1423	1419	8.12	1421	1411	5.74	ns	ns	ns
	end Leuc		1431				8.0	1425	1437	11.33		ns	
	end DS3	1406					8.20	1414	1398	11.55		ns	
	end WS3	1438					8.0	1458a	1419b	11.37		*	
Height change (mm)	DS1 [A]	42.2a	48.0a	51.3ab	65.0bc	74.8c	5.46	52.9	59.6	3.27	*	ns	ns
	WS1	66.0	61.0	59.3	58.7	59.3	4.54	60.7	60.3	2.74	ns	ns	*[A]
	Year 1 (DS1+WS1)	108.2a	109.0ab	110.7ab	123.7bc	132.2c	5.52	113.6	119.9	3.49	**	ns	ns
	DS2	51.0a		76.8b	60.3a	60.3a	4.99	68.6a	55.7b	3.53	*	*	ns
	WS2	37.6		33.8	37.7	35.7	4.48	36.6	35.8	3.17	ns	ns	ns
	Year 2 (DS2 + WS2)	88.7a		110.6b	98.0a	96.0a	4.49	105.1a	91.5b	3.17	**	**	ns
	Years 1+ 2	195.6a		223.2b	221.7b	228.2b	7.22	219.8	214.5	5.10	**	ns	ns
	DS3	2.1					4.90	5.0	-0.7	6.48		ns	
	WS3	32.7					4.65	44.0a	21.4b	6.57		*	
	Year 3 (DS3+WS3)	34.8					5.29	49.0a	20.5b	6.57		***	
	Years 1+2+3	230.5					5.59	244.7a	216.4b	7.90		*	
	Leuc BP		112.7				9.75	108.0	117.3	13.80		ns	
	Leuc total (DS1+WS1+BP)		221.7				10.72	221.3	222.0	15.17		ns	
LW/height ratio (kg/cm)	start	1.72	1.72	1.74	1.74	1.74	0.029	1.73	1.73	0.018	ns	ns	ns
	end DS1	1.88a	1.88a	1.91a	2.12b	2.24b	0.032	1.99	2.02	0.020	***	ns	ns
	end WS1	2.49a	2.53ab	2.55ab	2.62bc	2.68c	0.037	2.54a	2.61b	0.023	**	*	ns
	end DS2	2.41a		3.11b	3.16b	3.17b	0.043	2.88a	3.05b	0.030	***	***	ns
	end WS2	3.30a		3.71b	3.76b	3.79b	0.047	3.55a	3.73b	0.033	***	***	ns
	end DS3	3.25					0.039	3.14a	3.35b	0.055		*	
	end WS3	4.20					0.051	4.11	4.29	0.071		0.09	
	end Leuc BP		3.72				0.060	3.59a	3.86b	0.085		*	

[A] See Table 2 for description of periods and duration of seasons

[B] Interaction not shown

Table 4. Draft 1: effects of growth path (GP) and hormonal growth promotant (HGP) treatment on steer body condition score (BCS; 1-9 scale), and the depths of rib fat and P8 fat and the depth of eye-muscle

DS, dry season; WS, wet season; Leuc, L-leuc treatment; BP, Brian Pastures grazing phase; *, ** and ***, *P*<0.05, *P*<0.01 and *P*<0.001; ns, not significant; se, standard error of mean

		Growth path (GP)						HGP			*P*-value		
		L-nil	L-leuc	L-H	M-H	H-H	se	Nil	+H	se	GP	HGP	GP.HGP
BCS	start	5.8a	5.8a	5.7ab	5.4b	5.7a	0.086	5.7	5.7	0.054	ns	*	ns
	end DS1[A]	4.7a	4.8a	4.8a	5.9b	6.7c	0.105	5.5	5.3	0.066	***	0.09	ns
	end WS1	6.0	6.1	6.0	6.0	6.2	0.122	6.1	6.0	0.070	ns	ns	ns
	end DS2	5.4a		7.5b	7.4b	7.4b	0.112	6.9	6.9	0.079	***	ns	ns
	end WS2	7.6a		8.1b	8.0b	8.1b	0.088	7.9	8.0	0.056	*	ns	*[B]
	end Leuc[C]		7.9				0.064	7.9	7.9	0.091		ns	
	end DS3	7.2					0.054	7.2	7.2	0.077		ns	
	end WS3	7.9					0.063	7.9	7.9	0.078		ns	
Rib fat depth (mm)	start	1.2	1.2	1.0	1.2	1.3	0.070	1.2	1.1	0.044	ns	ns	ns
	end DS1	1.6a	1.6a	1.7a	2.2b	2.4b	0.115	1.9	1.9	0.068	**	ns	ns
	end WS1	2.5	2.5	2.5	2.4	2.6	0.149	2.4	2.6	0.094	ns	ns	ns
	end DS2	1.4a		4.2b	4.4b	4.2b	0.314	3.5	3.5	0.222	***	ns	ns
	end WS2	4.5a		5.8b	6.1b	5.7b	0.412	5.8	5.3	0.291	*	ns	ns
	end Leuc		7.9				0.626	7.3	8.5	0.885		ns	
	end DS3	3.0					0.217	2.9	3.1	0.306		ns	
	end WS3	4.9					0.422	4.7	5.1	0.596		ns	
P8 fat depth (mm)	start	1.6a	1.5ab	1.2b	1.5ab	1.8a	0.143	1.6	1.5	0.090	*	ns	ns
	end DS1	1.3a	1.2a	1.5a	2.6b	3.5c	0.203	2.2	1.9	0.129	***	0.09	ns
	end WS1	3.9	4.4	4.3	4.3	5.3	0.422	4.4	4.4	0.267	ns	ns	ns
	end DS2	2.3a		8.9b	8.6b	9.5b	0.585	7.1	7.5	0.391	***	ns	ns
	end WS2	8.4a		11.2b	10.4b	11.7b	0.670	11.2a	9.7b	0.474	**	*	ns
	end Leuc		14.1				0.694	13.9	14.4	0.906		ns	
	end DS3	5.7					0.611	5.3	6.1	0.702		ns	
	end WS3	10.3					0.611	10.9	9.8	0.853		ns	
Eye-muscle depth (mm)	start	43.7	42.6	42.5	41.8	42.2	1.075	42.7	42.4	0.680	ns	ns	ns
	end DS1	49.8a	47.6a	49.0a	54.3b	57.2b	1.247	51.4	51.7	0.685	***	ns	ns
	end WS1	50.5	52.2	52.7	52.5	53.0	0.566	52.0	52.4	0.566	ns	ns	ns
	end DS2	46.3a		57.7b	56.0b	55.8b	0.883	53.3	54.7	0.624	***	ns	ns
	end WS2	59.7a		65.5b	65.6b	63.3b	1.015	61.8a	65.2b	0.700	*	***	ns

	Growth path (GP)						HGP			*P*-value		
	L-nil	L-leuc	L-H	M-H	H-H	se	Nil	+H	se	GP	HGP	GP.HGP
end Leuc		70.0				1.008	68.5	71.4	1.425		ns	
end DS3	52.8					0.708	51.7	53.9	1.001		ns	
end WS3	67.8					1.515	67.7	67.9	2.088		ns	

[A] See Table 2 for description of periods and duration of seasons

[B] Interaction not shown

[C] End of period on leucaena at Brian Pastures

Table 5. Draft 2: effects of growth path (GP) and hormonal growth promotant (HGP) treatment on steer liveweight performance

LW, liveweight; ADG, average daily gain; DS, dry season; WS, wet season; Leuc, leucaena phase; Nil, no HGP implanted; +H, Compudose implants administered; *, ** and ***, $P<0.05$, $P<0.01$ and $P<0.001$; ns, not significant; se, standard error of mean

		Growth path (GP)						HGP			*P*-value		
		L-nil	L-leuc	L-H	M-H	H-H	se	Nil	+H	se	GP	HGP	GP.HGP
LW (kg)	start	209.2	208.7	208.5	208.9	208.8	3.34	208.7	208.9	2.11	ns	ns	ns
	end DS1	200.2a	200.8a	198.4a	258.1b	283.8c	3.79	226.6	229.9	2.40	***	ns	ns
	end WS1	341.3a	343.9a	339.0a	377.8b	395.1b	6.55	353.2a	365.7b	3.60	***	**	ns
	end DS2	373.7a		395.9ab	417.4bc	439.1c	10.74	398.7a	414.3b	5.94	*	**	ns
	end WS2	541.0a		549.6a	573.5b	584.7b	7.94	547.7a	576.7b	5.20	*	***	ns
	end Leuc		550.7				7.66	523.8a	577.6b	10.83		**	
	end DS3	538.7					4.07	520.3a	557.1b	5.75		***	
	end WS3	665.0					6.25	646.0a	684.0b	8.83		**	
ADG (kg)	DS1 [197 days] [A]	-0.05a	-0.04a	-0.05a	0.25b	0.38c	0.017	0.09	0.11	0.010	***	ns	ns
	WS1 [151 days]	0.94a	0.95a	0.93a	0.79b	0.74b	0.030	0.84a	0.90b	0.016	***	***	ns
	Year 1 (DS1+WS1)	0.38a	0.39a	0.38a	0.49b	0.54b	0.019	0.42a	0.45b	0.009	***	***	ns
	DS2 [119 days]	0.27		0.48	0.33	0.37	0.058	0.35	0.38	0.031	ns	ns	ns
	WS2 [245 days]	0.68		0.63	0.64	0.59	0.032	0.61a	0.66b	0.018	ns	**	ns
	Year 2 (DS2 + WS2)	0.55		0.58	0.54	0.52	0.015	0.52a	0.57b	0.010	ns	***	ns
	Years 1+ 2	0.47a		0.48a	0.51b	0.53b	0.011	0.48a	0.52b	0.007	*	***	ns
	DS3 [148 days]	-0.02					0.018	0.04a	-0.07b	0.026		**	
	WS3 [208 days]	0.60					0.028	0.60	0.60	0.031		ns	
	Year 3 (DS3+WS3)	0.35					0.017	0.37a	0.33b	0.019		*	
	Years 1+2+3	0.43					0.005	0.41a	0.45b	0.007		***	
	Leuc BP [260 days]		0.79				0.021	0.71a	0.87b	0.029		***	
	Leuc total (DS1+WS1+BP)		0.56				0.011	0.52a	0.61b	0.015		***	

[A] See Table 2 for a description of the periods; duration of each season

Table 6. Draft 2: effects of growth path (GP) and hormonal growth promotant (HGP) treatment on steer height measurements
DS, dry season; WS, wet season; Leuc, leucaena phase; Nil, no HGP implanted; +H, Compudose implants administered; LW, liveweight; *, ** and ***, $P<0.05$, $P<0.01$ and $P<0.001$; ns, not significant; se, standard error of mean

		Growth path (GP)						HGP			*P*-value		
		L-nil	L-leuc	L-H	M-H	H-H	se	Nil	+H	se	GP	HGP	GP.HGP
Height (mm)	start	1116	1113	1123	1122	1110	6.35	1114	1119	4.02	ns	ns	ns
	end DS1	1192a	1185a	1195a	1229b	1232b	7.03	1203	1210	4.45	***	ns	ns
	end WS1	1276a	1269a	1273a	1310b	1319b	7.47	1288	1290	4.70	**	ns	ns
	end DS2	1318		1325	1368	1357	13.72	1347	1337	9.05	0.09	ns	ns
	end WS2	1390a		1401a	1436b	1415ab	11.10	1425a	1396b	7.85	*	**	ns
	end Leuc		1385				8.40	1387	1383	11.26		ns	
	end DS3	1428					6.50	1433	1422	9.18		ns	
	end WS3	1454					6.30	1477a	1430b	8.89		***	
Height change (mm)	DS1 [A]	76.5a	72.0a	72.3a	107.6b	122.3c	4.81	89.1	91.2	3.04	***	ns	ns
	WS1	83.8	83.7	77.7	80.6	86.3	5.65	85.4	79.5	3.39	ns	ns	ns
	Year 1 (DS1+WS1)	160.3a	155.7a	150.0a	186.6b	208.7c	5.43	173.9	170.7	3.31	***	ns	ns
	DS2	42.2		52.0	58.7	38.7	13.02	53.1	42.6	8.31	ns	ns	ns
	WS2	72.3		76.3	68.2	57.2	7.45	78.3a	58.8b	4.49	ns	***	ns
	Year 2 (DS2 + WS2)	114.5ab		128.3a	126.8a	95.2b	9.17	131.5a	100.9b	6.48	*	***	ns
	Years 1+ 2	274.8a		278.3a	298.2b	304.7b	5.91	301.8a	276.3b	4.18	***	***	ns
	DS3	37.3					4.34	40.0	34.7	6.14		ns	
	WS3	27.7					4.63	44.0a	11.4b	6.54		**	
	Year 3 (DS3+WS3)	65.4					5.00	84.0a	46.8b	7.07		***	
	Years 1+2+3	338.2					6.17	365.0a	311.4b	8.72		***	
	Leuc BP		114.5				5.27	116.9	112.0	6.54		ns	
	Leuc total (DS1+WS1+BP)		269.8				5.16	274.9	264.7	6.49		ns	
LW/height ratio (kg/cm)	start	1.87	1.87	1.86	1.86	1.88	0.024	1.87	1.87	0.015	ns	ns	ns
	end DS1	1.68a	1.69a	1.66a	2.10b	2.30c	0.028	1.88	1.89	0.017	***	ns	ns
	end WS1	2.67a	2.71a	2.66a	2.88b	3.00c	0.039	2.74a	2.83b	0.022	***	***	ns
	end DS2	2.84		2.99	3.06	3.23	0.084	2.97a	3.10b	0.046	0.06	***	ns
	end WS2	3.89a		3.92a	4.00a	4.13b	0.045	3.84a	4.13b	0.030	*	***	ns
	end Leuc BP		3.98				0.045	3.78a	4.17b	0.063		***	
	end DS3	3.78					0.030	3.63a	3.92b	0.042		***	
	end WS3	4.58					0.053	4.37a	4.78b	0.064		***	

[A] See Table 5 for description of periods and duration of seasons

Table 7. Draft 2: effects of growth path (GP) and hormonal growth promotant (HGP) treatment on steer body condition score (BCS; 1-9 scale), and the depths of rib fat and P8 fat and the depth of eye-muscle

DS, dry season; WS, wet season; Leuc, L-leuc treatment; BP, Brian Pastures grazing phase; *, ** and ***, *P*<0.05, *P*<0.01 and *P*<0.001; ns, not significant; se, standard error of mean

		Growth path (GP)						HGP			*P*-value		
		L-nil	L-leuc	L-H	M-H	H-H	se	Nil	+H	se	GP	HGP	GP.HGP
BCS	start	6.2	6.1	6.2	6.2	6.3	0.104	6.3a	6.1b	0.066	ns	*	ns
	end DS1 [A]	4.7a	4.9a	4.6a	6.2b	6.9c	0.105	5.5	5.4	0.066	***	ns	ns
	end WS1	6.6	6.8	6.7	6.8	6.9	0.095	6.8	6.7	0.052	ns	ns	ns
	end DS2	6.8		7.4	7.2	7.5	0.156	7.2	7.2	0.086	0.09	ns	ns
	end WS2	7.7		7.8	7.8	7.9	0.058	7.7	7.8	0.041	ns	ns	ns
	end Leuc [B]		8.0				0.033	8.1	8.0	0.047		ns	
	end DS3	6.5					0.090	6.6	6.4	0.128		ns	
	end WS3	7.7					0.064	7.7	7.7	0.091		ns	
Rib fat depth (mm)	start	2.1	2.3	1.9	2.1	2.2	0.190	2.3	2.0	0.119	ns	ns	ns
	end DS1	1.0a	1.0a	1.0a	1.3b	1.9c	0.082	1.2	1.3	0.052	***	ns	ns
	end WS1	2.3a	2.3a	2.2a	2.3a	3.1b	0.161	2.5	2.4	0.102	**	ns	ns
	end DS2	2.2a		2.9b	2.7ab	3.5c	0.203	2.8	2.8	0.144	***	ns	ns
	end WS2	4.2		4.1	4.4	4.9	0.430	4.9a	3.9b	0.279	ns	*	ns
	end Leuc		6.9				0.374	7.7	6.2	0.528	ns	0.06	ns
	end DS3	3.4					0.410	3.7	3.0	0.511	ns	ns	ns
	end WS3	5.4					0.642	6.2	4.5	0.780	ns	0.07	ns
P8 fat depth (mm)	start	3.1	2.6	3.0	2.8	3.2	0.390	3.1	2.8	0.223	ns	ns	ns
	end DS1	1.1a	1.1a	1.1a	1.6b	2.8c	0.143	1.5	1.6	0.090	***	ns	ns
	end WS1	4.0	3.6	3.6	3.9	4.3	0.253	3.8	3.9	0.160	ns	ns	ns
	end DS2	4.4		5.8	5.4	5.6	0.547	5.2	5.4	0.330	ns	ns	ns
	end WS2	9.5		9.3	9.4	8.7	0.749	9.8	8.6	0.489	ns	0.07	ns
	end Leuc		11.3				0.557	11.8	10.8	0.788	ns	ns	ns
	end DS3	6.5					0.500	6.7	6.3	0.708	ns	ns	ns
	end WS3	12.1					1.153	12.7	11.6	1.412	ns	ns	ns
Eye-muscle depth (mm)	start	46.3	45.2	44.2	45.0	45.8	1.017	46.0	44.6	0.643	ns	ns	ns
	end DS1	33.0a	33.3a	30.9a	39.8b	44.3c	0.901	36.5	36.0	0.554	***	ns	ns
	end WS1	52.2a	53.0ab	51.3a	54.8bc	56.0c	0.901	53.3	53.6	0.570	**	ns	ns
	end DS2	47.8		50.5	51.2	53.7	1.253	50.4	51.2	0.784	0.06	ns	ns
	end WS2	62.3		62.8	63.4	64.5	0.998	62.1a	64.5b	0.706	ns	*	ns

	Growth path (GP)						HGP			*P*-value		
	L-nil	L-leuc	L-H	M-H	H-H	se	Nil	+H	se	GP	HGP	GP.HGP
end Leuc		67.6				1.389	65.1a	70.1b	1.654	ns	*	ns
end DS3	58.0					1.471	55.7	60.3	2.080	ns	ns	ns
end WS3	67.3					0.785	66.0	68.6	1.109	ns	ns	ns

[A] See Table 2 for description of periods and Table 5 for duration of seasons

[B] End of period on leucaena at Brian Pastures

Table 8. Effects of hormonal growth promotant (HGP) treatment on carcass traits at slaughter and on Meat Standards Australia (MSA) chiller-assessed traits for steers following various growth paths

Data are pooled for treatments L-H, M-H and H-H (H-plane groups) which were slaughtered together and for which growth path treatment differences were mainly non-significant (*P*>0.05); exceptions are discussed in the text. Groups L-nil and L-leuc were slaughtered at different times and ages of steers so comparisons across slaughter times are not valid. There were no significant growth path treatments x HGP interactions throughout. Nil, no HGP; +H, Compudose HGP implanted; *, ** and ***, *P*<0.05, *P*<0.01 and *P*<0.001; ns, not significant; se, standard error of mean

	L-nil				L-leuc				H-plane groups (L-H, M-H, H-H)			
	Nil	+H	se	*P*	Nil	+H	se	*P*	Nil	+H	se	*P*
Draft 1												
Permanent teeth [A]	6.0	6.1	0.27	ns	2.4	1.9	0.27	ns	3.7	3.7	0.20	ns
Hot standard carcass weight (kg)	314.7	318.9	6.36	ns	266.1	287.4	7.60	*	278.5	290.9	3.27	**
Dressing percentage	52.3	52.4	0.33	ns	52.1	51.8	0.64	ns	52.8	53.6	0.28	0.06
P8 fat depth (mm)	11.8	11.5	1.10	ns	13.4	14.3	1.14	ns	11.9	9.9	0.54	*
Price/kg carcass ($/kg)	2.78	2.78	0.016	ns	3.13 [B]	3.19	0.018	*	2.89	2.86	0.011	*
MSA un-grades (%)					6.7	6.7			17.8	15.6		
MSA boning group [C]	[D]				11.1	13.5	0.30	***	9.5	12.7	0.25	***
MSA boning group ≤10 (%) [CE]					38	0			82	0		
MSA rib fat depth (mm)					7.1	6.7	0.54	ns	8.4	6.9	0.44	*
MSA eye-muscle area (cm^2)					75.4	78.7	1.75	ns	68.6	70.9	0.72	*
Hump height (mm)					134.3	146.3	6.50	ns	158.4	167.5	4.33	ns
Ossification score					162	193	4.2	***	173	214	8.5	***
MSA AUS marbling score [F]					0.00	0.26	0.084	*	0.80	0.70	0.125	ns
MSA USDA marble score [F]					197	242	13.0	*	317	283	13.1	0.07
Meat colour score					2.20	1.47	0.155	***	1.55	1.93	0.132	*
Fat colour score					1.80	1.92	0.114	ns	1.14	1.50	0.101	**
Loin temperature (°C)					6.58	6.93	0.272	ns	9.55	9.43	0.091	ns
Carcass pH					5.56	5.47	0.053	**	5.55	5.58	0.015	ns
Draft 2												
Permanent teeth	4.7	4.6	0.32	ns	1.6	2.1	0.15	*	2.5	2.7	0.14	ns
Hot carcass weight (kg)	323.4	346.8	5.25	**	270.9	301.3	5.92	***	289.2	301.8	3.27	**
Dressing percentage	50.1	50.7	0.48	ns	51.8	52.5	0.39	ns	51.1	51.3	0.23	ns
P8 fat depth (mm)	11.7	11.2	1.58	ns	11.4	12.5	1.16	ns	8.3	7.3	0.38	0.08
Price/kg carcass ($/kg)	2.92	2.92	0.012	ns	3.44	3.41	0.016	ns	2.82	2.85	0.008	*
MSA un-grades (%)	0	6.7			13.3	6.7			8.9	24.4		
MSA boning group	9.7	12.9	0.44	***	8.2	12.2	0.37	***	8.0	12.7	0.25	***
MSA boning group ≤10 (%)	80	8			100	7			100	6		

	L-nil				L-leuc				H-plane groups (L-H, M-H, H-H)			
	Nil	+H	se	*P*	Nil	+H	se	*P*	Nil	+H	se	*P*
MSA rib fat depth (mm)	11.0	7.3	1.20	*	7.8	6.5	0.72	ns	8.04	7.33	0.476	ns
Eye-muscle area (cm^2)	73.3	76.2	1.71	ns	58.1	54.8	4.04	ns	69.5	69.2	1.42	ns
Hump height (mm)	114	118	4.7	ns	100	109	2.76	*	111	125	2.2	***
Ossification score	200	376	22.9	***	146	193	5.69	***	151	190	4.9	***
MSA AUS marbling score	0.07	0.08	0.074	ns	0.14	0.20	0.102	ns	0.51	0.20	0.076	**
MSA USDA marble score	203	216	15.2	ns	229	239	13.9	ns	288	242	10.8	**
Meat colour score					2.36	1.93	0.211	0.06	1.78	2.54	0.173	**
Fat colour score	3.33	3.00	0.187	ns	2.57	2.27	0.228	ns	1.66	1.95	0.123	ns
Loin temperature (°C)	7.99	8.28	0.119	ns	2.59	2.43	0.248	ns	8.56	7.94	0.109	***
Carcass pH	5.47	5.48	0.015	ns	5.61	5.53	0.025	**	5.59	5.62	0.021	ns

[A] Dentition is classified according to the eruption of pairs of permanent teeth, i.e., 0, 2, 4, 6 etc.

[B] No MSA premium paid by abattoir for this slaughter group

[C] Not analysed statistically

[D] Insufficient graded for MSA, mainly due to high dentition score (≥6 permanent teeth)

[E] Proportion grading MSA boning group ≤10, which receive the MSA bonus price.

[F] Marble scores (AUS-MEAT and US Department of Agriculture (USDA))

13.2 Detailed Report 2: Economic assessment of growth paths

Economic analysis of trial results

Optimising growth paths of beef cattle in northern Australia for increased profitability (GPO project)

MLA project code: B.NBP.0391

Department of Agriculture Fisheries and Forestry
Queensland
December 2012

This analysis was compiled by:
Fred Chudleigh
Principal Economist
Queensland Department of Agriculture, Fisheries and Forestry
2012

Summary

This paper presents the results of an economic analysis of part of the technical results of the research project: Optimising growth paths of beef cattle in northern Australia for increased profitability (GPO project) (MLA project code: B.NBP.0391) conducted at Swans Lagoon Research Station from 2008-2012. The project sought to understand the balance between feeding at a time when nutrients are used most efficiently at a younger age and restricting the effects of compensatory growth compared to feeding at a later time. In doing so it aimed to provide strategies that assist beef producers to most cost-effectively increase growth rates of their cattle; reduce age of turnoff and potentially provide access to the higher value markets.

The approach taken was to grow steers at Swans Lagoon Research Station over different growth paths by feeding different types and amounts of supplement at different times of their lives. Supplemented steers were fed at the rates of Low (L), Medium (M) and High (H) during the first dry season and then at high but variable rates in the second dry season so that all supplemented groups arrived at a suitable liveweight and condition by the end of the second dry season to be slaughtered.

Another group (L-nil), a control group, received a Low treatment in the first dry season after weaning and then were run without any further supplement until sold. This was a year later than the steers receiving the High or Medium levels of supplementation. A final group of steers (Low-leucaena) followed a Low treatment in Year 1 and then were moved to a high quality leucaena pasture at Brian Pastures to compare an improved pasture option with supplements.

The economic analysis of the project is based on the measured response functions for steer growth from combinations of pasture and supplements fed to growing steers. The results of the economic analysis broadly indicate:

- Treatments that applied expensive supplements to achieve high weight gains generally added less value per head than treatments that incurred lower supplement costs.
- Overall, the treatment of steers with a growth promotant (HGP) at suitable times over their lifetime improved profitability, even though the MSA grading system has inbuilt constraints that heavily discount steers that have received HGP treatments. In this trial, the premiums available for non HGP steers did not outweigh the benefits of the extra sale weight provided by the use of the HGP.
- The regular, ongoing use of high-cost supplements to target a younger age of turnoff for slaughter cattle on a north Australian beef breeding and fattening property is unlikely to improve overall profitability.
- The availability of a premium price for steers that met the MSA grade was not consistent across the life of the project. The pricing structure and premiums available was probably not sufficiently consistent to use as a base for an overall herd management strategy.
- A northern breeding and fattening herd that can improve the nutrition of its steers and maintain an appropriate relativity between the costs and benefits of doing so is likely to improve the overall profitability of the business. Any such strategy that dramatically reduces the age of turnoff of steers compared to the norm is also likely to increase the variability of the business returns. Much of this variability is due to the increase in drought risk caused by running proportionally more breeder cattle in the herd.

Project description

The project addresses the key issue of how to increase whole-of-life growth rates of cattle grazing tropical pastures in the most cost-effective way.

Reviews of prior research identified an abundance had already been undertaken to demonstrate the responses by cattle to various feeding strategies within a discrete period of time, for instance over a dry season, but there was very little information about how to incorporate these component strategies into a whole-of-life program.

The objective of the project relevant to this analysis is:

1. Evaluate and compare, including on an economic basis, different feeding strategies for increasing growth rates of steers in the tropics of northern Australia to a common liveweight/age end-point.

This economic analysis uses data collected within the project to meet this objective.

Project background

Strategies to increase growth rates and achieve heavier turnoff at younger age in the north Australian beef industry involve improving the nutrition of the animals, either by improved or alternative plant species or supplements at some stage of their growth path. Whilst there has been substantial component research investigating nutritional treatments for discrete parts of the animal's growth path (e.g., first dry season post-weaning), practical application of these treatments often results in the benefits of the improved nutrition being lost due to compensatory growth in the ensuing period leading to a reduced cost efficiency of feeding overall. The question essentially being asked by the project is: when would be the best time to feed an animal for the most profitable outcome – early in life, later in life just before marketing, or a combination of each?

There are several factors that impact on this decision. Firstly, it was considered far less expensive to feed a young animal for a particular liveweight gain (e.g., 0.5 kg/day) than an older animal because the young animal is lighter in body weight and also uses nutrients more efficiently (i.e., it is depositing more muscle and less fat and this requires less energy expenditure per unit liveweight gain). Although later pen feeding trials conducted by the project showed this assumption to be erroneous, the original contention was that feeding the entire supplement at a young age may improve efficiency.

However, the other factor which impacts on this is a phenomenon called compensatory, or 'catch-up', growth. When cattle have been restricted in growth over a period, as for instance happens during the dry season in northern Australia when pasture quality is low, they usually grow faster when that restriction is removed, for instance in the wet season, than cattle that were not previously restricted, i.e., they compensate in part for the period of restriction. Thus a lot of the liveweight gain advantage achieved through feeding cattle at a young age may be lost by the time they have been through one or more wet seasons because un-supplemented cattle have compensated or caught up. In contrast to the earlier statement, this suggested that delaying feeding until the cattle were older may be the most efficient way to feed supplements for economic gain.

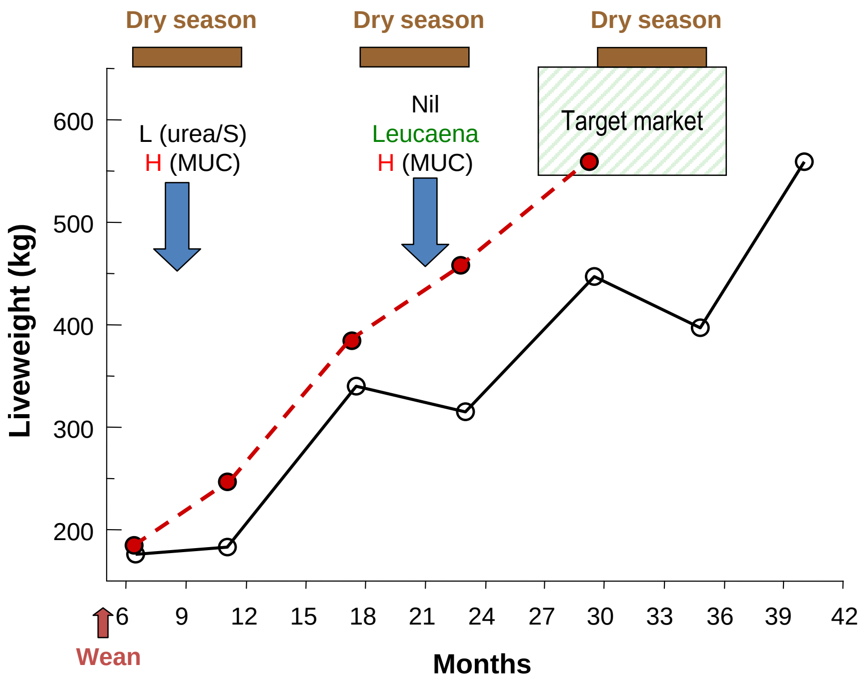
The project sought to understand the balance between feeding at a time when nutrients are used most efficiently at a younger age and restricting the effects of compensatory growth compared to feeding at a later time. In doing so it aimed to provide strategies that assist beef producers to most cost-effectively increase growth rates of their cattle, reduce age of turnoff and potentially provide access to the higher value markets.

Fig. 1 presents a stylised view of the timing and possible nature of the nutritional intervention options plus the hoped for response in the growth curve. Nutritional interventions can be implemented individually or in combinations.

The approach taken in this trial was to grow steers at Swans Lagoon Research Station over different growth paths by feeding different types and amounts of supplement at different times of their lives. This was done by feeding supplemented steers at the rates of Low (L), Medium (M) and High (H) during the first dry season and then at high but variable rates in the second dry season so that all groups arrived at a similar liveweight by the end of the second dry season. The steers were then grazed on in the following wet season until they reached condition suitable for slaughter by the end of this period. This would be one year younger than is normally expected for northern steers that did not receive supplements.

Another group (L-nil), a control group, received a Low supplement treatment in the first dry season after weaning and then were run without any further supplement until sold. This was a year later than the steers receiving the High or Medium levels of supplement and reflected the current management of steers to be sold as slaughter steers from native pastures in northern Australia. A final group of steers (Low-Leucaena; L-leuc) followed a Low supplement treatment in Year 1 and then were moved to a high quality leucaena pasture at Brian Pastures for the second dry season and following wet season to compare an improved pasture option with supplements. These steers would also be sold a year younger than the control group of steers.

Fig. 1. The timing and potential impact of nutritional intervention options



- Finish 12 months earlier
- Higher quality product

The target live weight and age end-point for supplemented groups was 500 kg live weight at 24 months, i.e., at the end of the second dry season post-weaning. This target was generally achieved by the supplementation program. The steers were then to be grazed in the following wet season and sent for slaughter at about 30 months of age. Live weights, supplement intake and skeletal development (frame size) of the cattle was monitored plus half the steers in each group were implanted with a hormonal growth promotant (HGP).

Economic analysis

A range of data was available for each steer in each treatment. Liveweight at the beginning and end of the trial plus the individual slaughter weight, sale value and final carcass value were available for each steer. The amount of supplement fed, husbandry costs, transport and feeding costs were available as treatment or individual steer costs and were allocated on an average cost per head basis for each treatment.

Table 1. Treatments applied in the steer trial

Treatment	Dry season 1	Wet season 1	Dry season 2	Wet season 2
L-nil	**Urea/S dry lick***	**Nil**	**Nil**	**Nil**
L-leuc	**Urea/S dry lick**	**Nil**	**Leucaena (Brian Pastures)**	**Nil**
L-H	**Urea/S dry lick**	**Nil**	**M3U10C (*ad lib.*)**	**Nil**
M-H	**M3U10C → M8U****	**Nil**	**M3U10C (restricted)**	**Nil**
H-H	**M3U10C*** (*ad lib.*)**	**Nil**	**M3U10C (restricted)**	**Nil**

*Urea/S dry lick: ca. 30 g urea/d + Rumensin
**M8U: molasses 8% urea + Na + P + Rumensin
***M3U10C: molasses 3% urea 10% copra meal + Na + P + Rumensin (MUP)

Steers were in the trial for different periods of time; at different stocking rates; on pastures of significantly different quality; in different locations and sold at different times to different abattoirs. The chosen methods of economic analysis attempt to take into account, as much as possible, these differences so that the final results for each treatment are broadly comparable.

Two separate methods of assessment are used to assess the economic benefits accruing to each treatment within the trial.

The first method identified the net value per head created by the treatments. This method calculated the final value achieved for each steer and then deducted all of the identifiable costs of achieving that value. The costs deducted were both cash and non-cash and therefore included the direct treatment costs as well as any indirect and opportunity costs associated with each treatment. In this way the steers that consumed more resources, for example, the amount of time taken to get to sale weights or supplements, had the value of those resources accounted for and deducted.

This method looks at the performance of each steer in each treatment and is referred to as the value added method. The final figure calculated (net value added) allows the approximate ranking of the treatments.

The second method used the average results and costs for each treatment and other available data to model each treatment as the output of a breeding and fattening beef business located in northern Australia. Each treatment was modelled as a breeder herd with a discrete steer finishing system based on each treatment within the trial.

Within this method, a representative northern Australian beef breeding and fattening herd was initially modelled with the control treatment applied to create a base herd turning off steers at an average age of 42 months. The remaining treatments were then modelled as alternative steer finishing systems. The herd size and structure was adjusted after each steer finishing system (treatment) was applied to maintain the same grazing pressure on the land resource underpinning the modelled herd, ensuring that the final returns are comparable.

The herd model was constructed using the Breedcow and Dynama suite of programs (Holmes 2012) with a separate base model developed for both the No 8 and No 9 steers. This base model was taken to be the production system currently applied on properties in northern Australia (or base herd) likely to implement the findings of the project.

The steers produced within the herd modelled for each treatment achieved the same average weight gains and incurred the same direct costs as each treatment group in the trial. Where appropriate, the grazing pressure applied by the overall herd was adjusted to take into account the efficiency gains and substitution effects likely to be encountered when feeding supplements.
This method of economic analysis produced a herd gross margin for each production system that took into account the variation in herd capital invested, efficiencies created and costs incurred by each production system.

In summary, the second method of analysis modelled a breeding herd to answer the question – what would my property, herd and profit look like if I changed my steer turnoff strategy to match the output of the treatments of the trial?

Assumptions and values used in the steer value added analysis

Two lots of steers entered the trial as separate age groups one year apart. These separate age groups of steers are referred to by their brand year - No 8's and No 9's. Steers are uniform in breed and age and enter the trial at about 200 to 210 kg liveweight and about 6-8 months of age.

The trial treatments were:

- L-nil with and without HGP
- L-leuc with and without HGP
- L-H with and without HGP
- M-H with and without HGP
- H-H with and without HGP

Approximately 150 steers were allocated across the treatments each year giving 15 steers in each treatment. As there were 3 replicates within each treatment, 5 steers started the trial in each replicate. In the analysis steers initially had costs allocated on an individual basis to look at the variation in performance within treatments and then the replicates were bulked together and averaged to provide overall treatment results. Steers that died or went missing during the trial were removed from the data on the basis that any deaths or losses did not reflect the underlying treatment.

Further details of the project management, data collection methods and statistical analysis of results can be found in the various milestone reports and final report for the project (Component A).

Purchase cost

All steers were valued at the start of the trial based on the market price for similar steers at the Charters Towers (Dalrymple) saleyards in the week the steers entered the trial. Freight from the sale yards and initial husbandry treatments were added to the purchase price to cover any induction cost to the property.

The No 8 steers were valued at $1.375 per kg live at the sale yards and the No 9 steers were valued at $1.68 per kg live reflecting the market prices ruling at the time. These prices were multiplied by the opening weight of each steer to establish an opening value.

Transport costs were calculated at $1.95 per km per deck with 3 decks used to convey the steers to the property.

Hormone growth promotant

Where applicable, steers treated with HGP had the following costs allocated:

- Compudose-400 (C-400) at $8.40 per dose
- Compudose-200 (C-200) at $4.80 per dose
- Compudose-100 (C-100) at $2.20 per dose
- Compudose-G (C-G) at $3.35 per dose

The No 8 steers treated with HGP received the following implants:

- Low-nil: C-400, C-100*, C-G, C-400
- Low-leucaena: C-400, C-100
- Low-High: C-400, C-100, C-G
- Medium-High: C-400, C-100, C-G
- High-High: C-400, C-100, C-G

*The cost of the C-100 implant was been removed as it was not a usual implant and was unlikely to have had a significant impact on weight gains. It was used to fill the gap between the use of C-400 and C-G.

The No 9 steers treated with HGP received the following implants:

- Low-nil: C-400, C-200, C-G, C-400
- Low-leucaena: C-400, C-200
- Low-High: C-400, C-200, C-G
- Medium-High: C-400, C-200, C-G
- High-High: C-400, C-200, C-G

Additional costs were added to the purchase cost of HGP implants to cover the labour cost of treating the steers. The total HGP treatment cost was set at the market price for the product plus $2 per head application cost. The application cost was based on 2 workers taking 0.5 days to muster, implant and return 100 steers to their paddock. Wages of $20 per hour for 5 hours x 2 workers are paid. ($20 x 2 x 5 = $200 /100 steers = $2 per head).

Bovine ephemeral fever (BEF) vaccine

All groups were injected with 2 doses of BEF vaccine in the first year and a single follow up dose each year following. The numbers of doses per group of steers were as follows: L-nil: 4 doses; L-leuc: 3 doses; L-H: 3 doses; M-H: 3 doses; H-H: 3 doses.

The cost was $9.00 per dose with no additional labour costs incurred. One of the doses and booster was given in year 1 at weaning and soon after with the remainder of the injections implemented with other activities and most probably coinciding with the HGP treatment. Steers that did not receive the HGP implant also incurred no application cost for BEF on the basis that the application coincided with other management activities. This allocation of application costs was also thought to reflect industry practice.

Supplement costs

The landed costs ($/tonne, at Swans Lagoon) of the various supplement components for the two drafts of steers were: molasses, 140; urea, 1240; copra meal, 540; salt, 370; DCP, 1160; and Rumensin 100, 8900, making a total cost of the MUP mix of $232/tonne. The cost of the commercial salt/urea/S mix was $909/tonne.

The average cost per head and intake of supplements for each season and each group is shown in Detailed Report 1, Tables 14 to 19. The average total costs per head are shown below for each age group and season fed.

Labour and other costs associated with supplement feeding were added to the direct cost of supplements. The labour and other costs were based on the estimated time taken to feed 100 steers in a paddock not too distant from the home base. The feeding out cost was calculated as follows:

Salt/urea dry lick (Low level supplementation)

This mix was purchased in bags, delivered to the paddock and poured into troughs as a once weekly event. The main time expended was in collecting the lick and driving to the paddock and back. Although in many cases lick feeding can be done in conjunction with water runs and normal stock checking and would add little extra time, the estimate for feeding 100 weaners was retained at 2 extra hours per week of labour.

Table 2. Cost of feeding No 8 steers

	2008 dry season $/head	2009 dry season $/head
L-nil	**$6.90**	
L-leuc	**$8.66**	
L-H	**$9.15**	**$243.20**
M-H	**$58.11**	**$219.08**
H-H	**$98.78**	**$215.60**

Table 3. Cost of feeding No 9 steers

	2009 dry season $/head	2010 dry season $ /head
L-nil	**$10.91**	
L-leuc	**$10.28**	
L-H	**$9.56**	**$35.83**
M-H	**$95.08**	**$33.34**
H-H	**$153.89**	**$34.44**

There was little capital cost for this feeding regime. Troughs were anything from half-44s to something more elaborate with a shelter over the top. The expected life of these feeders would be quite long. There were some depreciation and running costs associated with running a vehicle to take the supplement out to the paddock.

The feeding out cost for the salt urea mix was calculated as 2 hours per week @ $25 per hour. It therefore costs $50 per week to feed 100 weaners, giving a cost per weaner per week of 50 cents. This costing is thought to reflect the likely costs incurred by a beef business feeding supplements to growing steers.

Molasses-based supplements (Medium and High level supplementation)

These supplements were mixed in a tank on the back of a truck. All ingredients were mixed in the tank using a 5 HP motor driving paddles on a central axis (a typical truck mounted fortified molasses mixer). Molasses was delivered to the property and placed in storage tanks. The molasses was gravity fed or pumped into the tank on the back of a truck and urea, copra meal, salt, di-calcium phosphate and Rumensin added as the mixer was operating. Mixing time was about 20 min but this mostly occurred as the truck was driving out to the paddock. It was estimated to take 30 min to fill the tank on the truck, add the other components and deliver them to the paddock.

The capital costs incurred included molasses storage tanks, a truck mounted fortified molasses mixer and feed troughs for the paddock. It was assumed that the property would own a suitable truck and that little in the way of capital expenses could be allocated to the molasses from that source. The feeding out cost for the molasses mix was calculated at 2.5 hours per week @ $25 per hour. It therefore cost $62.50 per week to feed 100 weaners, giving a cost per weaner per week of 62.5 cents.

Plate 1. Weaner steers (No 8) on urea dry lick ration: November 2008

The increase in the cost of wages by $5 per hour for feeding out activities when compared to mustering is an allowance to cover some of the machinery and fuel costs incurred in feeding the molasses-based supplements. The costs allocated to feeding the molasses supplements in the trial are thought to be comparable to those that a commercial operation would incur.

Leucaena treatment

For this project every steer that grazed leucaena was treated with leucaena inoculant. However, the normal commercial process is to treat 10% of steers and allow natural transmission between steers. The cost of the inoculant in 2009 was $125/ bottle (5 doses per bottle, thus $25/dose). In 2010 (for the No. 9 steers) it was $25.75/dose. The inoculant cost was added in the analysis on the basis of only 10% of steers being treated - giving a cost of $2.50 per head for the No 8's and $2.75 per head for the No 9's.

The L-leuc steers were grazed as 3 separate groups and were rotated around paddocks at Brian Pastures research station. Normally they would have been grazed in a larger group but the replicates within the treatment group were kept separate for statistical purposes. No extra labour costs were added to cover the cost of the grazing system put in place to manage the steers on the leucaena as such additional costs would not be incurred in a commercial operation.

Plate 2. No 9 steers on MUC supplement Year 2 Dry: August 2010

Stocking rates

The stocking rates of all treatments for each season are shown in Detailed Report 1 – Tables 20 and 21. Where molasses based supplements were fed, the underlying stocking rate was adjusted to reflect the expected efficiency gains in carrying capacity due to the substitution of supplement for pasture. Estimates from the intake calculator (QuikIntake) were used to identify the expected efficiency gains and the stocking rate was increased accordingly for those groups.

The alteration to stocking rates was based on the knowledge that steers will substitute supplements for pasture - with steers on higher levels of supplement accommodating a higher stocking rate even though they are heavier than their counterparts on low supplement. In the trial it was estimated that the steers fed medium levels of supplements applied 70% of the grazing pressure of steers fed the low level of supplements and steers fed high levels of supplements applied 60% of the grazing pressure of steers fed low levels of supplements. Steers grazing leucaena had an effective stocking rate of 1 steer to 1.5 ha.

To account for the range of stocking rates and qualities of pastures accessed by trial steers, the gross income at sale earned by each steer was reduced by the opportunity cost of the grazing resource accessed. The inclusion of this opportunity cost operated in a similar way to an agistment charge and varied with the stocking rate, the value of the land and pasture grazed and the amount of time that the steers were in the grazing trial. The amount of opportunity cost charged each treatment is shown in Detailed Report 1 – Tables 20 and 21.

Therefore, steer treatments in the trial for longer periods of time were charged for the extra time. Steers that were fed supplements had their efficiency gains in stocking rate reflected in a lower charge for land and steers that grazed more valuable land and pasture combinations (the leucaena steers) paid a higher charge than those that grazed dry grass pasture. Land at Swans Lagoon was valued at $500/ha or about $2000 per adult equivalent (AE). Land at Brian Pastures was valued at $2000/ha with the leucaena pasture costing $400/ha to develop with an assessed effective life of 20 years.

Selling costs

Steers were sold directly to the abattoirs and incurred a MLA transaction levy of $5/head plus transport costs. All steers were sold to either JBS in Townsville or Teys at Beenleigh (only leucaena steers went to Beenleigh). The distance from Swans Lagoon to JBS, Townsville is 130 km with commercial carriers used to shift the cattle to the abattoirs at a cost of $1.95/deck/km. Steers were loaded at 20 heavy steers per deck. The distance from Brian Pastures to Teys Beenleigh is 340 km. The cost per km shown and loading shown above was also applied to the steers sold to Teys Beenleigh.

Transport costs Swans Lagoon to Brian Pastures for L-leuc group

A cost of $71.50 per steer was retained based on a cost of transport of $1.95 per deck and a distance of 1100 km. The steers load at 30 per deck incurred a total cost $2145.

The cost of transporting the steers to Brian Pastures was retained even though a commercial operator would be likely to find leucaena closer to home. The inclusion of the higher transport cost was offset by the benefits of the better quality pasture likely to be on offer at Brian Pastures. Leucaena closer to north Queensland may be accessed more cheaply but may not have the same quality of that available at Brian Pastures.

Opportunity cost of steer capital

The differing grazing periods of the steer treatments was accounted for in the analysis by charging interest on the purchase price of the steers for the period of time the steers were held. This was done to provide a benefit to treatments that held steers for lesser time periods and to increase the cost of treatments that required steers to be held for longer periods (i.e., L-nil). The inclusion of this opportunity cost as well as the proportional value of the land and pasture accessed by each treatment adjusts the total benefits gained to reflect the value of the resources used to gain the benefit.

Other costs

For the No 9 steers, the Low supplement treatment groups in dry season 1 (the 2009 dry season) had to be treated for cattle ticks at end of the dry season. This was not necessary for the Medium or High treatments in that first dry season, i.e. the M-H and H-H treatments.

No tick treatments were applied for the No 8s, or at any other time for the No 9s.

Assumptions and values used in the herd modelling

A breeding herd that included sufficient breeders, bulls and replacement stock to maintain a suitable herd of approximately 1000 breeding cows was modelled for both the No 8 and No 9 control treatment groups. Each herd was modelled in the program Breedcowplus[1] and initially based on the L-nil with HGP treatment. It was modelled as a 1000 breeder herd turning off steers between 36 and 48 months of age. Total herd size was 2125 AE.

The performance parameters applied to the modelled herd (other than the steer weight gains) are those expected on a relevant northern Australian beef cattle breeding and fattening property and did not change with the changing steer treatments. The steers exiting the L-nil treatment were effectively sold between 3 and 4 years old. The number of breeders for the base herd was chosen for convenience of calculation only.

Table 4 indicates the numbers of cattle in each class held by the starting or base breeding herd. To enable comparison between treatments total grazing pressure was maintained at 2125 AE with the model adjusting stock numbers in each class in response to changes in grazing pressure arising from the steer treatments. The full parameters of the base herd, including the weight ranges for each class, the selling prices and the husbandry costs are summarised in Detailed Report 1. All selling prices and treatment costs for classes other than the steers were held constant on a per head basis but varied on a per herd basis as the numbers of livestock in each class changed with each treatment. The steer prices, weight gains and treatment costs used in the herd models are those that were incurred or gained, on average, by the treatments of the trial.

A model of a breeding herd that is adjusted to sell steers at a younger age will typically have proportionally more female and breeder cattle in the herd and proportionally less steers. Where fed supplements improved the efficiency of the steer use of pasture, the AE rating of that group was adjusted to reflect the efficiency gains. This effectively allowed the base property to run slightly more cattle but at effectively the same grazing pressure.

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[1] Holmes, W.E. (2012). Breedcow and Dynama Herd Budgeting Software Package, Version 6.0 for Windows 95, 98, Me, NT, 2000, XP and 7. Training Series QE99002, Queensland Department of Agriculture, Fisheries and Forestry, Townsville

Table 4. Total cattle and adult equivalents for the No 8's base herd

Age and class of cattle	Number kept whole year	Number sold	AE*/head kept	AE/head sold	Total AEs
Extra for cows weaning a calf	na	na	0.35	na	212
Weaners 5 months	606	0	0.26	0.08	159
Heifers 1 year but less than 2	192	105	0.60	0.34	151
Heifers 2 years but less than 3	170	19	0.83	0.48	150
Cows 3 years plus	726	142	0.95	0.47	753
Spayed or surplus females all ages	0	0	0.00	0.00	0
Steers 1 year but less than 2	297	0	0.63	0.31	188
Steers 2 years but less than 3	292	0	0.94	0.46	274
Bullocks 3 years but less than 4	0	288	1.24	0.62	178
Bullocks 4 years but less than 5	0	0	0.00	0.00	0
Bullocks 5 years but less than 6	na	0	na	0.00	0
Bulls all ages	35	8	1.54	0.74	60
Total number	2318	561		Total AE	2125

*Adult equivalents

Adult equivalent rating adjustments for No 8 steers

The improved efficiency gained by feeding molasses based supplements was accounted for in the model by adjusting the AE rating of the class fed the supplements. For the No 8 steers:

- the L-H treatment had 184 days at 60% of the assessed stocking rate in the second year,
- the M-H treatment had 115 days at 70% of the stocking rate in year 1 and 184 days at 60% of the stocking rate in year 2, and
- the H-H treatment had 115 days at 60% of the stocking rate in year 1 and 184 days at 60% of the stocking rate in year 2.

Table 5 and Table 6 identify how these efficiency gains were used to adjust the AE rating of the class of livestock for the period of feeding.

Table 5. Calculation of stocking rate adjustment in Breedcowplus for No 8 steers

Year 1	**L-nil**	**L-H**	**M-H**	**H-H**
Wet season stocking days	35		35	35
Dry season stocking days	115		115	115
Percentage of time at wet season rate	23%		23%	23%
Percentage of time at dry season rate	77%		77%	77%
Wet season stocking rate	1.5		1.5	1.5
Dry season stocking rate	1.5		1.05	0.9
Number of steers per 100 ha at wet rate	66.67		66.67	66.67
Number of steers per 100 ha at dry rate	66.67		95.24	111.11
Average steers per annum	66.67		88.57	100.74
Increase in stocking rate per annum			33%	51%
Equivalent AE rating			75%	66%
Heifers plus steers			0.875	0.83
Year 2	**L-nil**	**L-H**	**M-H**	**H-H**
Wet season stocking days	181	181	181	181
Dry season stocking days	184	184	184	184
Percentage of time at wet season rate	50%	50%	50%	50%
Percentage of time at dry season rate	50%	50%	50%	50%
Wet season stocking rate	1.8	1.8	1.8	1.8
Dry season stocking rate	4	2.4	2.4	2.4
Number of steers per 100 ha at wet rate	55.56	55.56	55.56	55.56
Number of steers per 100 ha at dry rate	25.00	41.67	41.67	41.67
Average steers per annum	40.15	48.55	48.55	48.55
Increase in stocking rate per annum		21%	21%	21%
Equivalent AE rating		83%	83%	83%

Table 6. Breedcowplus AECalc sheet showing livestock classes that were adjusted in the H-H treatment

Standard weight of one AE (Kg)	455
Extra AE for cows weaning a calf	0.35

Description at Start of Rating Period	Months at Start of Rating	Months at End of Rating	Cattle carried through whole year: Months Rated	Lowest or Start Weight	Highest or End Weight.	AE/head Rating
Extra for cows weaning a calf	na	na	na	na	na	0.35
Weaners 5 months	5	12	7	180	230	0.22*
Heifers 1 year	12	24	12	225	325	0.60
Heifers 2 years	24	36	12	325	430	0.83
Cows 3 years onwards	na	na	12	430	430	0.95
Steers 1 year	12	24	12	287	448	0.67*
Steers 2 years	24	36	12	448	546	1.09
Bulls all ages	na	na	12	700	700	1.54

* see text below for explanation of calculation of AE.

Note that the adjustment to the calculation of AEs in Table 6 is made by multiplying the AEs calculated for the class by the Equivalent AE rating figure shown in Table 5. The 2 AE/head rating figures highlighted in Table 6 are the calculations adjusted to allow for the increased stocking rate made available through the feeding of supplements. If the adjustment was not made the rating for weaners to 5 months would be 0.26 while the 12 to 24 month old steers would be 0.81. The adjustment changes the total grazing pressure applied in the herd model to allow for the efficiency gains from feeding molasses-based supplements.

Adult equivalent rating adjustment for No 9 steers

For the No 9 steers:

- the L-H treatment had 88 days at 60% of the stocking rate in the second year, while
- the M-H treatment had 184 days at 70% of the stocking rate in year 1 and 88 days at 60% of the stocking rate in year 2.
- The H-H treatment had 184 days at 60% of the stocking rate in year 1 and 88 days at 60% of the stocking rate in year 2.

These effects on stocking rate calculations are shown in Table 7.

Leucaena steers

Steers that accessed leucaena pastures were sold from the base herd to a leucaena enterprise. The leucaena enterprise purchased the steers at the same value per kg live as the base enterprise received but incurred all of the transport and husbandry costs incurred by grazing the leucaena. The steer price used for the transfer was the amount that would be achieved for equivalent steers sold at the Dalrymple saleyards at about the time of transfer.

The leucaena enterprise was also charged the opportunity cost of the land and leucaena pasture accessed by the steers to account for the increased carrying capacity on the base property provided by moving the steers off that property to the leucaena pasture.

Table 7. Calculation of stocking rate adjustment in Breedcowplus for No 9 steers

Year 1	**L-nil**	**L-H**	**M-H**	**H-H**
Days in first Breedcowplus period	197		197	197
Non supplemented stocking days	13		13	13
Supplemented stocking days	184		184	184
Percentage of time at un-supplemented rate	7%		7%	7%
Percentage of time at supplemented rate	93%		93%	93%
Un-supplemented stocking rate	1.5		1.5	1.5
Supplemented stocking rate	1.5		1.05	0.9
Number of steers per 100 ha at un-supplemented rate	66.67		66.67	66.67
Number of steers per 100 ha at supplemented rate	66.67		95.24	111.11
Average steers per annum	66.67		93.35	108.18
Increase in stocking rate per annum			40%	62%
Reduction to get equivalent AE rating			71%	62%
Average for steers and heifers			86%	81%
Year 2	**L-nil**	**L-H**	**M-H**	**H-H**
Days in second Breedcowplus period	346	346	346	346
Non supplemented stocking days	258	258	258	258
Supplemented stocking days	88	88	88	88
Percentage of time at un-supplemented rate	75%	75%	75%	75%
Percentage of time at supplemented rate	25%	25%	25%	25%
Un-supplemented stocking rate	4	4	4	4
Supplemented stocking rate	4	2.4	2.4	2.4
Number of steers per 100 ha at un-supplemented rate	25.00	25.00	25.00	25.00
Number of steers per 100 ha at supplemented rate	25.00	41.67	41.67	41.67
Average steers per annum	25.00	29.24	29.24	29.24
Increase in stocking rate per annum		17%	17%	17%
Equivalent AE rating		86%	86%	86%

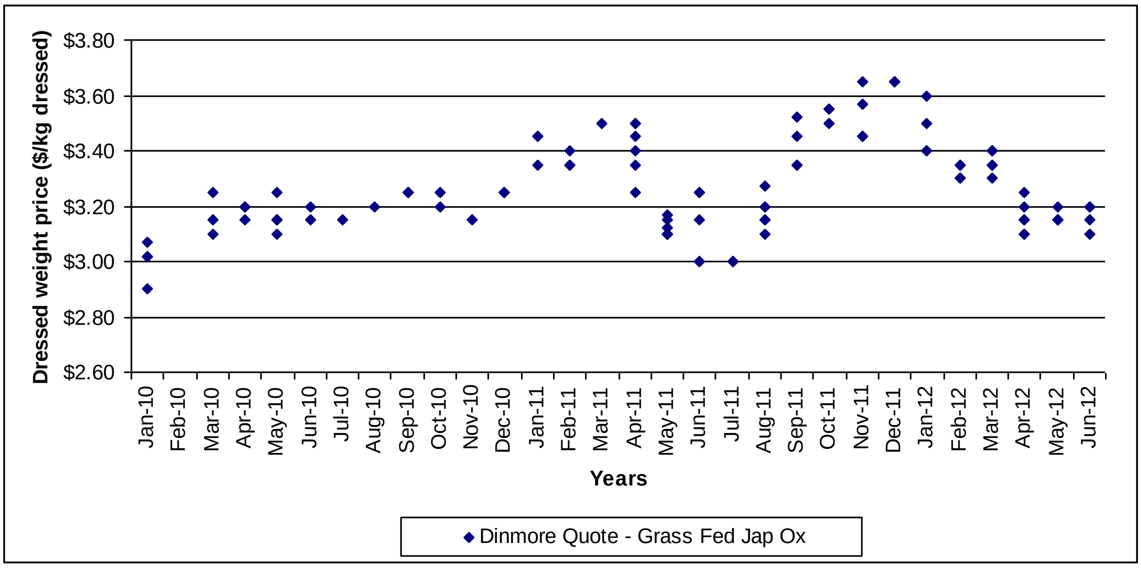
Steer prices

Steers produced by the treatment groups had up to a year between sale dates. This variation could potentially skew the results of any economic analysis as prices for livestock can vary by up to 10-15% over any given month. Fig. 2 shows the variation in Grass fed Jap Ox prices quoted by Dinmore abattoir over the period of the trial. This range of prices would be typical of the range at other abattoirs around Queensland over the same time period.

Where Fig. 2 shows a number of points arranged vertically in any month, these points represent the variation in quotes for that month. The quoted price for grass fed Jap Ox varied by up to 15% in some months over the life of the trial. Quoted prices for the MSA grade of steers targeted in the trial showed similar variability (data not shown).

The median price from May 2004 to June 2011 for grass fed Jap Ox at Dinmore abattoirs was $3.25/kg dressed weight and the average price from May 2004 to June 2012 was also $3.25/kg dressed weight. The variation in prices quoted around these average and median figures is about 12.5% over the life of the trial.

Fig. 2 Quoted over the hooks prices for grass fed Jap Ox* at Dinmore abattoirs



*Grade J, Dressed weight (kg) 300-319, Teeth 0-6, Fat (mm) 7-22

Table 8 indicates the quoted price for Dinmore abattoir when treatment groups were actually sold. It can be seen that most No 8 treatment groups were sold with the market at similar levels while the No 9s had the L-leuc treatment group sold while the market was slightly above the level which prevailed when the other 2 groups of No 9 steers were sold. The L-leuc No 9 treatment group appears to have sold on a market that was about 6.25% better than the average of the markets on which the other No 9 steers were sold. Obviously, the steers did not receive these prices as most of the steers were killed in Townsville. The quoted prices represent the overall level of the market at the time the steers were sold and are only used as a guide to the relativity of the sale prices achieved for the steers in the trial. The impact on the final results of the relatively better prices received by the No 9 L-leuc steers will be explored later in the analysis.

Table 8. Dinmore grass fed Jap Ox quote at the time treatment steers were sold

Treatment	slaughter date	Grass fed Jap Ox price quote $/kg dressed weight
No 8 steers		
L-nil	**21/06/2011**	**$3.00**
L-leuc	**1/03/2010**	**$3.07**
All supplemented	**10/06/2010**	**$3.15**
No 9 Steers		
L-nil	**28/05/2012**	**$3.15**
L-leuc	**9/3/2011**	**$3.40**
All supplemented	**7/06/2011**	**$3.25**

Opportunity cost of livestock capital in the herd model

The gross margins calculated for each modelled herd take into account any change in the underlying capital invested in the herd as the herd gross margins are reported on an “after interest” basis, the amount of interest charged being equivalent to the opportunity costs of the livestock capital tied up in the total herd. The rate of interest charged in the results provided is 5% per annum, an opportunity cost typical of the circumstances where funds are retrieved from or placed into cash accounts. The analysis was also completed with a higher rate of interest charged to reflect the opportunity cost of borrowed funds. This did not significantly alter the ranking of the results. (Data not shown).

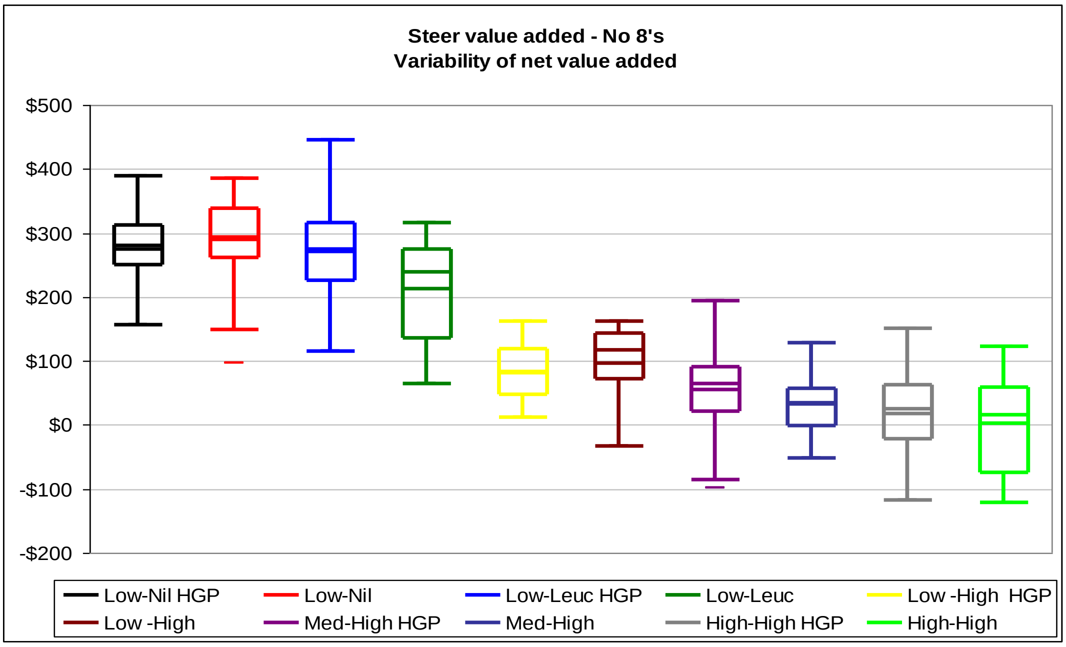
Results of the analysis

Value added analysis

The value added analysis initially calculated returns on an individual steer basis before they were grouped as treatments for analysis. The program used to analyse the data looks at the individual values for each treatment group and then displays the statistics of the treatments graphically as box plots. This means that the range in expected values achieved within each treatment is represented by the box plots shown in Figs. 3 and 4.

The extremities of the box plots represent the expected high and low values for each treatment. The mean and median values are represented by the 2 horizontal lines within the middle box and the top and bottom 25% of values are represented by the length of the line from the top or bottom of the box to the top and bottom horizontal lines of the box plot. All expected values lie within the limits of the box plots although where separate dots or lines are shown outside the top or bottom of the box plots they represent values for individual steers that statistically lay outside the range of the expected values.

Fig. 3. No 8 steers range in steer value added



For example, the third box from the left in Fig. 3 represents the range in individual values achieved by the No 8 steers that received the L-leuc with HGP treatment. Steers in this group added a net value of between $100 and $450 per head with a median value somewhere in the high $200's per head. About 25% of steers in this group added value of between $100 and $220 per head, 50% of steers added value of between $220 and $310 per head and 25% of steers added value of between $310 and $450 per head.

Conversely, the H-H treatment without HGP (far right green box of Fig. 3) had a median value added of $0, a low value of -$120 per head and a high value of $120 per head. In other words, the costs were greater than the value added in about 50% of the No 8 steers treated.

Treatments that applied expensive supplements to achieve high weight gains generally added less value per head than treatments that incurred lower supplement costs or applied more cost effective nutrition. In the No 9 steers there also appears a greater variation in returns in those treatments that did not apply HGP compared to similar nutrition regimes that did. That is, the box plots look more "stretched" in appearance.

Fig. 4. No 9 steers range in steer value added

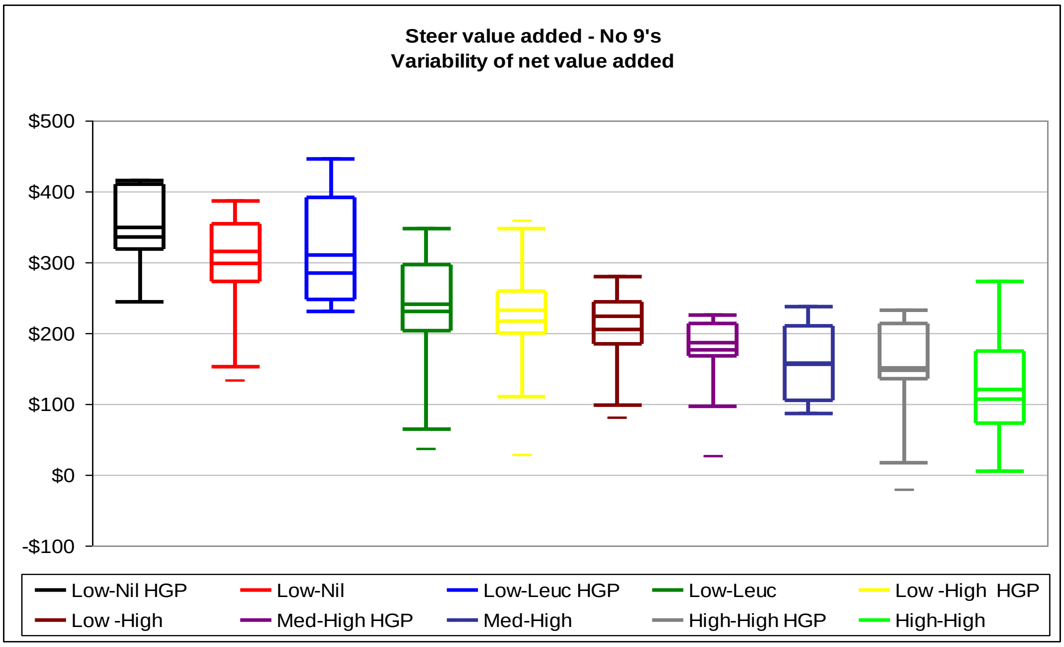


Table 9 records the average value per head added by each treatment. The ranking of net value added remains reasonably consistent across the 2 age groups with the L-nil with HGP treatment generally ranking first or second.

In the No 8 steers the benefit of applying HGP varied from $15 per head in the H-H treatment to $58 per head in the L-leuc treatment. This is after all treatment costs are paid. The L-nil and the L-H treatments in the No 8s were the only treatments in the overall trial not to show a return from the application of HGP.

In the No 9 steers, all treatments benefited from the application of HGP. Steers grazing leucaena again benefited by the greatest amount ($79 per head) even though they were targeting the MSA grade.

Table 9. Average value added by treatment and age group

Treatment		Net value added No 8's*	Rank	Net value added No 9's	Rank
L-nil	+ HGP	$275	2	$336	1
L-nil	no HGP	$289	1	$299	3
L-leuc	+ HGP	$271	3	$310	2
L-leuc	no HGP	$213	4	$231	4
L-H	+ HGP	$79	6	$218	5
L-H	no HGP	$93	5	$205	6
M-H	+ HGP	$59	7	$176	7
M-H	no HGP	$35	8	$157	8
H-H	+ HGP	$15	9	$148	9
H-H	no HGP	$0.50	10	$120	10

Herd model analysis

As the breeding herd within the herd model effectively produces all of the steers on the property, the herd model analysis does not include the purchase cost of the steers. Even so, the herd modelling approach possibly better reflects the level of difference likely to be encountered if the treatments were implemented on a northern beef breeding property and the weight gains and costs incurred in the trial paddock were replicated in the paddock of a commercial beef enterprise.

In this analysis, the difference between the treatments has been recorded as the percentage change in herd gross margin between the base herd (L-nil with HGP treatment) and the herd gross margin calculated for other modelled treatments. The rankings of the treatment are very similar to those achieved in the previous "value added" exercise although the L-leuc treatments now rank first and second in both age groups of steers.

Table 10. Herd model gross margins (after interest) for treatments and age groups

Treatment		**No 8's GM**	Comparison to base	Rank	**No 9's GM**	Comparison to base	Rank
L-nil	+ HGP	**$275,571**	Base	4	**$300,495**	Base	3
L-nil	no HGP	**$281,746**	2.24%	3	**$295,356**	-1.71%	5
L-leuc	+ HGP	**$313,005**	13.58%	1	**$349,537**	16.32%	1
L-leuc	no HGP	**$290,977**	5.59%	2	**$319,163**	6.21%	2
L-H	+ HGP	**$223,426**	-18.92%	6	**$295,611**	-1.63%	4
L-H	no HGP	**$231,616**	-15.95%	5	**$291,445**	-3.01%	6
M-H	+ HGP	**$215,350**	-21.85%	7	**$269,913**	-10.18%	7
M-H	no HGP	**$209,724**	-23.89%	8	**$263,645**	-12.26%	8
H-H	+ HGP	**$201,739**	-26.79%	9	**$258,224**	-14.07%	9
H-H	no HGP	**$197,978**	-28.16%	10	**$250,075**	-16.78%	10

Perusal of Table 10 indicates that the profitability of the modelled property can vary by up to 30% to 40% depending upon which strategy is chosen. A swing in net income of up to $100,000 per annum is possible for a property that runs a breeding herd of about 1000 breeders and chooses the right or wrong strategy. Choosing the right strategy can improve profitability by about 15%.

Once again, the response to treating steers with HGP is not consistent. The application of HGP did not pay in 2 treatment groups of the No 8 steers while all groups of No 9 steers treated with HGP showed better returns than the nil HGP steers in the same treatment group.

Overall, the treatment of steers with HGP at suitable times over their lifetime consistently improved the profitability of the grazing system, even though a grading system (such as MSA) has inbuilt constraints that heavily discount steers that have received HGP treatments. In this trial, the premiums available for non HGP steers did not outweigh the benefits of the extra sale weight provided by the use of the HGP.

Discussion

The physical trial data underpinning the economic models is very robust with the inputs and outputs of the treatments closely and accurately measured. There is also an understanding that the trial results are reasonably applicable across a range of seasons even though the later stages of the trial “suffered” a better than average dry season. The rates of supplements fed and the respective weight gains achieved generally follow expectations based on previous, more piecemeal research activities.

The economic analysis relies on combining the trial data with less accurate industry data and estimated values to calculate the ranking of the trial results in economic terms. Two separate methods were used to try to reduce some of the potential error introduced by any particular methodology. The results produced by the 2 methods are seen as reasonably consistent in their final ranking.

The transferral of the results of a replicated grazing trial held on a research property (or research properties) to a model of what may happen in a commercial setting is not without concerns. Any conclusions that may be drawn about the results of this analysis should keep in mind the usual caveats concerning such modelling exercises. Even so, there are some clear messages highlighted by the results of this analysis.

The first message is that the regular, on-going use of high-cost supplements to target a younger age of turnoff for slaughter cattle on a north Australian beef breeding and fattening property is unlikely to improve overall profitability at the current relationship between costs and returns. Unfortunately, the extra costs of the system will more than offset the extra benefits achieved for the usual north Australian breeding and fattening property that currently targets the sale of finished steers to abattoirs at 36 to 42 months of age.

Part of the problem is the high cost of the supplements fed to achieve the net gains in sale weight but the slim premiums paid for younger steers at the abattoirs, the compensatory growth likely to be achieved in the absence of the supplements and the change in the herd structure on a breeding property managed to meet such markets all conspire against such a strategy. Table 11 indicates the expected change in herd structure on a property running the base herd (L-nil with HGP) for the No 8 steers and the same property running steers receiving the H-H supplements.

One of the significant changes in herd structure caused by targeting a younger age of turnoff in steers is the larger number of wet females that potentially have to be carried through a drought when it occurs. A property operating the H-H strategy would likely go into a drought with about 1050 wet cows (850 + 199) while the L-nil strategy would likely go into the same drought with about 15% fewer females (726+170) in the same state and a much higher proportion of the herd able to be off-loaded as stores or into a feedlot. A herd with a relatively older age of turnoff of steers potentially reduces drought risk and may provide increased marketing flexibility compared to a herd with a younger age of turnoff in a drought management scenario.

Table 11. Modelled herd structure of L-nil with HGP and H-H with HGP

	Base Herd			H-H herd		
Age and class of cattle	**Number kept whole year**	**Number sold**	**Total AEs**	**Number kept whole year**	**Number sold**	**Total AEs**
Extra AE for cows weaning a calf	na	na	212	na	na	248
Weaners 5 months	606	0	159	708	0	155
Heifers 1 year but less than 2	192	105	151	225	122	177
Heifers 2 years but less than 3	170	19	150	199	22	176
Cows 3 years plus	726	142	753	850	166	880
Spayed or surplus females all ages						
Steers 1 year but less than 2	297		188	347	0	233
Steers 2 years but less than 3	292		274		342	187
Bullocks 3 years but less than 4		288	178			
Bulls all ages	35	8	60	41	9	70
Total number	2318	561	2125	2370	661	2125

Part of the costs associated with changing the herd structure on northern properties has been accounted for in the herd modelling exercise. An average allowance has been made for expected drought feeding costs of breeding stock and those costs increase in proportion to the number of female stock run on the property but some of the other advantages provided by having a more flexible turnoff strategy due to the number of age groups of steers on the base property are not accounted for. Even though one of the targets of the trial was to access the premiums available for steers turned of at younger ages, the availability of a premium price for younger steers that meet the MSA grade was not consistent across the life of the project.

Fig. 5 provides a comparison of the quoted price for grass fed Jap Ox and MSA grass fed ox at the Dinmore abattoirs between January 2010 and June 2012. It is considered likely that other abattoirs in Queensland showed a similar range and variation in quoted prices over the same period of time. The variability in prices for the MSA grade appears to be greater than the quoted price for Jap Ox and, on occasions, appears to be lower than the price quoted for Jap Ox in the same month. The pricing structure and premiums shown in Fig. 5 is probably not sufficiently consistent to use as a base for an overall herd management strategy.

For example, selling MSA steers in June or July 2011 would have been at up to a $0.30/kg dressed weight discount to Jap Ox steers sold in September, October or November of the same year. Even though the MSA quote is nearly always more than the Jap Ox quote in the same month, the variation in prices between selling months makes it very difficult to predict that Jap Ox steers will sell for less than MSA grade steers on a per kg basis from the same property. This makes it difficult to justify extra expenditure made in the hope of gaining a higher price per kg from MSA steers.

Another insight that may be drawn from the economic analysis is that the profitability of northern beef enterprises can most likely be improved by the judicious use of pastures and feeding technologies that improve the nutrition and performance of steers by a larger margin than it costs to do so. In this trial, the transfer of the steers to leucaena pasture at a young age did improve the profitability of the enterprise in the herd modelling analysis even though significant transport and “agistment” costs were incurred in doing so. Table 12 shows the modelled herd structure for the L-nil base herd and the L-leuc herd. As the steers are effectively shifted off the property at a young age in this strategy, the change in the herd structure on the base property is quite pronounced.

A northern herd that can improve the nutrition of its steers and maintain an appropriate relativity between the costs and benefits of doing so is likely to improve the overall profitability of the business. Any strategy that dramatically reduces the age of turnoff of steers compared to the norm is also likely to increase the variability of the business returns. Much of this variability is due to the increase in drought risk caused by running proportionally more wet cows in the herd. Even with the potentially increased cost of drought risk of the L-leuc herd accounted for in the analysis, the strategy was still able to significantly improve the overall profitability of the business.

Fig. 5. Quoted over-the-hooks price for grass-fed Jap Ox and MSA grass-fed ox at Dinmore abattoir (Jan 2010 to June 2012)

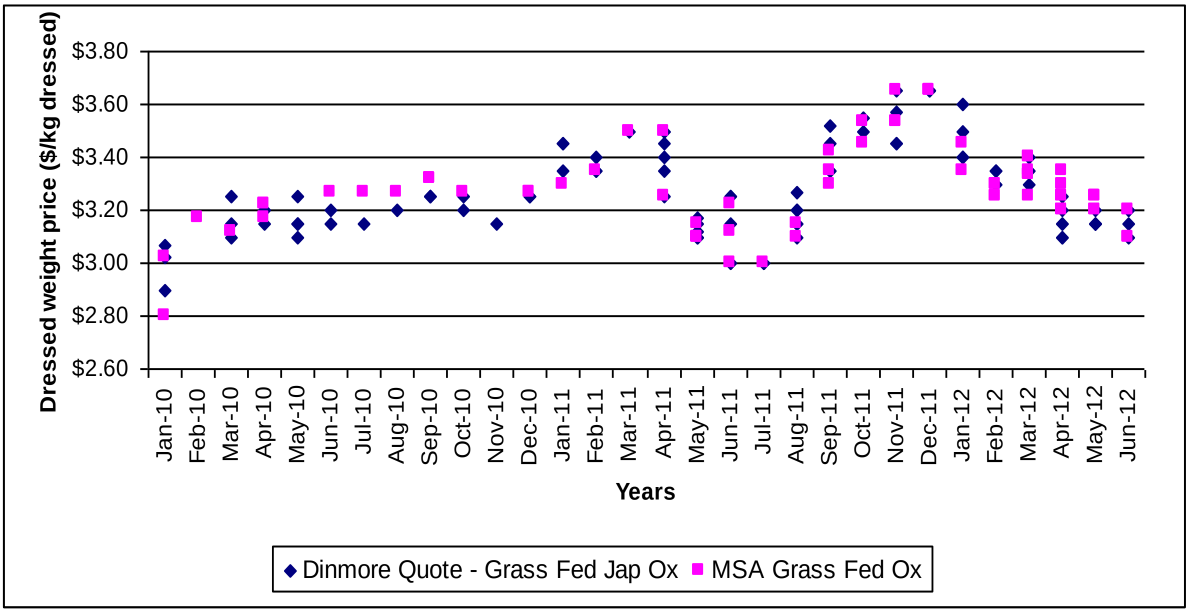


Table 12. Modelled herd structure of L-nil with HGP and L-leuc with HGP

	Base Herd			L-leuc herd		
Age and class of cattle	Number kept whole year	Number sold	Total AEs	Number kept whole year	Number sold	Total AEs
Extra AE for cows weaning a calf	na	na	212	na	na	285
Weaners 5 months	606	0	159	815	0	214
Heifers 1 year but less than 2	192	105	151	259	141	204
Heifers 2 years but less than 3	170	19	150	229	25	202
Cows 3 years plus	726	142	753	978	191	1013
Spayed or surplus females all ages						
Steers 1 year but less than 2	297		188	0	399	126
Steers 2 years but less than 3	292		274	na	na	
Bullocks 3 years but less than 4		288	178			
Bulls all ages	35	8	60	47	11	80
Total number	2318	561	2125	2370	661	2125

The month or timing of sale of the steers as they left the trial may have had some impact on the results of the steers. Even though it is very difficult to adjust the actual prices received without bringing some form of bias into the analysis, the L-leuc steers in the No 9's are seen as receiving an undue advantage and will be adjusted. The amount of advantage was estimated to be about 6.25% above the market that ruled at the time of sale of the other No 9 treatments.

Table 13 compares the herd gross margin for the L-nil Base herd with the L-leuc herd – both with HGP. The third column in the table shows the results of the L-leuc treatment steers modelled with the sale price of the steers adjusted to reflect the higher prices available at the time of sale relative to the other treatments. It can be seen that a 6.25% reduction in the sale price of the steers sold off the leucaena pasture did reduce the total gross margin by about $25,000 per annum but does not change the ranking of the treatment. It is still able to maintain its ranking as the most profitable system.

Any system that offers (on paper) an 8% to 16% increase in the total gross margin of the enterprise is certainly worthy of further investigation. The major unknown in this analysis is the impact on herd structure and profitability of those northern properties with suitable soils and facilities that plant pastures like leucaena to finish steers. Whether the benefits (and costs) of the leucaena accessed by trial steers at Brian Pasture can be replicated elsewhere cannot be answered.

Sensitivity analysis

The results of the economic analysis are likely to be sensitive to changes in the key drivers of the performance of each feeding system. The most important factors in this analysis are seen as the premiums paid for steers turned off at a younger age or better quality, the amount of benefit gained from feeding the supplements and the cost of the supplements.

The price premiums paid for younger or better quality steers are more important to the relativity profitability of treatments than the general level of prices for steers which is likely to change the profitability of the treatments within the trial equally. The price data presented in this analysis indicates a high level of variability in steer prices paid for MSA or Jap Ox steers, even though there was usually a premium for MSA grades over Jap Ox grades. This indicates that a producer of Jap Ox may or may not suffer a price discount compared to a producer of MSA steers. There was a reasonable probability that selling steers in different months could lead to a greater difference in prices than selling steers into specific grades in the same month.

This variability in prices paid for all grades across all months makes it very difficult to test the results of the economic analysis for sensitivity to a price premium for the MSA grade. Such a premium may or may not exist depending upon when the different classes of steers are sold.

Table 13. Summary of herd modelling outputs for No 9 steers

	L-nil + HGP	L-leuc + HGP	L-leuc + HGP with price adjustment
Total AEs	2125	2125	2125
Total cattle carried	2281	2357	2357
Weaner heifers retained	298	413	413
Total breeders mated	984	1363	1363
Total calves weaned	596	825	825
Weaners/total cows mated	60.56%	60.56%	60.56%
Overall breeder deaths	3.19%	3.19%	3.19%
Female sales/total sales %	47.95%	47.20%	47.20%
Total cows and heifers sold	261	362	362
Maximum cow culling age	12	12	12
Heifer joining age	2	2	2
One yr old heifer sales %	35.26%	35.26%	35.26%
Two yr old heifer sales % ...	10.00%	10.00%	10.00%
Total steers & bullocks sold	283	404	404
Max bullock turnoff age	3	1	1
Average female price	$511.55	$511.55	$511.55
Average steer/bullock price	$993.96	$509.49	$509.49
Capital value of herd	$625,956	$867,147	$867,147
Imputed interest on herd val.	$31,298	$43,357	$43,357
Net cattle sales	$415,060	$391,010	$391,010
Direct costs excluding bulls	$67,896	$77,530	$77,530
Bull replacement	$15,371	$21,294	$21,294
Gross margin for herd	$331,793	$292,187	$292,187
GM after imputed interest	$300,495	$248,829	$248,829
GM per adult equivalent	$156.14	$137.50	$137.50
GM/AE after interest	$141.41	$117.10	$117.10
Leucaena GM for steers after interest		$100,708	$74,761
Comparable GM (after interest)	**$300,495**	**$349,537**	**$323,590**
Comparison to base	100.0%	116.32%	107.69%
Rank	3	1	1

The level of benefit to growth of feeding supplements is more or less decided by the trial results. It appears unlikely that feeding supplements with the same composition in different years would lead to a markedly different relationship between the level of input and the amount of growth than the range already described in this trial.

The price paid for molasses-based supplements has risen over recent years and on this basis it was decided to see if a lower price for these supplements would improve the ranking of the high input treatments. The next 3 figures show the results of the value added analysis for the No 8 steers if:

1. the cost of the molasses-based supplements is unchanged (Fig. 6)
2. The cost of the molasses-based supplements is reduced by 25% (Fig. 7), and
3. the cost of the molasses-based supplements is reduced by 50% (Fig. 8).

The No 8 steers were chosen for this exercise as they had substantially greater supplement costs than the No 9 steers and did not have a ‘favourable’ dry season (short and rain-interrupted) during their feeding period.

Fig. 6. Base value added for No 8 steers

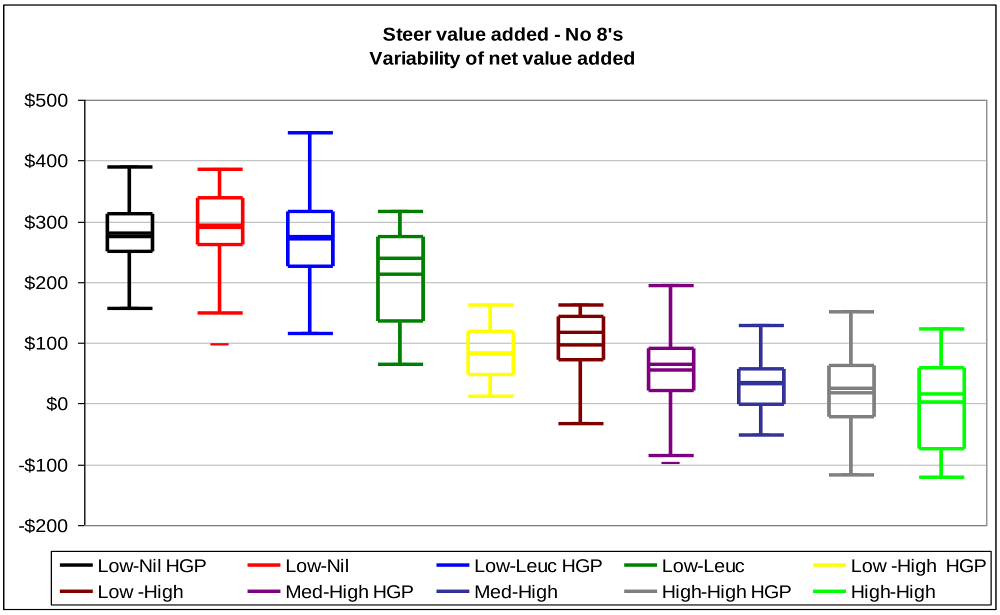
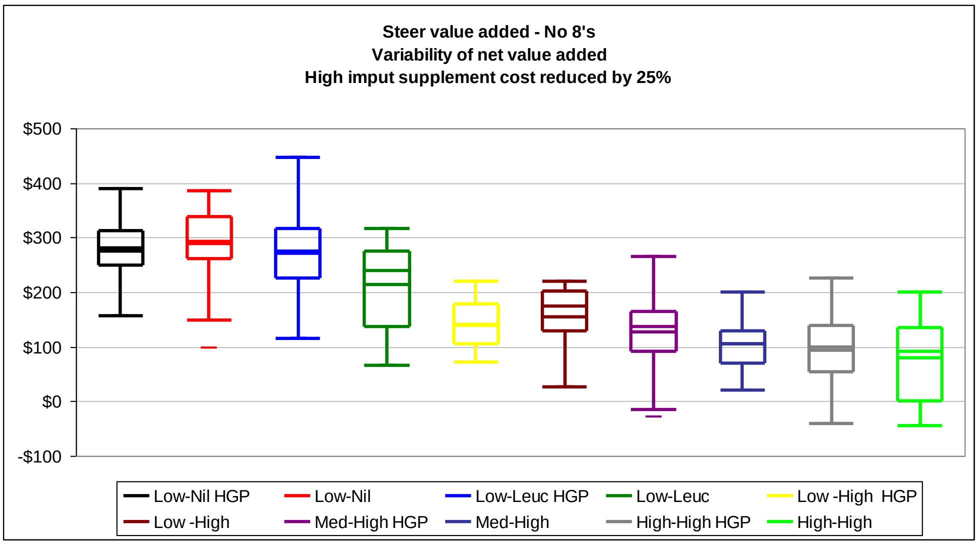
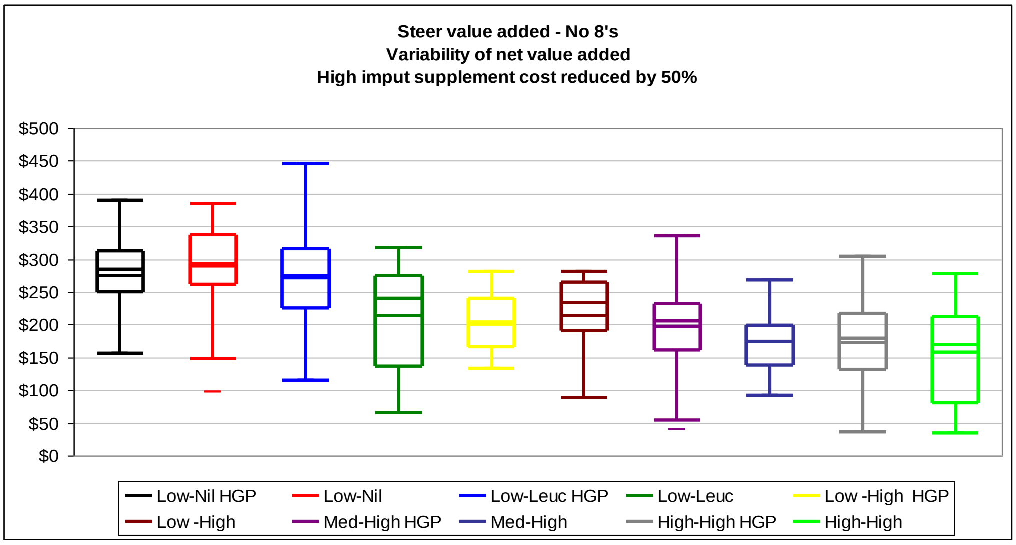


Fig. 7. High input supplement costs reduced by 25% for No 8 steers



Reducing the cost per tonne of the molasses-based supplements by 50% does improve the value added per head in those treatments by a considerable amount. Unfortunately, the reduction in supplement cost is not sufficient to overcome the other costs associated with the treatments (like the feeding-out cost), and these treatments generally remain relatively less profitable than the low-input or leucaena-based treatments.

Fig. 8. **High input supplement costs reduced by 50% for No 8 steers**



References

Holmes WE (2012) 'Breedcow and Dynama Herd Budgeting Software Package, Version 6.0 for Windows 95, 98, Me, NT, 2000, XP and 7'. Training Series QE99002. (Queensland Department of Agriculture, Fisheries and Forestry: Townsville)

Appendix

Average supplement intake and cost

Table 14. Average cost of feeding for No 8 steers

	2008 dry season per head	2009 dry season per head
Low - Nil	$6.90	
Low – Leucaena	$8.66	
Low – High	$9.15	$243.20
Medium - High	$58.11	$219.08
High - High	$98.78	$215.60

Table 15. Average rate of intake for No 8 steers 2008 dry season

	Low -Nil	Low -Leucaena	Low -High	Medium - High	High - High
Average rate of intake (grams per head per day)	66.64	83.68	88.40	2297	3904
Average cost of intake (per day)	$0.0600	$0.0753	$0.0796	$0.5053	$0.8589
Cost of supplement (per gram)	$0.00090	$0.00090	$0.00090	$0.00022	$0.00022
Cost of supplement (per tonne)	$900.00	$900.00	$900.00	$220.00	$220.00

Table 16. Average rate of intake for No 8 steers 2009 dry season

	Low -Nil	Low -Leucaena	Low -High	Medium - High	High - High
Average rate of intake (grams per head per day)			6008	5412	5326
Average cost of intake (per day)			$1.3218	$1.1906	$1.1717
Cost of supplement (per gram)			$0.00022	$0.00022	$0.00022
Cost of supplement (per tonne)			$220.00	$220.00	$220.00

Table 17. Average cost of feeding for No 9 steers

	2009 dry season per head	2010 dry season per head
Low - Nil	$10.91	
Low Leucaena	$10.28	
Low - High	$9.56	$35.83
Medium - High	$95.08	$33.34
High - High	$153.89	$34.44

Table 18. Average rate of intake for No 9 steers 2009 dry season

	Low - Nil	Low Leucaena	Low - High	Medium - High	High - High
Average rate of intake (grams per head per day)	81.76	77.07	71.67	2349	3802
Average cost of intake (per day)	$0.0593	$0.0559	$0.0520	$0.5167	$0.84
Cost of supplement (per gram)	$0.00073	$0.00073	$0.00073	$0.00022	$0.00022
Cost of supplement (per tonne)	$725.00	$725.00	$725.00	$220.00	$220.00

Table 19. Average rate of intake for No 9 steers 2010 dry season

	Low - Nil	Low Leucaena	Low - High	Medium - High	High - High
Average rate of intake (kilograms per head per day)			1.85	1.72	1.78
Average cost of intake (per day)			$0.407	$0.379	$0.391
Cost of supplement (per kilogram)			$0.220	$0.220	$0.220
Cost of supplement (per tonne)			$220.00	$220.00	$220.00

Table 20. No 8 steers stocking rates and opportunity cost of grazing

		Year 1		**Year 2**		**Year 3**			
	Start date	Dry period to	Wet period to	Dry period to	Wet period to	Dry period to	Wet period to	TOTAL	
Low-Nil	18/08/2008	16/12/2008	1/07/2009	7/01/2010	10/06/2010	20/12/2010	20/06/2011		
		Dry days	Wet days	Dry days	Wet days	Dry days	Wet days		
	days	120	197	190	154	193	182	1036	days
	rate (steer/ha)	1.5	1.8	4	4	4	4		
	Opportunity cost / head	$8.63	$17.00	$36.44	$29.53	$37.01	$34.90		
Low-Leucaena		**Year 1**		**Year 2**					
		Dry	Wet	Dry	Wet				
	days	120	197	243				560	days
	rate (steer/ha)	1.5	1.8	1.5					
	Opportunity cost / head	$8.63	$17.00	$85.05					
	Leucaena pasture			$34.20					
Low-High		**Year 1**		**Year 2**					
		Dry	Wet	Dry	Wet				
	days	120	197	190	154			661	days
	rate (steer/ha)	1.5	1.8	2.4	4				
	Opportunity cost / head	$8.63	$17.00	$21.86	$29.53				
Medium-High		**Year 1**		**Year 2**					
		Dry	Wet	Dry	Wet				
	days	120	197	190	154			661	days
	rate (steer/ha)	1.05	1.8	2.4	4				
	Opportunity cost / head	$6.04	$17.00	$21.86	$29.53				
High-High		**Year 1**		**Year 2**					
		Dry	Wet	Dry	Wet				
	days	115	197	190	154			656	days
	rate (steer/ha)	0.9	1.8	2.4	4				
	Opportunity cost / head	$4.96	$17.00	$21.86	$29.53				

Table 21. No 9 steers stocking rates and opportunity cost of grazing

		Year 1		**Year 2**		**Year 3**		TOTAL	
	Start date	End Dry period	End Wet Period	End Dry period	End Wet Period	End Dry period	End Wet Period		
Low-Nil	25/06/2009	8/01/2010	14/07/2010	20/12/2010	7/06/2011	13/12/2011	28/05/2012		
		Dry	Wet	Dry	Wet	Dry	Wet		
	days	197	187	159	169	189	167	1068	days
	rate (steer/ha)	1.5	1.8	4	4	4	4		
	Op cost / head	$14.17	$16.14	$30.49	$32.41	$36.25	$32.03		
Low-Leucaena		**Year 1**		**Year 2**		**Year 3**			
		End dry	End wet	End dry	End wet	End dry	End wet		
	days	197	187	238				622	days
	rate (steer/ha)	1.5	1.8	1.5					
	Op cost / head	$14.17	$16.14	$83.30					
	Leucaena pasture			$33.49					
Low-High		**Year 1**		**Year 2**		**Year 3**			
		End dry	End wet	End dry	End wet	End dry	End wet		
	days	197	187	159	169			712	days
	rate (steer/ha)	1.5	1.8	2.4	4				
	Op cost / head	$14.17	$16.14	$18.30	$32.41				
Medium-High		**Year 1**		**Year 2**		**Year 3**			
		End dry	End wet	End dry	End wet	End dry	End wet		
	days	197	187	159	169			712	days
	rate (steer/ha)	1.05	1.8	2.4	4				
	Op cost / head	$9.92	$16.14	$18.30	$32.41				
High-High		**Year 1**		**Year 2**		**Year 3**			
		Dry	Wet	Dry	Wet	Dry	Wet		
	days	197	187	159	169			712	days
	rate (steer/ha)	0.9	1.8	2.4	4				
	Op cost / head	$8.50	$16.14	$18.30	$32.41				

Parameters of the base breeding herd

Table 22. Opening and closing weights (kg) plus adult equivalent ratings for base herd model

Description	Months at	Months at	Cattle carried through whole year:				Sale stock carried past rating boundary:				
at Start of Rating Period	Start of Rating	End of Rating	Months Rated	Lowest or Start Wt	Highest or End Wt.	AE/head Rating	Sale Month	Months Rated	Start Weight	Weight at Sale	AE/hd Rating
Extra for cows weaning a calf	na	na	na	na	na	0.35	na	na	na	na	na
Weaners 5 months.	5	12	7	180	230	0.26	7	2	180	250	0.08
Heifers 1 year	12	24	12	225	325	0.60	7	7	225	300	0.34
Heifers 2 years	24	36	12	325	430	0.83	7	7	325	420	0.48
Cows 3 years onwards	na	na	12	430	430	0.95	6	6	430	420	0.47
Steers 1 year	12	24	12	238	338	0.63	6	6	238	330	0.31
Steers 2 years	24	36	12	338	516	0.94	6	6	338	500	0.46
Bullocks 3 years	36	48	12	516	609	1.24	6	6	516	609	0.62
Bullocks 4 years	48	60	12	0	0	0.00		0	0	0	0.00
Bullocks 5 years	60	72	12	0	0	0.00		0	0	0	0.00
Bulls all ages	na	na	12	700	700	1.54	6	6	700	650	0.74

Table 23. Sale weight and values for base herd model

Group Description:	Live weight kg/head	Price $/kg	Commission % of Value	Other selling $/head	Freight $/head	Gross Price	Total Selling & Freight Costs	Net Price
Heifers 1 year	300	$1.60	0.00%	$5.00	$6.09	$480.00	$11.09	$468.91
Heifers 2 years	420	$1.40	0.00%	$5.00	$0.00	$588.00	$5.00	$583.00
Cows 3 years	420	$1.30	0.00%	$5.00	$7.50	$546.00	$12.50	$533.50
Steers 3 years	609	$1.45	0.00%	$5.00	$12.68	$885.35	$17.68	$867.67
Cull bulls	650	$1.25	0.00%	$5.00	$13.50	$812.50	$18.50	$794.00

Table 24. Husbandry costs incurred by the Low Nil with HGP herd

Husbandry costs/head	**Husbandry Cost $/Weaner:**				**Husbandry Cost $/Female**				**Husbandry Cost $/Steer**			**Herd Bulls $/hd:**
(variable costs only)	Heifers Kept	*Heifers Sold*	Steers Kept	*Steers Sold*	1-2 yrs Kept	2-3 yrs Kept	3 yrs + Kept	*3 yrs + Sold*	1-2 yrs Kept	2-3 yrs Kept	*3-4 yrs Sold*	Bulls Kept
5 in 1 vaccine	$0.38	*$0.38*	$0.38	*$0.38*								
Botulism C&D							$0.90	*$0.90*				$0.90
Botulism single vac	$2.50	*$2.50*	$2.50	*$2.50*								
Weaner drench	$1.50	*$1.50*	$1.50	*$1.50*								
Vibrio for bulls												$7.00
Weaner feed	$20.00		$20.00									
Pregnancy test						$4.00						
Dry season breeder lick (includes feeding out cost)					$20.00	$20.00	$20.00					$20.00
Bull fertility test (new bulls only)												$20.00
Steers Bovine Ephemeral Fever vaccination			$9.00						$9.00	$9.00	*$9.00*	
Steer supplement first period									$6.98			
Steers supplement first period feeding out cost									$8.21			
Steer HGP costs									$10.40	$5.35	*$10.40*	
Total husbandry cost/group ...	$24.38	*$4.38*	$33.38	*$4.38*	$20.00	$24.00	$20.90	*$0.90*	$34.59	$14.35	*$19.40*	$47.90

Table 25. Calving and death rate assumptions

Cattle age start year	Weaners	1	2	3	4	5	6	7	8	9	10	11
Cattle age end year	1	2	3	4	5	6	7	8	9	10	11	12
Calves weaned/cows retained	na	0.0%	80.0%	40.0%	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%
Female death rate	2.0%	1.5%	4.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Spayed or surplus female death rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Male death rate	2.0%	1.5%	1.5%	1.5%	1.0%	*No entries allowed for bullocks past 5 yrs of age*						

Summary of value added analysis results

Table 26. No 8 steers value added analysis

Treatments	Low-Nil With HGP	Low-Nil No HGP	Low -leuc With HGP	Low-leuc No HGP	Low-High With HGP	Low-High No HGP	Medium-High With HGP	Medium-High No HGP	High-High With HGP	High-High No HGP
Income of treatments										
Steer sale gross value ($/head)	$885.33	$870.66	$916.93	$846.46	$831.89	$829.53	$837.46	$796.38	$829.27	$794.52
Steer sale price dressed ($/kg)	$2.78	$2.78	$3.19	$3.18	$2.87	$2.93	$2.86	$2.88	$2.86	$2.88
Steer sale weight dressed (kg)	319	314	287	266	290	283	293	277	290	276
Steer sale price liveweight ($/kg)	$1.46	$1.45	$1.65	$1.66	$1.54	$1.58	$1.54	$1.51	$1.52	$1.50
Steer sale weight liveweight (kg)	609	599	554	511	540	526	544	527	546	529
Costs of treatments										
Steer purchase cost ($/head)	$286.39	$284.44	$285.38	$287.12	$285.58	$288.50	$286.67	$288.64	$286.09	$285.69
Steer purchase price ($/kg liveweight)	$1.38	$1.38	$1.38	$1.38	$1.38	$1.38	$1.38	$1.38	$1.38	$1.38
Steer purchase weight (kg)	208	207	208	209	208	210	208	210	208	208
Transport cost to property	$21.40	$21.40	$21.40	$21.40	$21.40	$21.40	$21.40	$21.40	$21.40	$21.40
HGP	$26.15	$0.00	$14.60	$0.00	$19.95	$0.00	$19.95	$0.00	$19.95	$0.00
Bovine Ephemeral Fever	$36.00	$36.00	$27.00	$27.00	$27.00	$27.00	$27.00	$27.00	$27.00	$27.00
Supplement first period	$6.98	$6.90	$8.66	$8.66	$9.13	$9.13	$58.11	$58.11	$98.78	$98.78
Supplement feeding out cost first period	$8.21	$8.21	$8.21	$8.21	$8.21	$8.21	$10.27	$10.27	$10.27	$10.27
Supplement second period	$0.00	$0.00	$0.00	$0.00	$242.92	$243.00	$219.08	$219.08	$215.60	$215.60
Supplement feeding out cost second period	$0.00	$0.00	$0.00	$0.00	$16.43	$16.43	$16.43	$16.43	$16.43	$16.43
Transport to leucaena	$0.00	$0.00	$71.50	$71.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
leucaena bug drench	$0.00	$0.00	$2.50	$2.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Opportunity cost of steer capital	$43.72	$43.45	$23.53	$23.67	$27.80	$28.06	$27.90	$28.07	$27.84	$27.81
Selling costs	$17.68	$17.68	$38.15	$38.15	$17.68	$17.68	$17.68	$17.68	$17.68	$17.68
Opportunity cost of land and pasture	$163.52	$163.52	$144.88	$144.88	$77.03	$77.03	$74.44	$74.44	$73.36	$73.36
Total cost of treatments	$610.07	$581.59	$645.81	$633.09	$753.13	$736.44	$778.92	$761.11	$814.39	$794.00
Net value added No 8s*	$275.27	$289.07	$271.12	$213.37*	$78.76	$93.09	$58.54	$35.27	$14.88	$0.52
Net value added (no L Leucaena N price adjustment)	$275.27	$289.07	$271.12	$201.97	$78.76	$93.09	$58.54	$35.27	$14.88	$0.52
Rank	2	1	3	4	6	5	7	8	9	10

* The price of the Low Leucaena steer treatment has been adjusted to reflect MSA premiums that should have been paid

Table 27. No 9 steers value added analysis

Treatments	**Low-Nil With HGP**	**Low-Nil No HGP**	**Low -leuc With HGP**	**Low-leuc No HGP**	**Low-High With HGP**	**Low-High No HGP**	**Medium-High With HGP**	**Medium-High No HGP**	**High-High With HGP**	**High-High No HGP**
Income of treatments										
Steer sale gross value ($/head)	$1,012	$945	$1,028	$934	$822	$786	$866	$824	$894	$842
Steer sale price dressed ($/kg)	$2.92	$2.92	$3.41	$3.44	$2.82	$2.82	$2.86	$2.83	$2.86	$2.83
Steer sale weight dressed (kg)	346.77	323	301	271	291	279	302	291	313	298
Steer sale price liveweight ($/kg)	$1.48	$1.4632	$1.79	$1.78	$1.44	$1.44	$1.48	$1.43	$1.47	$1.46
Steer sale weight liveweight (kg)	684	646	574	523	571	546	587	575	607	578
Costs of treatments										
Steer purchase cost ($/head)	$347.37	$350.78	$350.67	$353.16	$350.22	$350.34	$351.72	$350.18	$352.44	$351.12
Steer purchase price ($/kg liveweight)	$1.68	$1.68	$1.68	$1.68	$1.68	$1.68	$1.68	$1.68	$1.68	$1.68
Steer purchase weight (kg)	207	209	209	210	208	209	209	208	210	209
HGP	$32.95		$17.20		$22.55		$22.55		$22.55	
Bovine Ephemeral Fever + tick control	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00
Supplement first period	$11.08	$10.89	$10.26	$10.18	$9.54	$9.54	$97.62	$97.79	$152.51	$152.78
Supplement feeding out cost first period	$13.14	$13.14	$13.14	$13.14	$13.14	$13.14	$16.43	$16.43	$16.43	$16.43
Supplement second period					$35.83	$35.83	$33.34	$33.34	$34.44	$34.44
Supplement feeding out cost second period					$7.86	$7.86	$7.86	$7.86	$7.86	$7.86
BEF booster	$18.00	$18.00	$9.00	$9.00	$9.00	$9.00	$9.00	$9.00	$9.00	$9.00
Transport to leucaena			$71.50	$71.50						
leucaena bug drench			$2.50	$2.50						
Dectomax			$5.00	$5.00						
Opportunity cost of steer capital	$50.82	$51.32	$29.88	$30.09	$34.16	$34.17	$34.30	$34.15	$34.37	$34.25
Selling costs	$17.68	$17.68	$38.15	$38.15	$17.68	$17.68	$17.68	$17.68	$17.68	$17.68
Opportunity cost of land and pasture	$161.48	$161.48	$147.10	$147.10	$81.01	$81.01	$76.76	$76.76	$75.35	$75.35
Total cost of treatments	$676	$646	$717	$703	$604	$582	$690	$666	$746	$722
Net value added No 9s	$336	$299	$310	$231	$218	$205	$176	$157	$148	$120
Rank	1	3	2	4	5	6	7	8	9	10

Summary of herd model analysis results

Table 28. No 8s Breedcowplus analysis

Treatment	Low Nil with HGP	Low Nil no HGP	Low Leucaena with HGP	Low Leucaena no HGP	Low High with HGP	Low High no HGP	Medium High with HGP	Medium High no HGP	High High with HGP	High High no HGP
Total adult equivalents.	2125	2125	2125	2125	2125	2125	2125	2125	2125	2125
Total cattle carried	2318	2341	2328	2330	2353	2375	2366	2383	2370	2384
Weaner heifers retained	303	306	408	408	352	355	354	356	354	356
Total breeders mated	1000	1010	1346	1347	1161	1172	1168	1176	1170	1176
Total calves weaned	606	611	815	816	703	710	707	712	708	712
Weaners/total cows mated	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%
Overall breeder deaths	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%
Female sales/total sales %	47.95%	47.95%	47.20%	47.20%	47.58%	47.58%	47.58%	47.58%	47.58%	47.58%
Total cows and heifers sold	265	268	357	357	308	311	310	312	310	312
Maximum cow culling age	12	12	12	12	12	12	12	12	12	12
Heifer joining age	2	2	2	2	2	2	2	2	2	2
One yr old heifer sales %	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%
Two yr old heifer sales %	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
Total steers & bullocks sold	288	291	399	400	339	343	341	344	342	344
Max bullock turnoff age	3	3	1	1	2	2	2	2	2	2
Average female price	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55
Average steer/bullock price	$867.67	$852.99	$470.40	$462.00	$814.21	$811.84	$819.77	$778.68	$811.59	$776.84
Capital value of herd	$636,115	$642,346	$856,271	$856,979	$738,853	$745,619	$743,004	$748,138	$744,105	$748,443
Imputed interest on herd val.	$31,806	$32,117	$42,814	$42,849	$36,943	$37,281	$37,150	$37,407	$37,205	$37,422
Net cattle sales.	$385,441	$384,950	$370,496	$367,444	$433,966	$437,127	$438,300	$427,208	$436,154	$426,749
Direct costs excluding bulls	$62,443	$55,313	$71,563	$67,465	$155,453	$149,920	$167,555	$161,705	$178,938	$172,970
Bull replacement	$15,621	$15,774	$21,027	$21,044	$18,143	$18,310	$18,245	$18,371	$18,272	$18,379
Gross margin for herd	$307,377	$313,864	$277,906	$278,935	$260,369	$268,897	$252,500	$247,131	$238,944	$235,400
GM after imputed interest	$275,571	$281,746	$235,092	$236,086	$223,426	$231,616	$215,350	$209,724	$201,739	$197,978
GM per adult equivalent	$144.65	$147.70	$130.78	$131.26	$122.53	$126.54	$118.82	$116.30	$112.44	$110.78
GM/AE after interest	$129.68	$132.59	$110.63	$111.10	$105.14	$109.00	$101.34	$98.69	$94.94	$93.17
Leucaena gross margin for steers after interest			$77,912	$54,891						

Comparable GM (after interest)	**$275,571**	**$281,746**	**$313,005**	**$290,977**	**$223,426**	**$231,616**	**$215,350**	**$209,724**	**$201,739**	**$197,978**
Comparison to base	Base	+2.24%	+13.58%	+5.59%	-18.92%	-15.95%	-21.85%	-23.89%	-26.79%	-28.16%
Rank	4	3	1	2	6	5	7	8	9	10

Table 29. No 9s Breedcowplus analysis

	Low Nil with HGP	Low Nil no HGP	Low Leucaena with HGP	Low Leucaena no HGP	Low High with HGP	Low High no HGP	Medium High with HGP	Medium High no HGP	High High with HGP	High High no HGP
Total adult equivalents	2125	2125	2125	2125	2125	2125	2125	2125	2125	2125
Total cattle carried	2281	2313	2357	2366	2403	2422	2342	2348	2330	2347
Weaner heifers retained	298	302	413	414	359	362	350	351	348	351
Total breeders mated	984	998	1363	1368	1186	1195	1156	1159	1150	1158
Total calves weaned	596	604	825	828	718	724	700	702	696	701
Weaners/total cows mated	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%	60.56%
Overall breeder deaths	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%	3.19%
Female sales/total sales %	47.95%	47.95%	47.20%	47.20%	47.58%	47.58%	47.58%	47.58%	47.58%	47.58%
Total cows and heifers sold	261	265	362	363	315	317	307	307	305	307
Maximum cow culling age	12	12	12	12	12	12	12	12	12	12
Heifer joining age	2	2	2	2	2	2	2	2	2	2
One yr old heifer sales %	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%	35.26%
Two yr old heifer sales %	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
Total steers & bullocks sold	283	287	404	406	347	349	338	339	336	339
Max bullock turnoff age	3	3	1	1	2	2	2	2	2	2
Average female price	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55	$511.55
Average steer/bullock price	$993.96	$927.57	$509.49	$487.93	$805.03	$768.73	$848.69	$805.49	$875.93	$823.69
Capital value of herd	$625,956	$634,642	$867,147	$870,353	$754,571	$760,544	$735,379	$737,080	$731,686	$736,886
Imputed interest on herd val.	$31,298	$31,732	$43,357	$43,518	$37,729	$38,027	$36,769	$36,854	$36,584	$36,844
Net cattle sales	$415,060	$401,752	$391,010	$383,704	$440,013	$430,813	$443,575	$429,970	$450,504	$436,020
Direct costs excluding bulls	$67,896	$59,079	$77,530	$73,976	$88,143	$82,665	$118,834	$111,371	$137,728	$131,006
Bull replacement	$15,371	$15,584	$21,294	$21,373	$18,529	$18,676	$18,058	$18,100	$17,967	$18,095
Gross margin for herd	$331,793	$327,088	$292,187	$288,355	$333,340	$329,472	$306,682	$300,499	$294,809	$286,919
GM after imputed interest	$300,495	$295,356	$248,829	$244,837	$295,611	$291,445	$269,913	$263,645	$258,224	$250,075
GM per adult equivalent	$156.14	$153.92	$137.50	$135.70	$156.87	$155.05	$144.32	$141.41	$138.73	$135.02
GM/AE after interest	$141.41	$138.99	$117.10	$115.22	$139.11	$137.15	$127.02	$124.07	$121.52	$117.68
Leucaena gross margin for steers after interest			$100,708	$74,326						
Comparable GM (after interest)	**$300,495**	**$295,356**	**$349,537**	**$319,163**	**$295,611**	**$291,445**	**$269,913**	**$263,645**	**$258,224**	**$250,075**
Comparison to base	100.0%	-1.71%	16.32%	6.21%	-1.63%	-3.01%	-10.18%	-12.26%	-14.07%	-16.78%
Rank	3	5	1	2	4	6	7	8	9	10

Leucaena gross margin analysis

Table 30. No 8 steers fed leucaena with HGP

Output							per head	Total for group
No of steers		399						
Steer value at end		$1.65	$/kg x	554	kg live weight		$916.92	$365,852
less		Extra selling costs		Livestock levy			$5	$1,995
				Freight out			$33.15	$13,227
Gross income expected at end							**$878.77**	**$350,630**
							-	-
Variable costs								
What is each steer worth at the start?								
Steer weight into paddock				336	kg live			
Steer value ($/kg)				$1.40				
	Steer cost						$470.40	$187,690
What will it cost to feed the steers?								
Feeding cost ($/week)				$3.44	per week			
Estimated number of weeks				34.71	weeks		$119.24	$47,578
What will be the final weight?								
Expected weight gain per day					0.89848	kg		
Number of days (calculated)					243	days		
Final weight of steer					554.3302	kg		
Other costs?								
Trucking in	30	steers/deck	1100	kms	$1.95	per km	$71.50	$28,529
Interest	on steer	5	%				$15.66	$6,248
Treatment costs		Growth promotant					$4.20	$1,676
		Mustering and travelling					$0.00	$0
		Veterinary costs					$2.50	$998
	Losses at	0	% of steers				$0.00	$0
		Other costs					$ -	$0
Total variable costs							**$683.50**	**$272,718**
Gross margin							$195.27	$77,912

Table 31. No 8 steers fed leucaena without HGP

Output							per head	Total for group
No of steer		400						
Steer value at end		$1.66	$/kg x	511	kg live weight		$846.00	$338,400
less		Extra selling costs		Livestock levy			$5	$2,000
				Freight out			$33.15	$13,260
Gross income expected at end							**$807.85**	**$323,140**
							-	-
Variable costs								
What is each steer worth at the start?								
Steer weight into paddock				330	kg live			
Steer value ($/kg)				$1.40				
	Steer cost						$462.00	$184,800
What will it cost to feed the steers?								
Feeding cost ($/week)				$3.44	per week			
Estimated number of weeks				34.71	weeks		$119.24	$47,697
What will be the final weight?								
Expected weight gain per day					0.74294	kg		
Number of days (calculated)					243	days		
Final weight of steer					510.5344	kg		
Other costs?								
Trucking in	30	steers/deck	1100	kms	$1.95	per km	$71.50	$28,600
Interest	on steer	5	%				$15.38	$6,152
Treatment costs		Growth promotant					$0.00	$0
		Mustering and travelling					$0.00	$0
		Veterinary costs					$2.50	$1,000
	Losses at	0	% of steers				$0.00	$0
		Other costs					$ -	$0
Total variable costs							**$670.62**	**$268,249**
Gross margin							$137.23	$54,891

Table 32. No 9 steers fed leucaena with HGP

Output							per head	Total for group
No of steers		404						
Steer value at end of period		$1.79	$/kg x	574	kg live weight		$1,027.62	$415,160
less		Extra selling costs		Livestock levy			$5	$2,020
				Freight out			$33.15	$13,393
Gross income expected at end							**$989.47**	**$399,748**
							-	-
Variable costs								
What is each steer worth at the start of the period?								
Steer weight into paddock				351	kg live			
Steer value at start ($/kg)				$1.45				
	Steer cost						$509.49	$205,833
What will it cost to feed the steers?								
Feeding cost ($/week)				$2.98	per week			
Estimated number of weeks of feeding				39.14	weeks		$116.79	$47,183
What will be the final weight?								
Expected weight gain per day					0.81204	kg		
Number of days					274	days		
Final weight of steer					573.87	kg		
Other costs?								
Trucking in	30	steers/deck	1100	kms	$1.95	per km	$71.50	$28,886
Interest	on steer	5	%				$19.12	$7,724
Treatment costs		Growth promotant					$6.80	$2,747
		Mustering and travelling					$0.00	$0
		Veterinary and other costs					$16.50	$6,666
	Losses at	0	% of steers				$0.00	$0
		Other costs					$ -	$0
Total variable costs							**$740.20**	**$299,039**
Gross margin							$249.28	$100,708

Table 33. No 9 steers fed leucaena without HGP

Output							per head	Total for group
No of steers		406						
Steer value at end		$1.78	$/kg x	523	kg live weight		$933.00	$378,798
less		Extra selling costs		Livestock levy			$5	$2,030
				Freight out			$33.15	$13,459
Gross income expected at end							**$894.85**	**$363,309**
							-	-
Variable costs								
What is each steer worth at the start?								
Steer weight into paddock				337	kg live			
Steer value ($/kg)				$1.45				
	Steer cost						$488.65	$198,392
What will it cost to feed the steers?								
Feeding cost ($/week)				$2.98	per week			
Estimated number of weeks				39.14	weeks		$116.79	$47,417
What will be the final weight?								
Expected weight gain per day					0.67934	kg		
Number of days (calculated)					274	days		
Final weight of steer					523.1400	kg		
Other costs of agistment?								
Trucking in	30	steers/deck	1100	kms	$1.95	per km	$71.50	$29,029
Interest	on steer	5	%				$18.34	$7,446
Treatment costs		Growth promotant					$0.00	$0
		Mustering and travelling					$0.00	$0
		Veterinary and other costs					$16.50	$6,699
	Losses at	0	% of steers				$0.00	$0
		Other costs					$ -	$0
Total variable costs							**$711.78**	**$288,983**
Gross margin							$183.07	$74,326

13.3 Detailed Report 3: Stage of maturity of steers x supplement response trial

Effect of stage of maturity of cattle on responses to supplements fed with low quality forages

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Introduction

In order to achieve the higher overall growth rates required to finish cattle in northern Australia for premium markets demanding heavy carcasses at young age, it is often necessary to feed supplements during periods of low growth. These supplements are commonly imposed during the dry seasons when feeding is more practical and responses to additional nutrients are optimised. A typical growth path of cattle from weaning to slaughter can span 2 or more dry seasons and supplements can potentially be fed in any of these. One question being asked in the grazing study from this project is: what is the best age to impose the nutritional intervention on the cattle. At the extremes this could involve feeding young, growing cattle soon after weaning or alternatively supplementing mature-aged cattle in the last dry season before slaughter. The question is then one of whether there are differences in the utilisation of nutrients by the different aged cattle and, by corollary, whether supplements should therefore be formulated differently according to their age and stage of development. This is the practical question being addressed in the studies described below.

As cattle age, the proportional deposition of different tissue types changes such that there is relatively more protein and less fat deposited in young compared with older animals, and *vice versa* (CSIRO 2007). The energy cost for protein deposition is markedly higher than for fat (McRae and Lobley 1982; Butler-Hogg and Cruickshank 1989; Poppi 1990), largely related to the higher, energy-demanding turnover of protein relative to fat (Geenty and Rattray 1987). However, energy used solely for protein synthesis results in 5-6 times greater empty body weight gain than when it is used solely for fat deposition, largely due to the association of water with lean tissue deposition (*ca*. 3.5 g water + 1 g protein; CSIRO 2007). Accordingly, it might be expected that young cattle with their higher protein deposition and composition would be more efficient in their conversion of additional nutrients to growth than older animals. However, the types of nutrients required by the different age groups also changes with stage of maturity and it is also likely that their responses will also differ with diet composition. Older cattle in the fattening phase require glucogenic precursors to support fat synthesis (MacRae and Lobley 1982), as perhaps provided by starch in grains, whilst younger cattle have a high demand for protein for lean growth (Orskov *et al.* 1976). In support, tables provided by AFRC (1993) of metabolisable protein (MP) and ME requirements for cattle stipulate MP/ME ratios (g/MJ) of 6.2 and 4.3 for 200 and 500 kg steers, respectively, growing at 1 kg/day. Nevertheless, clear evidence of the dietary influence on body composition is not abundant.

The experiments described below were designed to compare the response by young and older cattle to supplements providing different combinations of nutrients, including high concentrations of rumen degradable and undegraded protein, grain starch with high rumen fermentation characteristics, and a source of soluble sugars. The supplements were based around a protein meal in the form of cottonseed meal, a grain source in barley and molasses as a fermentable sugar source. By using commercially-used feed sources, and providing these in a dose response manner, the ensuing response curves should provide a framework for formulating practical feed supplements for grazing cattle.

Materials and methods

Two pen feeding experiments, hereafter Exp1 (carried out in 2008) and Exp2 (2010), of similar design and with similar objectives but using different supplement treatments, were carried out at Brian Pastures Research Station near Gayndah, Queensland. As the experimental design and procedures were similar for both experiments the description of methodology below refers to both except where otherwise indicated. The experiments were carried out with endorsement by the Staff Access Animal Ethics Committee of the Dept of Agriculture, Fisheries and Forestry, Queensland with approval references SA-2008/09/263 and SA-2010/09/328, respectively.

Animals, treatments and experimental design

For both experiments, Brahman crossbred steers (*ca.* 5/8 *Bos indicus* content) of 2 age groups but of the same genetic origin were sourced from the commercial herd at Swans Lagoon Research Station, 120 km south-east of Townsville. The ages of the steers were *ca.* 10-12 months (Young) and *ca.* 33-36 months (Old). At the commencement of the studies the average liveweight of the steers was 195.5 (± 7.00; sd) and 424.6 (± 18.87), and 203.3 (± 7.43) and 440.1 (± 16.38) kg, for Young and Old steers in Exp1 and Exp2, respectively. A basal diet of low quality hay was fed *ad libitum* to all steers, this being pangola grass (*Digitaria eriantha* subspecies *Pentzii*) in Exp1 and black speargrass (*Heteropogon contortus*) in Exp2. The experimental design was a randomised block incorporating response surfaces with 2 age groups x 2 supplement types x 4 levels of feeding with from 2 to 4 replicates per feeding level (see below), plus unsupplemented Control steers. Steers were fed in individual pens with 42-44 pens used in total.

In Exp1, the 2 supplements used were barley grain mix plus urea-sulphur (Bar1) and cottonseed meal (CSM). The cottonseed meal was fed without additives. The barley mix was formulated by thoroughly mixing coarsely-cracked (roller-milled) barley (94.33%; w/w, as fed), salt (0.94%), limestone (0.94%), molasses (1.89%) and water (1.89%). Steers on the barley treatments also received 200 g (Young) or 440 g (Old) daily of a urea-ammonium sulphate solution (urea-S), formulated to balance rumen degradable nitrogen (RDN) with digestible organic matter (DOM) supply in the rumen. This solution contained, by weight as fed, 20.45% urea, 5.45% ammonium sulphate (Gran-am®; Incitec Pivot Ltd, Australia) and 75% water so that the steers received, daily, 40.9 (Young) or 90.0 (Old) g urea. The barley mix was offered at 0.5, 1.0, 1.5 and 2.0% liveweight (W)/day whilst the CSM was offered at 0.25, 0.5, 0.75 and 1.0%W/day. The lower intakes for CSM were for commercially practical reasons and also based on past results (McLennan 1997). For each age group there were 2 replicates for each feeding level except when Bar1 was fed at 2%W/day, when 3 steers were used to counter the likelihood of incomplete intake of supplement by 1 or more steers. There were 4 unsupplemented Controls for each age group.

In Exp2, the 2 supplements used were a barley-based treatment (Bar2) similar to the Bar1 described for Exp1 and a molasses-based mix containing urea and protein meal (MUP). The Bar2 supplement differed slightly to that used in Exp 1 in that

Rumensin®100 (active ingredient monensin at 100 g/kg; Elanco®, Eli Lilly Australia Pty Ltd) was added in order to be consistent in this respect with the MUP mix. Thus the barley mix comprised coarsely-cracked (roller-milled) barley (94.30%; w/w, as fed), salt (0.94%), limestone (0.94%), molasses (1.89%), water (1.89%) and Rumensin® 100 (0.05%). Steers on the Bar2 treatments also received the urea-S solution, as described above. The MUP mix was the same as used in the growth path grazing study at Swans Lagoon (McLennan *et al.* 2013). It contained molasses (86.9%; w/w, as fed), urea (2.6%), copra meal (8.7%), salt (0.87%), dicalcium phosphate (0.87%) and Rumensin®100 (0.04%), which was thoroughly mixed for at least 20 min in a mixing tank incorporating motor-driven paddles. Both the barley mix and the MUP were offered at 0.5, 1.0, 1.5 and 2.0%W/day. For each age group there were 2 replicates for each feeding level except with supplements fed at 2%W/day when 3 and 4 steers, respectively, were used to counter the likelihood of incomplete intake of supplement. There were 3 unsupplemented Controls for each age group.

Procedures

Each experiment consisted of a 6 day initial equilibration, a 70 day experimental and a 4 day final equilibration period. During the initial equilibration period steers in excess of the number required were fed the basal hay *ad libitum*, without supplements, in group pens. At the end of this period, they were weighed full and fasted (24 h off feed, 16 h off water) and the required number were allocated to treatments by stratified randomisation on the basis of the fasted liveweight (day 0). Within age groups steers were divided into 2 weight classes at allocation with each class representing a block in the above pen structure and with blocks allocated to either the eastern or western side of the pen complex. Steers were allocated to pens randomly within blocks.

The hay was fed once daily (0800 h) and residues of hay and supplement were collected once weekly. Hay was fed to each steer at an amount estimated, after bunk inspection, to provide about 15% in excess of its intake on the previous day thereby maintaining *ad libitum* intake. The urea-S solution was sprinkled on and mixed into the hay once daily soon after the hay was fed out. It was fed separate from the barley mix to reduce the possibility of urea toxicity in the event of rapid grain intake. The other supplements were fed out in separate feeders from the hay to allow the intake of both dietary components to be accurately determined. The CSM and MUP supplements were fed once daily at the same time as the hay. In both experiments, the barley mix was fed twice daily in equal quantities, about 1 h after the hay and at 1600 h, in order to reduce the rate of grain intake and the possibility of acidosis. For the same reason, the amount of barley mix fed was slowly and incrementally increased to treatment rates over the first 10 days of the experiments. Each week the steers were weighed full before feeding and the amount of supplement fed daily was adjusted, on an individual steer basis, on these new weights to maintain a constant intake on a liveweight basis. Representative samples of the hay and supplements fed out, and the residue hay and supplement, were collected weekly and dried to constant weight at 60°C to determine dry matter (DM) content. For the molasses, MUP mix and MUP residue feeds, triplicate weighed sub-samples were taken into aluminium trays to which were added approximately equal weights of water and weighed amounts of oven-dried paper towel used to take up the diluted molasses sample. This combination was then dried to constant weight at 60°C over about 4 days and DM content determined. Feed samples were bulked over 35 day periods for later chemical analyses. At the end of the 70 day experimental phase the steers were weighed full and fasted and then returned to their pens and fed the basal hay *ad libitum* for 4 days to equilibrate gut fill after which they were again weighed full and fasted.

From day 43 to 49 a total collection of the faeces from the concrete floor of each pen was undertaken at least 3 times daily. Each day the total faeces for each steer was weighed, thoroughly mixed and a representative 10% by weight sub-sample taken and frozen. After the final collection, the daily sub-samples for each individual steer were thawed, bulked and mechanically mixed. Duplicate sub-samples were taken and dried to constant weight at 60^{o}C and faecal DM output and the digestibility of DM (DMD) were determined.

On day 58, rumen fluid was collected *per os* from all steers using a stomach tube and vacuum pump under mild vacuum. Feeding was staggered in time so that sampling of each steer occurred *ca.* 3 h after feeding the hay, which coincided with 3 h after feeding the CSM, MUP and urea-S and 2 h after feeding the morning portion of the barley mix supplements. The pH of the rumen fluid was measured immediately and the fluid was then strained through nylon stocking and divided into several samples, viz., (i) 16 mL acidified to pH<3 with concentrated sulphuric acid for determination of the concentration and molar proportions of volatile fatty acids (VFAs); and (ii) 4 mL added to equal volume of 0.2N hydrochloric acid to determine ammonia-nitrogen (NH_3-N) concentration. At the same time a 10 mL sample of blood was taken from the tail vein of steers into heparinised glass tubes, placed on ice for a short time and then centrifuged to collect the plasma which was then frozen at -18^{o}C awaiting analysis for urea-N concentration. The amount of CSM, MUP and barley mix, but not hay or urea-S, consumed between feeding and sampling was also determined.

Lab analyses

Samples of hay, barley, barley mixes and cottonseed meal were ground through a 1 mm screen prior to analysis. The ash content was determined by combusting *ca.* 1 g of oven-dried ground sample in an electric muffle furnace (Thermogravimetric Analyser TGA-701, LECO Corporation, USA) at 600°C for 2 h, and organic matter (OM) was determined by difference. The total N concentrations of samples were determined by a combustion method (Sweeney 1989) using an Elementar Rapid-N analyser (Elementar Analysensysteme, Germany) calibrated using AR-grade aspartic acid. The fibre content was determined using the following methods: crude fibre by standard AOAC (1975) procedures, ADF content by the method of Van Soest (1963) and the NDF content by the method of Van Soest and Vine (1967), all adapted for the Fibretec 2021 Fibrecap System (application sub-notes ASN 3801, 3804 and 3805, respectively) by FOSS TECATOR. The ether extract (EE; crude fat) content was determined by Soxhlet extraction using hexane. Starch was analysed by conversion to glucose using a two-step enzyme treatment, and colorimetric determination of glucose with a glucose oxidase/peroxidise reagent. The enzymes and other reagents were supplied in kit form (Megazyme, provided by Deltagen, Boronia, Victoria). The enzymatic breakdown of starch using a heat-stable α-amylase and amyloglucosidase is based on the procedure of McCleary *et al.* (1997). Phosphorus (P) content was measured by a colorimetric method (AOAC 1980) following ignition at 600^{o}C to constant weight and digestion with concentrated hydrochloric acid. Following ignition of samples at 600^{o}C for 3 h together with a concentrated hydrochloric acid digestion, calcium concentration was determined by atomic absorption spectroscopy using a nitrous oxide-acetylene flame. The NH_3-N concentration in rumen fluid was determined using an Olympus AU Reply Clinical Auto-analyser, based on a reaction described by Bolleter *et al.* (1961) and plasma urea-N concentration was determined on the same analyser using a commercially available kit (Thermo Fisher Scientific Company, Australia) based on a reaction described by Talke and Schubert (1965).

Statistical analyses

All statistical analyses were performed using regression analyses in GenStat (2011), with a significance level of 5%. The aim of the statistical analyses was to describe the response curves for different variables (average daily gain (ADG), DMD etc.) to supplement dry matter intake (SuppDMI), expressed either as a percentage of liveweight (%W)/day or kg/day, for the various diets (Bar, CSM and MUP) within young and old steers. Analyses use the actual rather than intended supplement DMI as supplement was not always completely consumed, and for the purpose of describing the response curves, the controls, within age groups, were considered as being the zero SuppDMI points of both supplement types within an experiment. No comparisons were made across experiments.

For each variable tested, a series of analyses were performed to determine the final response curves. For each regression performed, replication was fitted first so that any results accounted for any differences between replications. A preliminary regression tested whether the pen side or size had any effect after fitting age and supplement type within age over SuppDMI. In no cases did pen side or size have any significant effect and so was not included in any further analyses.

For each variable a full regression model was performed which included replicate, age and the linear and quadratic components for each supplement type (e.g., Bar and MUP) within age group (Young and Old). From there, the quadratic co-efficients were compared to 0 using t-tests to determine whether the response curves were linear or quadratic. Where the quadratic co-efficients were not significantly different to 0 ($P>0.05$) they were removed from the model. The models were re-run to test the linear co-efficients in the same manner. Once the degree of polynomial (null, linear or quadratic) was determined, a separate regression was performed to determine whether there were any differences between supplement types, within age, for models of the same degree of polynomial. Where differences between supplement types were significant ($P<0.05$) they are presented as separate response curves. The R^2 for each age by diet fitted curve relative to replication and age was calculated along with its residual standard deviation (RSD) to show how well each curve fits the data.

Results

Diet composition

The chemical composition of the hays and supplements offered in Exp1 and Exp2 are shown in Table 1. The very low quality of the hays is evidenced by their low crude protein (CP; 31-42 g/kg DM) and high neutral detergent fibre (NDF) contents (>650 g/kg DM). The supplements fed provided a ready source of additional protein, in the order CSM, MUP and the barley mixes, and additional fermentable energy as either digestible fibre, starch or soluble sugars.

Intake of supplements and animal health

Exp1

In general, the CSM supplement was completely consumed by the steers whereas at the higher levels of feeding, some steers did not consume their full allocation of the Bar1 mix. There were 2 isolated, transient (3-4 days) and mild cases of acidosis in Old steers fed Bar1 but these steers recovered quickly and soon achieved previous grain intake levels. There were no obvious adverse effects from feeding the CSM.

Exp2

At low to medium levels of feeding, both supplement types were rapidly consumed by the steers. However, despite providing continuous access to supplements, the highest prescribed levels of intake (2%W/day) of either supplement were not achieved. There was 1 suspected case of acidosis in 1 Old steer fed the higher level of Bar2 supplement but the steer recovered quickly and resumed intake at its previous rate. There were no clinical signs of molasses toxicity in steers of either age fed the MUP supplement.

Liveweight change

For both experiments, comparisons were generally made between the dose response relationships for different supplement types, within age group of steers, where the independent variable (X-axis) was supplement intake expressed as %W/day of the steers. The following description of effects will mainly follow this approach. The only exception to the above is that in the case of liveweight change, the interaction of age group and supplement type was investigated with supplement intake expressed as kg/day. As in both experiments the liveweight trends were found to be similar regardless of whether weights were measured on a full or fasted weight basis, or whether the final equilibration period was included in the analysis, the liveweight changes presented here are for full liveweights over the 70 day experimental periods only. Response relationships for the various measurements are summarised in Table 2. No attempt has been made to compare across experiments.

Table 1. Chemical composition of the hay and supplements (g/kg DM)

MUP, molasses-based mix containing urea and protein meal (see text for full composition); OM, organic matter; N, nitrogen; NDF, neutral detergent fibre; ADF, acid detergent fibre; CF, crude fibre; EE, ether extract; Ca, calcium; P, phosphorus; -, not determined

	OM	N	NDF	ADF	CF	EE	Starch	Ca	P
Exp1									
Pangola grass hay	942	6.7	653	364	-	-	-	1.6	2.0
Cottonseed meal	925	76.9	187	113	77	28	-	2.0	12.7
Barley grain	968	17.7	176	-	43	23	568	<1.0	3.5
Barley mix	954	17.7	156	-	37	21	-	3.0	3.6
Exp2									
Speargrass hay	930	4.9	709	407	-	-	-	2.5	1.1
Barley grain	979	23.7	144	41	30	23	512	<1.0	3.0
Barley mix	971	23.2	146	45	33	24	-	1.8	3.1
Molasses	861	10.5	-	-	-	-	-	7.4	1.1
MUP mix	869	25.3	-	-	-	-	-	3.3	2.0

Exp1

In the absence of supplement the Control steers gained 0.11 (Young) and 0.17 (Old) kg/day, indicative of the relatively low quality of the pangola grass hay. The responses to feeding supplements are illustrated in Fig. 1A and the equations describing them are included in Table 2. With the Young steers, the response to Bar1 was linear whereas with CSM it was quadratic and gains were higher than for Bar1 within the range of comparative intakes. Calculated from the response relationship, peak growth rate for steers fed CSM was 1.06 kg/day achieved when intake was 0.72%W/day. For the Old steers both response curves were quadratic and for both supplement types the responses were apparently greater than the respective ones for the Young steers. The calculated peak growth rates were 1.49 and 1.29 kg/day with intakes of 1.52 and 0.69%W/day of Bar1 and CSM, respectively. As with the Young steers the response for the Old steers tended to be greater for CSM than Bar1 for the majority of the common range of intakes but the separation of response curves was less than for their Young counterparts.

Exp2

The growth response curves for this experiment are illustrated in Fig. 1B and the relevant equations are in Table 2. In the absence of supplement Young steers maintained liveweight (0.02 kg/day) whilst Old steers lost 0.21 kg/day on the speargrass basal diet. With Young steers responses to increasing intakes of Bar2 or MUP were both linear, with the response for Bar2 much greater than with MUP (0.81 vs. 0.44 kg gain/%W of supplement intake). By contrast, responses to the same supplements fed to Old steers were both quadratic but again were higher for the Bar2 than the MUP supplement. Calculated peak growth rates for the older steers were 1.46 and 1.32 kg/day with intakes of 0.91 and 1.43%W/day of Bar2 or MUP, respectively. These responses for Old steers were greater than the respective responses for Young steers.

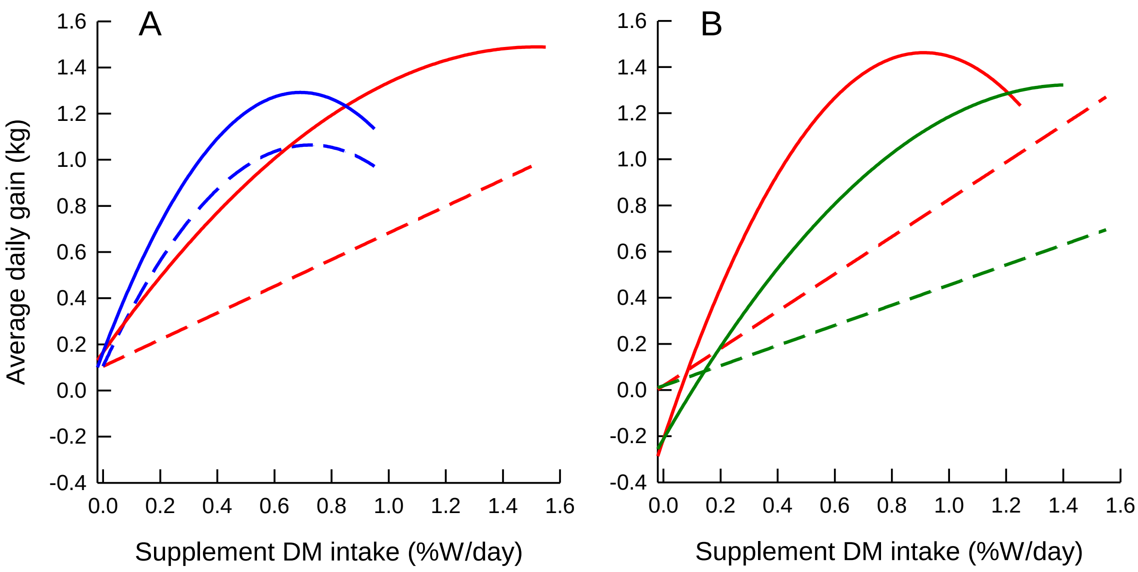

Fig. 1. Effects of intake of barley mix (Bar1; red lines) and cottonseed meal (blue) in Experiment 1 (A) and barley mix (Bar2; red) and molasses-urea-protein meal mix (MUP; green) in Experiment 2 (B) on the average daily gain of Young (dashed lines) or Old (solid lines) steers fed low quality hay *ad libitum*. Treatments are described in the text and the equations describing the relationships are given in Table 2.

Intake and digestibility

The effects of supplement type and level on intake of hay and total DM for both age groups of steers are shown in Fig. 2A (Exp1) and Fig. 2B (Exp2) and the equations describing these regression lines are given in Table 2.

Exp1

The intake of pangola grass hay averaged 1.70%W/day for Young steers but was considerably lower at 1.27%W/day for Old steers. With Young steers there was a quadratic effect of supplement on the intake of hay and total DM with no difference between supplement types. Hay intake tended to increase slightly with low to mid-range supplement intake but then decline at higher supplement intakes whilst total DM intake increased across the full range of feeding. The trends were similar to this for Old steers receiving the Bar1 supplement but with CSM there was an initial pronounced increase in hay intake, peaking when CSM intake was about 0.77%W/day, and then a decline at higher levels of feeding. Total DM intake increased quadratically with CSM intake and tended to exceed that for the Bar1 treatment over the range of comparative intakes.

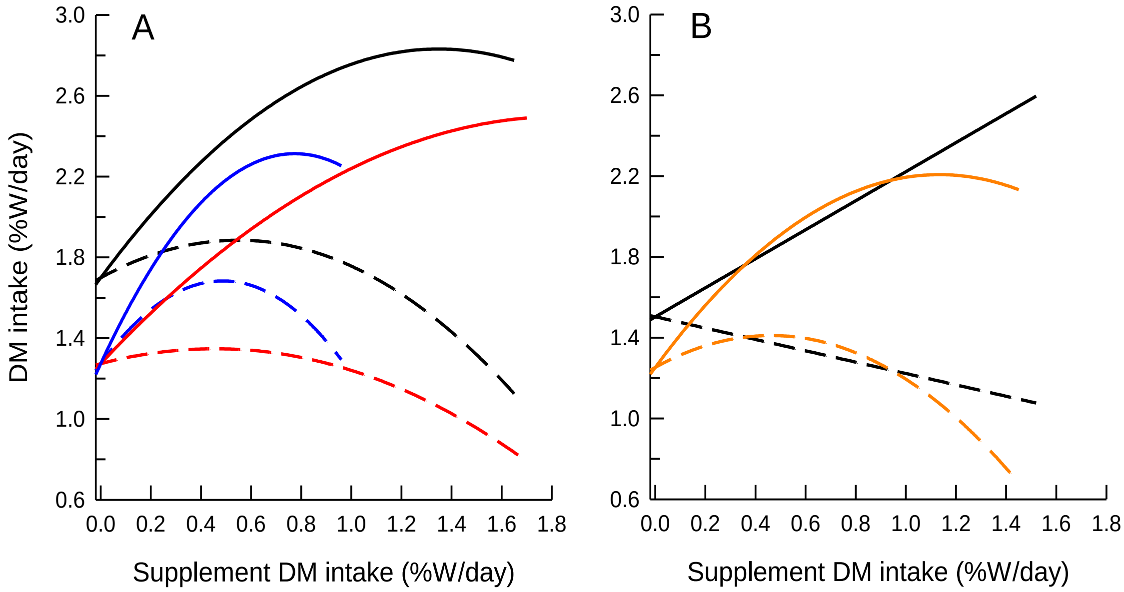

Fig. 2. Effects of supplement intake on the intake of hay (dashed lines) and total (solid lines) dry matter (DM) in Experiments 1 (A) and 2 (B) by steers fed low quality hay *ad libitum*. In Experiment 1 combined regression lines (black) are shown for Young steers receiving both supplement types and separate regression lines are shown for Old steers receiving the barley mix (Bar1; red) and cottonseed meal (CSM; blue), whilst in Experiment 2 combined regression lines are shown for both the barley mix (Bar2) and molasses-urea-protein meal mix (MUP) supplements for Young (black) and Old (orange) steers. Treatments are described in the text and the equations describing the relationships are given in Table 2.

With unsupplemented pangola grass hay DMD for Young and Old steers averaged 54.9 and 57.3%, respectively. For both age groups DMD increased linearly with increasing intake of Bar1 supplement, the respective rates being 7.9 and 8.6 percentage units per %W/day of supplement fed. When Young steers were fed CSM, DMD increased quadratically and peaked at 60.4% when supplement intake was 0.54%W/day. The DMD increased linearly with CSM fed to Old steers but the rate was less at 3.8 percentage units per %W/day of supplement intake than for Bar1. The calculated digestibilities of the Bar1 and CSM supplements were 77.7 and 64.6%, respectively.

Exp2

The intake of speargrass hay averaged 1.50 and 1.25%W/day for Young and Old steers, respectively. Within steer age groups, there was no effect of supplement type on intake so regression equations combined for supplement type are presented in Fig. 3 (B) and in Table 2. As intake of supplement increased, intake of hay declined linearly for Young steers but changed quadratically with Old steers such that there was a slight increase in intake at low levels of feeding but then a sharp decline at higher intakes. Total intake increased linearly for Young steers and quadratically for Old steers.

A single linear equation describes the relationship between supplement intake (%W/day) and DMD for both age groups and both the Bar2 and MUP supplements. DMD averaged 50.0% for the unsupplemented speargrass hay and increased by 9.7

percentage units per %W/day of supplement intake. The calculated digestibilities of the Bar2 and MUP supplements were 72.6 and 73.8%, respectively.

Rumen and blood metabolites

Exp1

The equations relating the effects of supplement intake, averaged over the total feeding period (%W/day), on concentrations of various metabolites are shown in Table 2. Relationships were also examined with the supplement intake determined for the 3 h prior to sampling but the trends were not different from those averaged on a daily basis. The concentration of NH_3-N in rumen fluid 3 h after feeding was very low for the unsupplemented Young steers (*ca*. 2 mg/L) but higher for the Old steers (*ca*. 61 mg/L). The Bar1 supplement had no significant effect on NH_3-N concentration in rumen fluid when fed to the Old steers and only a weak relationship for the Young steers, as indicated by the low R^2 and high RSD largely as a result of 1 steer with an abnormally high concentration (274 mg/L). By contrast, there was a strong positive linear relationship between intake of CSM and concentrations of NH_3-N for both Young and Old steers with the increases greater per unit intake of supplement for the Young compared with Old steers (248 vs 166 mg/L per %W/day).

Urea-N concentrations in blood plasma averaged 3.7 and 4.7 mg/dL for unsupplemented Young and Old steers, respectively (Table 2). Increasing intakes of CSM were associated with linear increases in plasma urea-N concentrations for both age groups of steers with the rate of increase higher for Old steers than their Young counterparts (29.7 vs. 17.3 mg/dL per %W/day). However, feeding the Bar1 supplement only increased plasma urea-N concentration in Old steers and the rate of increase was low (3.7 mg/dL per %W/day of supplement) in comparison to that for the CSM supplemented steers.

Without supplement, concentrations of VFA in rumen fluid were low for both Young and Old steers, at 62.6 and 52.9 mmol/L, respectively. The average molar proportions of acetate were 69.4 and 70.4, of propionate were 15.9 and 14.7 and of butyrate were 13.0 and 13.1 mmol/100 mol total VFA for Young and Old Control steers, respectively. Supplement had no effect on propionate molar proportion but increasing intakes of CSM, but not Bar1, in Young steers, and of Bar1 and CSM (combined effects) in Old steers, were associated with increased VFA total concentration, reduced proportions of acetate and increased proportions of butyrate in rumen fluid. The molar proportion of branched-chain fatty acids (BCFA) was increased linearly by all supplement types, with CSM having a bigger effect than Bar1 for both ages of steers (Table 2).

Exp2

Urea-N concentrations in plasma averaged 4.7 and 2.2 mg/dL for unsupplemented Young and Old steers, respectively. Concentrations increased linearly with increasing intakes of Bar2 in Young steers whilst for Old steers they increased with both supplement types but more with the Bar2 than with the MUP supplement (Table 2).

Discussion

Liveweight gain

For these experiments we were able to source cattle of different ages and thus at different physiological stages of growth but of the same genetic origin. This provided the opportunity to compare cattle of different age groups for their utilisation of supplements without the confounding effects of genetics. The cattle were typical of commercial *Bos indicus* crossbred cattle from northern Australia and were similar to those used in the grazing study described elsewhere in this report (McLennan *et al.* 2013). At approximately 200 and 430 kg liveweight the Young and Old steers had relative sizes of 0.33 and 0.72, respectively, where relative size is the liveweight expressed as a proportion of the standard reference weight (SRW) of the steer (here assumed to be 600 kg), this being approximately that weight achieved by the animal when skeletal development is complete and body condition score is mid-range (CSIRO 2007). Thus there would have been distinct differences in initial body composition and theoretically in the proportions of the various tissue types deposited in liveweight gain during the experiments (CSIRO 2007).

The pangola grass hay used in Exp1 was of sufficient quality to sustain growth rates of both age groups of steers at just above maintenance whereas on the speargrass hay from Exp2, Young steers only maintained weight and Old steers made small losses. Both grasses could be considered typical of the quality of pasture grazed for much of the dry season in northern Australia. The liveweight responses of Young steers in these experiments are consistent with those we recorded previously with steers of similar age and LW (McLennan 1997, 2004); notably, linear responses to ‘energy sources’ such as grain- and molasses-based mixes and quadratic responses of a higher order to protein meals. Furthermore, the response to grains have generally been higher than to the molasses-based mixes and in the current study this was repeated despite the inclusion (at about 8 percent by weight) of a protein meal in the molasses.

Considering the Young steers alone, the steep response to CSM and the superior response with this protein meal compared with the grain-based mixes (and by inference with MUP as Bar2 had higher growth response than MUP in Exp2), especially at low intakes, suggest an initial deficiency of N in the rumen which is corrected by a protein source of medium to high rumen degradability. Assuming a rumen degradability of protein of 87% for pangola grass (Bowen 2003), the calculated ratio of RDP/digestible DM (DDM) for unsupplemented steers was about 66 g/kg, providing plenty of scope for responses to a rumen degradable source of protein before the proposed optimal range of 130-170 g RDP/kg DOM (AFRC 1993; CSIRO 2007) was exceeded. Based on calculated supply of RDP with assumptions for protein degradabilities in barley and CSM of 0.86 and 0.71 (AFRC 1993), respectively, and that 0.8 of the urea fed in the Bar1 treatments was consumed and was used in the rumen with 0.8 efficiency, the calculated RDP/DDM for the Bar1 treatments were 108, 112, 119 and 133 g/kg for diets including 0.5, 1.0, 1.5 and 2.0%W/day of supplement, respectively. Thus even allowing for the conversion of DDM to DOM, it appears that there was a deficiency of RDP in the Bar1 rations except at the highest level fed. The urea was included to ensure sufficient RDP for complete utilisation of the barley component of the diet but was obviously insufficient to overcome the deficit in the hay component as well. The corresponding RDP/DDM value when CSM was fed at 0.5%W was 168 g/kg, thus supporting the assertion that a major reason for the difference in responses between CSM and Bar1 at low intakes was the greater availability of degradable protein in the rumen from CSM leading to increased supply of microbial protein, as well as undegraded protein from CSM, for absorption in the intestines. At higher intakes the response to CSM plateaud out and it is possible that at these higher inclusion rates the CSM was being used largely as an energy source by the growing steers. It is of practical significance that providing CSM to the Young steers at just 0.7%W/day, or about 1.4 kg/day for a 200 kg steer, increased growth rate from around maintenance to over 1 kg/day. The same response with the Bar1 mix required an intake of about 1.6%W/day.

With Old steers the superior performance with CSM compared to the barley mix was still evident but differences were smaller than for the Young steers. However, it appears that RDP was still a major deficiency for these older steers supported by the fact that the calculated RDP/DDM values for the Bar1 rations fed at 0.5, 1.0, 1.5 and 2.0%W/day were 117, 119, 123 and 131 and for the CSM at 0.5%W/day was 179 g/kg. The increasing responses with increasing intakes of Bar1 and Bar2 supplements suggest increased overall energy intake, with the energy and protein increasingly balanced in the rumen as supplement intakes increased.

The inferior performance of molasses as an energy source relative to grains has been reported previously (Pate 1983), including in our own research (see this report; McLennan 1997). Gulbransen (1985) showed that at the low intakes used for survival feeding of cattle (up to 3 kg/day), molasses had *ca.* 85% of the energy value of grain sorghum on a DM basis. Furthermore, under *ad libitum* production feeding, he reported substantial increases in the feed intake and growth rate of cattle as sorghum progressively replaced molasses in the ration. In studies with finishing steers, Lofgreen and Otagaki (1960) showed that at feeding rates of 10% of the DM in the ration, molasses had a relatively high net energy value but as its proportion increased to 25 to 40% the net energy value was almost halved. Subsequently, Lofgreen (1965) showed that at feeding levels of 15% of total DM and less, molasses had a net energy value of 74% of that of barley. In our study the growth rate was about 36% lower on average across levels of feeding for the MUP treatment relative to Bar2 notwithstanding the inclusion of protein meal in MUP to alleviate a recognised protein deficiency in molasses.

The inferior liveweight responses by Young compared with Old steers in both experiments when supplement intakes were expressed on a liveweight basis, were unexpected. As detailed earlier, young cattle deposit relatively more lean tissue than fat compared to their older counterparts and, per unit of ME intake, would therefore be expected to gain at a faster weight. However, it should be noted that the Old steers in both of our studies were generally only in store body condition (score 5 in a 1-9 range) at the start of feeding and thus still had considerable scope to deposit lean tissue before progressing into a fattening phase, especially in the early part of the feeding period. The other contributing factor in our findings may be that the Old steers would have been approaching their mature body size with skeletal development nearly complete. Thus less nutrients would have been required by these Old steers for bone elongation compared with the Young steers which were in the rapid phase of skeletal development. Both groups of steers had come through a period of moderate growth prior to the start of the experiments, the Young steers being recently weaned and the Old steers having grazed wet season pastures, so it is unlikely that the higher growth rates of Old steers was associated with compensatory growth effects.

Given the large difference in size of the steers and thus in the amount of supplement consumed by the 2 age groups, it was logical to compare them using supplement intakes expressed as a function of LW, as has been described above and is illustrated in Fig. 1. However, the results discussed above may be an artefact of the units used for comparing weight gains. An alternative is to express growth rates as fractional body weight gains, i.e., gains (kg/day) as a proportion of the liveweight (kg) of the animal so that both supplement intake and growth rate are expressed in similar terms, i.e., as a function of body weight. Using this approach, the differences between Young and Old steers on the Bar1 ration in Exp 1 were quite small and favoured the Young steers (see Fig. 3A), unlike the trends described above. However, with the CSM supplement Young steers markedly outperformed their older counterparts also showing a reversal of trends discussed earlier and supporting the contention that young, growing steers have a higher requirement for protein during the period when lean growth is prioritised.

A further alternative, but one which again uses similar units on both axes, is to express growth rate and supplement intake in absolute terms as kg/day. Using this approach the responses were not different between Young and Old steers for any of the supplements fed in either experiment, but the differences between supplements remained. An example of these findings is presented using Exp1 results in Fig. 3B where the similar responses by Young and Old steers, and the superior responses to CSM compared with Bar1, are shown.

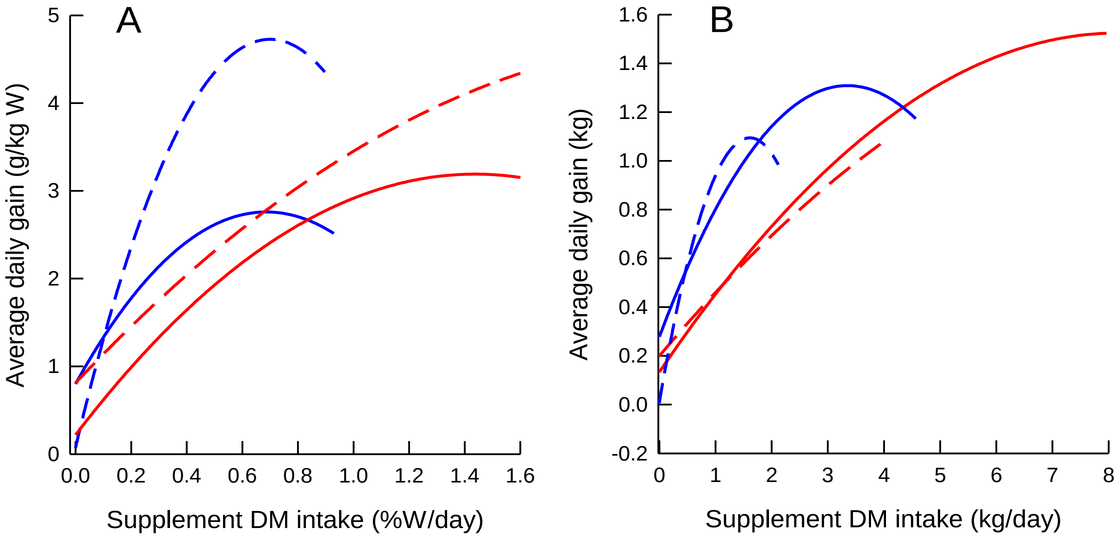

Fig. 3. Effects of intake of barley mix (Bar1; red lines) and cottonseed meal (blue) in Experiment 1 on the average daily gain of Young (dashed lines) or Old (solid) steers fed low quality pangola grass hay *ad libitum*, where intakes and growth rates are expressed as (A) a proportion of the liveweight (LW) of the steers or (B) in absolute terms (kg/day). Treatments are described in the text

Some caution is required in interpreting these latter results as the range of intakes for any supplement type was obviously quite large but with Young steers having much lower absolute intakes than Old steers by virtue of their lighter weights, but within supplement type a single relationship could be applied to both age groups. This result is of most practical importance to cattle producers and their advisors. It indicates that for the same amount of supplement (kg/day) the growth response (kg/day) will be the same regardless of age of the cattle. This tends to support the results from the grazing study (McLennan *et al.* 2013) where the efficiency of use of the MUP supplement was similar for steers 12 months apart in age. The results may be quite different, however, if the older cattle go into a fattening phase during the feeding period and the different nutrient requirements for different age groups and for lean and fat tissue deposition becomes more important.

Intake

The higher relative intakes of hay by unsupplemented Young compared with Old steers are consistent with theoretical predictions from the feeding standards. Predicted intakes in CSIRO (2007) for 200 and 450 kg steers with a SRW of 600 kg, selecting a diet of 50% DMD, were 1.75 and 1.20%W/day, respectively. This order of difference aligns with the present results for different aged steers. In both experiments, with both age groups of cattle and with all supplement types, there were clear associative effects on intake between the supplement and forage components of the diet which thus presumably affected the overall intake of ME by the steers. These associative effects are well documented in the literature (e.g., Chase and Hibberd 1987; Schiere and de Wit 1995; Dixon and Stockdale 1999; Moore *et al.* 1999; CSIRO 2007) and have been reported often in our own research (McLennan 1997, 2004), but are less well understood or predictable. Examples of both positive associative effects, where provision of supplement increased forage intake and negative effects (substitution), where forage intake was reduced in the presence of supplement, are evident in our current results although there did not appear to be any clear age of steer effect in this delineation. Positive associative effects were generally recorded with low intakes of supplement (to about 0.5%W/day) and these were replaced by negative effects as supplement intake increased. The most pronounced stimulus in forage intake was with the feeding of CSM, especially to Old steers. Such effects are generally recorded when low quality forages with specific nutrient deficiencies for rumen microbial activity, or for the animal in general, are supplemented with concentrates having high concentrations of those nutrients (Schiere and de Wit 1995; Dixon and Stockdale 1999). Given the very low quality of the tropical forages used in our studies, it is likely that the primary limiting nutrient was RDN (see above) and this deficiency was ameliorated with just small amounts of CSM (0.5%W/day) but only incrementally with increasing intake of the barley- and molasses-based mixes. It is also likely that the steers responded in part to increased supply of protein from CSM escaping rumen fermentation for absorption post-ruminally. With the higher supplement intakes, the decline in forage intake was likely associated with other limitations to total intake, these being of either a physical or metabolic nature (Weston 1996), or both. Moore *et al.* (1999) predicted that voluntary forage intake would be decreased by supplements if the ratio of total digestible nutrients (TDN) to CP in the forage was <7, indicating adequate N, and in our experiments the estimated ratio exceeded 11 for both hay types providing scope to increase hay intake especially with supplements like CSM high in CP content. Despite the reductions in forage intake with increasing supplement consumption, total ME intakes increased, consistent with the growth rates responses reported above. The reduced forage intake but higher total intake when high levels of supplement were fed may have resulted through a reduction in the digestion of the fibrous component of the diet by virtue of preferential digestion of the more fermentable carbohydrates in the supplements (Dixon and Stockdale 1999).

Increases in the DMD of the total diets with supplement were consistent with the higher DMD for the supplement compared with the hay they replaced. The energy sources of barley and molasses had a linear effect of increasing digestibility of the total diets whereas CSM, which was lower in digestibility than the other supplements, had a quadratic effect with DMD peaking when CSM intake was only 0.5%W/day.

Rumen and blood metabolites

In Exp1, the major increases in the concentration of both NH_3-N in rumen fluid and urea-N in blood plasma of steers occurred when CSM was fed. Previous research has shown that the protein of CSM has a high degradability in the rumen, with values of 0.71-0.79 reported (AFRC 1993; Moss *et al.* 1998; McLennan 2004) reported, and our results support this notion. The inclusion of increasing amounts of CSM in the diet was associated with steep, linear increases in concentrations of both metabolites which represent N utilisation. By comparison, the Bar1 supplement had either no effect or a very minor one on the concentrations of either metabolite in Exp1. These results, however, are probably an artefact of the feeding method used for the different supplements. The CSM was fed in one meal coinciding with hay delivery in the morning and was usually quickly consumed by steers of both ages. Thus the concentrations of NH_3-N in rumen fluid and urea-N in plasma were likely to closely reflect CSM intake in the 3 h between feeding and sampling. By contrast, to prevent acidosis, the Bar1 supplement was fed in 2 equal meals with half provided 1 h after the hay was fed in the morning. This barley mix was also readily consumed except at the highest intake levels. However, with the Bar1 steers the supplemental N came from both the barley mix and the urea-S solution that was mixed daily with the fresh hay allocation, with the latter being by far the major contributor of N. The urea was not included in the barley mix to prevent urea toxicity in the case of the supplement being rapidly consumed. Thus N intake in the time before sampling would have been largely a function of the proportion of the day’s hay allowance, and thereby urea, that was consumed in the first 3 h after feeding. Furthermore, all steers in each age group on the Bar1 treatments received the same amount of urea so differences in NH_3-N concentration in rumen fluid would thus have mainly reflected the small contributions from the varying barley intakes. In addition, rapid uptake of NH_3-N by microbes given a highly fermentable energy source in barley starch would have prevented high accumulations of ammonia in the rumen. Nevertheless, the lack of any appreciable accumulation of NH_3-N in the rumen of steers on the Bar1 rations does caution the need to ensure RDN is not limiting for utilisation of both the supplement and forage components and under practical feeding conditions inclusion of the NPN source in the grain mix is desirable.

The concentration of urea-N in plasma is less sensitive to immediate intake of urea than for rumen ammonia and in both experiments there was a linear effect of Bar1 intake on urea-N concentration with Old steers and also with Young steers in Exp 2. The lack of increase in plasma urea-N concentrations with intake of MUP in Exp2 by Young steers, and lower (smaller slope) linear response with Old steers compared with Bar2 treatments, is probably a reflection of the rapid uptake of ammonia by rumen microbes as calculated intakes of urea ranged from 23 to 100 g/day for Young steers and 48 to 203 g/day for Old steers. In contrast with the Bar2 supplement where the barley mix and urea were fed separately, the urea was fed mixed with the molasses in the MUP treatment and it is possible that this led to better uptake of ammonia from the urea by rumen microbes in synchrony with release of soluble sugars from molasses, resulting in better utilisation of RDN and less accumulation of urea-N in blood.

Conclusions

These studies have confirmed earlier findings in relation to the ranking of supplement types for stimulating growth in young cattle, viz. that CSM provided a higher response than barley, especially at low intakes, and barley was associated with higher growth responses than a molasses-based mix. The ranking of supplements for improving growth was similar when they were fed to mature-aged steers. For any supplement type there were differences between age groups in their utilisation of additional nutrients for growth when growth (kg/day) was related to supplement intake expressed as a proportion of liveweight (%W/day), in favour of the older steers, but when the growth and supplement intake were related in absolute terms, i.e., both as kg/day, there seems to be no difference between young and older cattle in supplement utilisation. This has important practical implications for ration formulation, indicating that similar responses can be expected from the same supplement intake irrespective of the age of the steers. The applicability of this general recommendation if the older steers progress to a fattening stage, is questioned. Nevertheless, the information provided in these studies can be used in formulating cost-effective rations for cattle of varying age grazing low quality tropical forages.

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References

AFRC (1993) ‘Energy and protein requirement of ruminants. An advisory manual prepared by the AFRC technical committee on response to nutrient.’ (CAB International: Wallingford, UK)

AOAC (1975) ‘Official methods of analysis.’ (Association of Official Analytical Chemists: Washington, DC)

AOAC (1980) ‘Official methods of analysis.’ (Association of Official Analytical Chemists: Washington, DC)

Bolleter WT, Bushman CJ, Tidwell PW (1961) Spectrophotometric determination of ammonia as indophenol. *Analytical Biochemistry* **33**, 592-594.

Bowen MK (2003) Efficiency of microbial protein production in cattle grazing tropical pastures. PhD Thesis. University of Queensland, St Lucia, Australia.

Chase CC, Hibberd CA (1987) Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn grain. *Journal of Animal Science* **65**, 557-566.

Coppock CE, Lanham JK, Horner JI (1987) A review of the nutritive value and utilization of whole cottonseed, cottonseed meal and associated by-products by dairy cattle. *Animal Feed Science and Technology* **18**, 89-129.

CSIRO (2007) ‘Nutrient requirements of domesticated ruminants.’ (CSIRO Publishing: Melbourne, Australia)

Dixon RM, Stockdale CR (1999) Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research* **50**, 757-773.

GenStat (2011) ‘GenStat for Windows, Release 14.1.’ (VSN International Ltd: Oxford)

Gulbransen B (1985) Survival feeding of cattle with molasses 2. Feeding steers with molasses/urea plus either sorghum grain (*Sorghum vulgare*) or cottonseed meal (*Gossypium hirsutum*). *Australian Journal of Experimental Agriculture*. **25**, 4-8.

Johnson RR (1976) Influence of carbohydrate solubility on non-protein nitrogen utilization in the ruminant. *Journal of Animal Science* **43**, 184-191.

Lofgreen GP (1965) Net energy of fat and molasses for beef heifers with observations on the method for net energy determination. *Journal of Animal Science* **24**, 480-487.

Lofgreen GP, Otagaki KK (1960) The net energy of blackstrap molasses for fattening steers as determined by a comparative slaughter technique. *Journal of Animal Science* **19**, 392-403.

McCleary BV, Gibson TS, Mungford DC (1997) Measurement of total starch in cereal products by amyloglucosidase - α-amylase method. *Journal of Association of Official Analytical Chemists* **80**, 571-579.

McLennan SR, Leng RA, Nolan JV (1998) Whole cottonseed supplements for cattle given a molasses-based diet. *Animal Production in Australia* **22,** 141-144.

McLennan SR, Plasto AW, Doogan VJ, Dillon RD (1998) Whole cottonseed and cottonseed meal supplements for cattle given a hay-based diet. *Animal Production in Australia* **22,** 111-114.

McLennan SR (1997) 'Developing profitable strategies for increasing growth rates of cattle grazing tropical pastures'. Project DAQ.100 Final Report. (Meat Research Corporation, Australia)

McLennan SR (2004) 'More effective supplements for the northern beef industry'. Project NAP3.122 Final Report. (Meat and Livestock Australia)

McLennan SR, Fordyce G, Bowen MK, Cherry D, Enchelmaier K, Campbell J, Dawson K, Poppi DP (2013) Consequences of changes to post-weaning growth path due to supplements and leucaena on growth and carcass characteristics of steers in the seasonally-dry tropics of Australia. In 'Optimising the growth paths of cattle for increased profitability'. Project B.NBP.0391 Final Report to Meat and Livestock Australia (this report, in preparation)

Moss RJ, Buchanan IK, Casey ND, Matschoss AL, Martin PR (1998) Degradability of protein concentrates available in north Australia. *Proceedings of the Australian Society of Animal Production* **22**, 340.

Offer NW, Axford RFE, Evans RA (1978) The effect of dietary energy source on nitrogen metabolism in the rumen of sheep. *British Journal of Nutrition* **40**, 35-44

Palmquist DL, Jenkins TC (1980) Fat in lactation rations: review. *Journal of Dairy Science* **63**, 1-14.

Pate FM (1983) Molasses in beef nutrition. In, 'Molasses in Animal Nutrition'. (National Feed Ingredients Association, Des Moines, Iowa)

Schiere JB, de Wit J (1995) Feeding urea ammonia treated rice straw in the tropics.II. Assumptions on nutritive value and their validity for least cost ration formulation. *Animal Feed Science and Technology* **51**, 45-63.

Smith NE, Collar LS, Bath DL, Dunkley WL, Franke AE (1981) Digestibility and effects of whole cottonseed fed to lactating cows. *Journal of Dairy Science* **64**, 2209-2215.

Sniffen CJ, Robinson PH (1987) Symposium: protein and fiber digestion, passage, and utilization in lactating cows. *Journal of Dairy Science* **70**, 425-441.

Sweeney RA (1989) Generic combustion method for determination of crude protein in feeds – collaborative study. *Journal of Association of Official Analytical Chemists* **72**, 770-774.

Talke H, Schubert GE (1965) Enzymatische harnstoffbestimmung in blut and serum in optischen test nach warburg. *Klinische Wochschrift (Berlin)* **43**, 174-175.

Van Soest PJ (1963) Use of detergents in the analysis of fibrous feeds. II. A rapid method for determination of fiber and lignin. *Journal of Association of Official Analytical Chemists* **46,** 829-835.

Van Soest PJ, Wine RH (1967) Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell wall constituents. *Journal of Association of Official Analytical Chemists* **50**, 50-55.

Weston RH (1996) Some aspects of constraint to forage consumption by ruminants. *Australian Journal of Agricultural Research* **47**, 175-197.

Winks L (1984) 'Cattle growth in the dry tropics of Australia'. (Australian Meat Research Committee Review no. 45)

Table 2. Effect of age of steers (Age) and supplement type (Ration) and intake, expressed either as %W/day (XL) or kg/day (XK), on average daily gain, on hay and total dry matter (DM) intake, on dry matter digestibility (DMD) and on concentrations of urea-nitrogen (urea-N) in plasma and of ammonia-nitrogen (NH3-N) and volatile fatty acid (VFA), and on molar proportions of individual VFAs in the rumen fluid, for steers fed hay alone or with supplement

Unless otherwise stated, comparisons are between supplement types within steer age groups. Where there was no significant difference between response relationships for the two age groups and/or supplement types a combined regression equation is given (Comb.) and the degree of fit of the various components to that combined equation is given separately.

Bar1 and Bar2, barley mixes used in Experiments 1 and 2 (Exp1 and Exp2); CSM, cottonseed meal; MUP, molasses-based mix containing urea and protein meal; RSD, residual standard deviation.

P-values are given for the linear (Lin.) and quadratic (Quad.) coefficients in the regression equations; *, ** and *** represent *P*<0.05, 0.01 and 0.001, respectively; –, *P*>0.05

Y	Age	Ration	Equation	R^2	RSD	Lin.	Quad.
Exp1							
Average daily gain (kg)	Young	Bar1	$Y = 0.105 + 0.578 XL$	0.90	0.140	***	***
		CSM	$Y = 0.105 + 2.647 X - 1.827 XL^2$	0.97	0.099	***	**
	Old	Bar1	$Y = 0.166 + 1.743 X - 0.574 XL^2$	0.97	0.123	***	**
		CSM	$Y = 0.166 + 3.258 X - 2.357 XL^2$	0.81	0.275	***	***
Hay DM intake (%W/day)	Young	Comb.	$Y = 1.699 + 0.680 X - 0.623 XL^2$			**	***
		Bar1		0.64	0.189		
		CSM		0.32	0.210		
	Old	Bar1	$Y = 1.274 + 0.324 X - 0.358 XL^2$	0.61	0.157	-	*
		CSM	$Y = 1.274 + 1.685 X - 1.734 XL^2$	0.63	0.167	**	**
Total DM intake (%W/day)	Young	Comb.	$Y = 1.699 + 1.680 X - 0.623 XL^2$			***	***
		Bar1		0.91	0.189		
		CSM		0.86	0.210		
	Old	Bar1	$Y = 1.274 + 1.324 X - 0.358 XL^2$	0.94	0.157	***	*
		CSM	$Y = 1.274 + 2.685 X - 1.734 XL^2$	0.92	0.167	***	**
DMD (%)	Young	Bar1	$Y = 54.94 + 7.918 XL$	0.88	2.241	***	-

Y	Age	Ration	Equation	R^2	RSD	Lin.	Quad.
		CSM	$Y = 54.94 + 18.04\ XL – 16.67\ XL^2$	0.47	2.420	**	*
	Old	Bar1	$Y = 57.34 + 8.62\ XL$	0.95	1.405	***	-
		CSM	$Y = 57.34 + 3.84\ XL$	0.42	1.727	*	-
Plasma urea-N conc. (mg/dL)	Young	Bar1	No relationship				
		CSM	$Y = 3.646 + 17.26\ XL$	0.72	4.583	***	-
	Old	Bar1	$Y = 4.688 + 3.74\ XL$	0.43	3.221	*	-
		CSM	$Y = 4.688 + 29.72\ XL$	0.88	4.569	***	-
Rumen NH_3-N conc. (mg/L)	Young	Bar1	$Y = 2.21 + 54.1\ XL$	0.20	67.64	*	-
		CSM	$Y = 2.21 + 248.3\ XL$	0.86	37.42	***	-
	Old	Bar1	No relationship				
		CSM	$Y = 61.25 + 166.4\ XL$	0.81	39.47	***	-
Rumen VFA conc. (mmol/L)	Young	Bar1	No relationship				
		CSM	$Y = 62.60 – 47.9\ XL + 107.7\ XL^2$	0.78	10.86	-	*
	Old	Comb.	$Y = 52.87 + 24.82\ XL$			***	-
		Bar1		0.50	17.11		
		CSM		0.29	17.38		
Acetate molar proportion (% of total)	Young	Bar1	No relationship				
		CSM	$Y = 69.36 – 3.23\ XL$	0.65	1.03	*	-
	Old	Comb.	$Y = 70.37 – 2.327\ XL$			**	-
		Bar1		0.37	1.98		
		CSM		0.16	2.16		
Butyrate molar proportion (% of total)	Young	Bar1	No relationship				
		CSM	$Y = 12.96 + 2.054\ XL$	0.32	1.08	*	-
	Old	Comb.	$Y = 13.11 + 1.427\ XL$			*	-

Y	Age	Ration	Equation	R^2	RSD	Lin.	Quad.
		Bar1		0.18	1.64		
		CSM		0	1.95		
Branched-chain fatty acids (% of total)	Young	Bar1	$Y = 0.572 + 0.3197 XL$	0.29	0.331	**	-
		CSM	$Y = 0.572 + 1.185 XL$	0.80	0.213	***	-
	Old	Bar1	$Y = 0.529 + 0.661 XL$	0.82	0.224	***	-
		CSM	$Y = 0.529 + 1.153 XL$	0.84	0.185	***	-
Exp2							
Average daily gain (kg)	Young	Bar2	$Y = 0.019 + 0.808 XL$	0.94	0.115	***	-
		MUP	$Y = 0.019 + 0.437 XL$	0.81	0.145	***	-
	Old	Bar2	$Y = -0.212 + 3.672 XL - 2.013 XL^2$	0.95	0.191	***	***
		MUP	$Y = -0.212 + 2.149 XL - 0.752 XL^2$	0.89	0.263	***	*
Average daily gain (kg)	Young / Old	Bar2	$Y = -0.039 + 0.561 XK - 0.0568 XK^2$	0.93	0.174		
		MUP	$Y = -0.039 + 0.228 XK$	0.87	0.208		
Hay DM intake (%W/day)	Young	Comb.	$Y = 1.503 - 0.281 XL$			***	-
		Bar2		0.36	0.257		
		MUP		0.36	0.147		
	Old		$Y = 1.253 + 0.684 X - 0.743 XL^2$			*	**
		Bar2		0.76	0.151		
		MUP		0.44	0.134		
Total DM intake (%W/day)	Young	Comb.	$Y = 1.503 + 0.719 XL$			***	-
		Bar2		0.72	0.257		
		MUP		0.92	0.147		
	Old		$Y = 1.253 + 1.684 X - 0.743 XL^2$			***	**
		Bar2		0.90	0.151		

Y	**Age**	**Ration**	**Equation**	**R^2**	**RSD**	**Lin.**	**Quad.**
		MUP		0.93	0.134		
DMD (%)	Young	Comb.	Y = 50.55 + 8.51 XL			***	-
		Bar2		0.70	3.465		
		MUP		0.72	3.307		
		Comb.	$Y = 46.95 + 25.21 XL – 10.40 XL^2$			***	*
	Old	Bar2		0.80	3.508		
		MUP		0.87	3.060		
Plasma urea-N conc. (mg/dL)	Young	Bar2	Y = 4.696 + 3.29 XL	0.46	2.933	***	-
		MUP	No relationship				
	Old	Bar2	Y = 2.226 + 11.90 XL	0.89	2.238	***	-
		MUP	Y = 2.226 + 2.80 XL	0.79	0.938	*	-

13.4 Detailed Report 4: Composition of molasses-based mix pen trial

Composition of molasses-based supplements for cattle fed low quality tropical forages

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[Prepared for Animal Production Science: ASAP conference paper]

Introduction

The growth path optimisation grazing trial (McLennan *et al.* 2013a) has demonstrated that growth rates of cattle can be markedly increased during the dry season by feeding high energy supplements including those based on molasses, urea and a protein meal such as copra meal (MUP). These recent results support those from previous grazing trials using a similar supplement type (Lindsay 1996, 1998; Fordyce 2009). However, cattle consume high amounts of the supplement which translates to a high cost of feeding. In order to maximise the likelihood that such a feeding regime will result in an economically favourable outcome it is essential that the conversion rate of supplement fed to additional liveweight gain is optimised. In the above grazing trial, this conversion rate was between 8.8 and 10.2 kg MUP supplement, costing from $1.70 to $3.10, per kg additional gain during the dry season and these conversion rates were increased by subsequent compensatory growth in the wet season periods, thereby increasing the real cost of gains.

Pen feeding studies carried out by our research group, including those described in this report have indicated that higher growth responses per unit supplement intake could be achieved using either grains such as barley or protein meals like cottonseed or copra meals compared with the MUP mix. However, protein meals are often very costly, are sometimes in low supply late in the dry season and are difficult to feed due to problems associated with achieving even distribution of the protein meal through the herd. The main practical issue with feeding grain in the paddock is the risk of acidosis unless proper measures are taken and rate of intake limited, for instance using self-feeders which are not commonly found on grazing properties in northern Australia. This has restricted grain usage in extensive grazing situations. In addition, most grain is produced in southern regions of Queensland and in southern states so the cost of freight becomes a major impediment to its use in northern regions. Cattle producers in northern Australia have confidently used molasses-based supplements for the last three decades without major stock losses and are comfortable with this form of supplementary feeding. Nevertheless, the poor economic returns from feeding in general limit its use except for situations targeting increased survival of at-risk cattle.

The present experiment was therefore designed to investigate ways of increasing the response to molasses-based supplements without major increases in cost. Earlier experiments have shown increases in growth rate when whole cottonseed has been included in diets using molasses as the major feed source (McLennan *et al.* 1998; Hunter 2012) and anecdotal evidence is that inclusions of grain and/or oil will increase responses. The value of such inclusion were assessed in the current experiment which also used a barley-based supplement as a positive control.

Materials and methods

The experiment was carried out with endorsement by the Staff Access Animal Ethics Committee of the Dept of Agriculture, Fisheries and Forestry, Queensland with approval reference SA-2012/07/388.

Animals, treatments and experimental design

Commercial Brahman crossbred weaner steers (*ca.* 5/8 *Bos indicus*) were sourced for the experiment from Swans Lagoon Research Station, Millaroo in July 2012. The steers were approximately 9-10 months of age and averaged 190.2±7.03 (s.d.) kg liveweight at the commencement of the trial. They were similar, and of the same genetic origin, to those used in the pen studies described previously (McLennan *et al.* 2013b). Upon arrival at Brian Pastures Research Station, Gayndah, all steers were vaccinated with Ultravac 5-in-1 (ultrafiltered antigens of *Clostridium perfringens* type D, *C. tetani*, *C. septicum* and *C. novyi* type B and a purified formol culture of *C. chauvoei*, Pfizer Animal Health) and at the same time were vaccinated against bovine ephemeral fever (BEF). A second BEF vaccination was administered about 2 weeks later just after the start of the trial. Just prior to the trial the steers were treated with Cydectin Pour-On (Moxidectin, Virbac Animal Health) to reduce internal and external parasite burdens.

The steers were fed a basal diet of *Heteropogon contortus* (speargrass) hay *ad libitum* with or without supplement. The experimental design was a randomised block incorporating a response surface with 5 supplement types x 4 levels of feeding x 2 replications (steers), plus 4 Control (unsupplemented) steers, equalling 44 steers in total. For the analysis the main emphasis was on defining the response surfaces for the various supplement types. The supplements fed were (i) barely grain mix (Bar); (ii) molasses, urea, protein meal mix (MUP); (iii) MUP mix plus added barley (MUP-B); (iv) MUP mix plus added whole cottonseed (MUP-W); and (v) MUP mix plus added barley and whole cottonseed (MUP-BW). The Bar mix contained, w/w as fed, rolled barely (100 parts), molasses (2), water (2), limestone (1), salt (1) and Rumensin (0.05). The MUP mix contained molasses (100 parts), urea (3), copra meal (10), salt (1), dicalcium phosphate (1) and Rumensin (0.05) and was thus similar in composition to that used in the GPO grazing study described elsewhere in the report. The MUP-B, MUP-W and MUP-BW mixes were formulated by adding an additional 8.75 parts barley, 17.5 parts whole cottonseed (WCS) or 8.75 parts barley and 8.75 parts WCS, respectively, to 100 parts MUP mix, w/w as fed. The final DM composition of the various supplements is shown in Table 1. Steers on the Bar treatment also received 200 g/day of a urea-ammonium sulphate solution (urea/S) formulated to ensure availability of adequate rumen degradable protein (RDP) for optimum ruminal fermentation of the organic matter (OM) from the barley, i.e., targeting a minimum of 130 g RDP/kg digestible OM. This solution contained, by weight as fed, 20.45% urea, 4.55% ammonium sulphate (GranAm) and 75% water so the steers received 40.9 g urea daily.

Table 1. Final composition (%DM) of the experimental rations

Bar, barley mix; MUP, molasses-urea-protein meal mix; MUP-B, MUP mix containing barley; MUP-W, MUP mix containing whole cottonseed; MUP-BW, MUP mix containing barley and whole cottonseed; DCP, di-calcium phosphate; WCS, whole cottonseed; see text for full supplement composition

	Barley	Molasses	Urea	Copra meal	Lime-stone	Salt	DCP	Rumensin	WCS
Bar	96.3	1.6			1.0	1.0		0.06	
MUP		84.0	3.3	10.6		1.1	1.1	0.05	
MUP-B	8.0	77.3	3.0	9.7		1.0	1.0	0.05	
MUP-W		71.3	2.8	9.0		0.9	0.9	0.05	15.1
MUP-BW	7.5	71.4	2.8	9.0		0.9	0.9	0.05	7.5

Procedures

The experiment consisted of a 6 day initial equilibration, a 70 day experimental and a 5 day final equilibration period. During the initial equilibration phase steers were fed speargrass hay *ad libitum* in group pens of 3 steers. At the end of this period (Day 0) they were weighted full (unfasted) and then fasted (24 h off feed, 16 h off water) and allocated to treatments by stratified randomisation on the basis of the fasted weight. During the experimental period the steers were weighed full once weekly in the morning before feeding. At the end of this period they were weighed full and fasted (as above) and then returned to the pens for the 5 day final equilibration period during which time they were fed speargrass hay alone *ad libitum*. They were then weighed full and fasted.

At allocation, the pens were divided into two blocks of 22 pens according to their orientation in the pen complex (East or West) and the steers were divided into two weight classes (reps) so that the two reps occupied either the southern or northern ends of blocks 1 and 2. Within this design steers and treatments were randomly allocated to individual pens.

The hay was fed daily from 0700 h. Hay was fed to each steer at a level estimated, by daily bunk inspection, to provide approximately 15% in excess of its intake on the previous day thereby maintaining *ad libitum* intake. The exception to this procedure was that, in the first 2 weeks, hay intake was slightly restricted to steers on treatments with high supplement allocation (1.5–2.0%W/day) in order to increase their supplement intake. In subsequent weeks hay provision was *ad libitum* for all steers. The urea/S solution for the Bar groups was sprinkled on and mixed into the hay once daily soon after the hay was fed out. To reduce the risk of acidosis, the Bar mix was fed out in a separate feeder to the hay in approximately equal portions twice daily at 0800 h and 1600 h. In addition, its intake was gradually stepped up to treatment levels over the first 10 days. The molasses-based mixes were prepared by first thoroughly mixing the molasses/urea/copra meal/salt/DCP/Rumensin, i.e., the MUP mix, in a mixing tank incorporating motor-driven paddles. When completely mixed (about 20 min), the required amounts of the MUP supplement were weighed out and fed once daily at 0800 h to the steers from feeders separate from the hay trough. At the same time, the additives of barley and WCS for the MUP-B, MUP-W and MUP-BW treatments, which had been weighed out separately, were sprinkled on top of the above MUP mix. The steers tended to consume these additives from the top of the MUP mix soon after feeding. Supplement allocation to individual steers was re-calculated weekly following weighing of the steers so that the intake remained constant on a percentage of liveweight basis.

Residues of hay and supplement were collected once weekly or, in the case of supplements, more regularly if residues built up over time. Representative samples of the hay and supplements offered and of the residues collected were dried to constant weight at 60^0C to determine dry matter (DM) content. For molasses-based samples, the material was weighed into an aluminium tray, a small amount of water was added to produce a slurry and a pre-weighed and pre-dried piece of paper towel added to absorb the mixture before drying to constant weight. This was done to provide a greater surface area for drying. Feed samples of hay and supplement components were bulked over the 70 day experimental period for later chemical analysis.

From day 57 to 62 (inclusive) the total faeces output was collected from the concrete floor of each pen of the 4 Control steers, 3 times daily. The daily faeces collected was weighed, thoroughly mixed and a representative sample of 10% of total weight was taken and frozen for each steer. After the final collection the sub-samples for were thawed, bulked for individual steers and thoroughly mixed using a dough mixer. Duplicate sub-samples of this bulked sample were taken and dried to constant weight at 60^0C and faecal DM output and the digestibility of DM (DMD) were determined.
The methods of laboratory analyses were the same as described in a previous paper in this report (see Stage of Maturity pen paper).

Statistical methods

All statistical analyses were performed using regression analyses in GenStat (2011), with a significance level of 5%. The aim of the statistical analyses was to describe the response curves for different variables (e.g., average daily gain (ADG) or DM intake) to supplement dry matter intake (SuppDMI) for different supplement types. The measured, rather than the intended, SuppDMI was used for each steer. The Controls were included in response curves for all supplement types as points with zero SuppDMI. For each variable tested, a series of analyses were performed to determine the final response curves. For each regression performed, replication was fitted first so that results accounted for any between-replicate differences. A preliminary regression tested whether the pen side or size had any effect but as these had no significant effect in any case they were omitted from further analyses.

For each variable a full regression model was developed which included replicate and the linear and quadratic components for each supplement type. From here, the quadratic co-efficients were compared to 0 via t-tests to determine whether the response curves were linear or quadratic. Where the quadratic co-efficients were not significantly different to 0 ($P>0.05$) they were removed from the model. The models were then re-run to test the linear co-efficients in the same manner. Once the degree of polynomial (null, linear or quadratic) was determined, separate regressions was performed to determine differences between supplement types for models of the same degree of polynomial. Where differences between supplement types were significant ($P<0.05$) they are presented as separate response curves. The R^2 for each fitted curve relative to replication was calculated along with its residual standard deviation (RSD) to show how well each curve fitted the data.

Results and discussion

Feed composition

The chemical composition of the hay, supplements and supplement components are shown in Table 2. The extremely low quality of the speargrass hay is highlighted by its low CP content of 1.9%.

Intake of supplements and animal health

Most supplements fed at the low to medium levels were consumed in total but intake was in some cases incomplete where supplements were fed at 1.5-2.0%W/day. However, as stated above, actual and not intended intake of supplement has been used in the statistical analysis of results. The calculated average proportions of molasses in the total diet consumed (DM basis) for the various ration types were (range across intake levels): Bar, 0.3-1.1%; MUP, 16.2-39.0%; MUP-B, 16.8-52.9%; MUP-W, 13.4-41.7%; and MUP-BW, 13.0-42.8%. In general, where barley and WCS were added to the MUP mix, these additives were readily consumed within a short period after feeding. No steers showed any signs of ill-health from the feeding of the barley- or molasses-based mixes; in particular, there were no clinical signs of acidosis or laminitis in grain-fed steers or of molasses toxicity in those fed molasses-based supplements.

Table 2. Chemical composition of the hay and supplements (g/kg DM)

MUP, molasses-based mix containing urea and protein meal (see text for full composition); OM, organic matter; N, nitrogen; NDF, neutral detergent fibre; ADF, acid detergent fibre; EE, ether extract; Ca, calcium; P, phosphorus; -, not determined

	OM	N	NDF	ADF	EE	Ca	P
Speargrass hay	897	3.1	709	418	12	3.2	1.3
Barley grain	973	16.4	194	58	23	<1.0	3.4
Barley mix	963	16.2	204	51	19	2.3	3.3
Molasses	860	10.5	-	-	-	7.4	1.1
MUP mix	865	28.4	-	-	-	11.8	3.2
Whole cottonseed	960	39.7	389	327	201	1.5	6.8
Copra meal	941	32.4	405	255	17.1	0.7	4.9

Liveweight changes

The liveweight trends were statistically similar irrespective of whether they were measured for the experimental period only or experimental plus final equilibration period, and by full or fasted weight, so the data presented here is for full liveweight changes over the experimental period only. The Control steers recorded only slight weight loss (0.09 kg/day) over this period. By contrast all supplemented steers gained weight, as indicated by the response curves in Fig. 1 (A) and the equations describing them in Table 3. In increasing order of response, the supplements can be grouped into 3 categories, i.e., those based on MUP either alone or with barley, those combining MUP and WCS with and without barley, and barley alone (Table 3). There was no effect of including barley in either the MUP or MUP+WCS mixes

(*P*>0.05). For each supplement grouping, the response to increasing supplement intake was linear with slopes of the regressions indicating an additional 0.48, 0.58 and 0.75 kg liveweight gain per %W fed as supplement, respectively (Table 3). Across molasses-based supplements the maximum gain was about 0.8 kg/day, appreciably below that of 1.1 kg/day for the Bar treatment.

Quantitatively, the responses recorded here were comparable to those reported in the previous study using steers of similar age and genetic origin and given a similar low quality speargrass hay (McLennan *et al.* 2013b). In that experiment the responses to molasses- and barley-based mixes, of the same composition as the MUP and Bar used here, averaged 0.44 and 0.81 kg per %W/day of supplement fed, respectively. Other early research by our group had similarly shown a much higher response with a barley-urea mix compared with a molasses-urea-mineral supplement (McLennan1997) given to young steers fed low quality tropical hay. Thus the current results reinforce the clear evidence of inferior cattle performance with molasses-based supplements relative to grains, or to barley in particular, and support the general literature showing the lower energy value of molasses relative to grains, as reviewed in the present report (McLennan *et al.* 2013b).

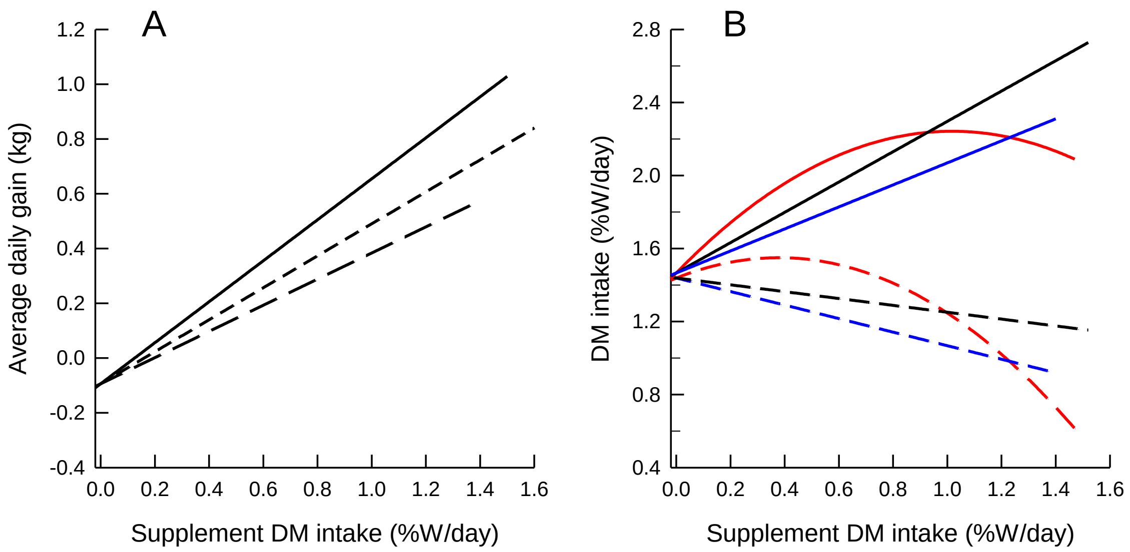

Fig. 1. Effects of supplement dry matter (DM) intake on (A) the average daily gain of steers fed Bar (solid line), MUP and MUP-B combined (medium dash) and MUP-W and MUP-BW combined (short dash), and on (B) the intake of hay (dashed lines) DM for steers fed Bar (red), MUP-B (blue) and MUP-W and MUP-BW combined (black), and of total (solid lines) DM for steers fed Bar (red), MUP-B (blue) and MUP, MUP-W and MUP-BW combined (black). Treatments are described in the text and the equations describing the relationships are given in Table 3.

The calculated conversion rate in the current pen study of about 4.8 kg MUP/kg additional gain is considerably better than that of 8.8 recorded in the grazing study for this project (McLennan *et al.* 2013a) where average intakes of MUP for young steers in the first dry season post-weaning were 3.8-3.9 kg/day (as fed) for drafts 1 and 2. Several reasons could be offered for the poorer conversion under grazing conditions. First, it could reflect a higher quality of diet selected by grazing cattle compared with the speargrass hay offered in pens, thus reducing the response to the added nutrients. Second, in the grazing study the conversion rate for MUP was calculated on the difference between the response by steers to MUP and that for urea-S supplement, not that of an unsupplemented control group. Under conditions conducive to urea responses, growth rate increases of the order of 0.23 kg/day could be expected from urea-based supplementation of young cattle relative to their unsupplemented counterparts (see McLennan *et al.* 2013a). Finally, it is possible that if MUP intake was increased beyond the maximum achieved in the pens (*ca.* 1.2%W/day) the response curve would lose linearity and plateau out, thereby increasing the conversion rate. However, the MUP intakes for the 2 drafts of young steers in the grazing trial averaged 1.19%W/day so should have been within the linear part of the response curve.

Given the superior performance with Bar compared with MUP overall, it might be expected that the inclusion of barley in the molasses-based ration (MUP-B) would stimulate growth rate of the steers. There is published evidence that provision of combined sources of carbohydrate with varying degradation rates, such as starch from grain and soluble sugars from molasses, supports higher microbial protein yield that either source alone (Johnson 1976; Offer *et al.* 1978; Sniffen and Robinson 1987). This MUP-B treatment was based on anecdotal but uncorroborated evidence from commercial feeding situations that the inclusion of grain at about 10 parts per 100 parts MUP improved growth performance of cattle. That there was no increase in growth rate with inclusion of the barley with the MUP supplement here suggests the inclusion rate was too low for any measurable effect. The level of barley inclusion was relatively low at 8% of total DM and this was partly counterbalanced by a 7% reduction in molasses content, so the additional energy contribution (per kg supplement) would have been minor even allowing for the lower energy value of molasses compared with barley (see above). Thus our results do not support the inclusion of grain in the molasses mix at the low levels used here and it appears that considerably higher inclusion rates would be required for measurable increases in growth. However, Hunter (2012) found no difference in growth rate of steers when comparing diets comprising 60% molasses with one of 40% molasses plus 20% grain sorghum. Whilst it appears that this lack of effect of adding barley to MUP in the current study is mirrored by a similar lack of effect when included in the MUP-WCS supplement, this latter comparison is confounded by differences in the inclusion rate for WCS in the latter supplements.

The increase in growth rate of steers when WCS was added to the MUP mix supports earlier findings of McLennan *et al.* (1998) in which rumen-cannulated steers were given a basal diet comprising a molasses-urea-P mix fed *ad libitum*, a restricted amount of wheat straw (0.75%W/day, DM) and 200 g/day of cottonseed meal. Replacing a daily supplement of 200 g WCS and 55 g urea with an isonitrogenous supplement of 1000 g WCS increased growth rate from 0.78 to 1.20 kg/day. This study provided the first evidence we are aware of where gains in excess of 1 kg/day were achieved by cattle on molasses-based diets and has been recently corroborated by the results of Hunter (2012). He reported growth rates by steers averaging 1.4 kg/day on finishing diets comprising (DM basis) 45% molasses and 20% WCS, considerably higher than that achieved here (*ca.* 0.8 kg/day) with the MUP-W treatment at the highest feeding level where the selected diet comprised (DM basis) *ca.* 40% molasses and 8.5% WCS. It is interesting to speculate on the reasons for the difference in performance in these experiments. Apart from the forage source used, in that Hunter (2012) fed an alkali-treated bagasse (*ca.* 50% DMD) comprising 28% of the diet compared with the speargrass hay used in our study which comprised 43% of the total DM consumed, the main difference in diet composition appears to be the higher proportion of WCS in the former study although Hunter did use a hormonal growth promotant which he surmised would provide an extra 0.1-0.2 kg/day response. McLennan *et al.* (1998) also included about 21% WCS in the diet. Higher inclusion rates of WCS than we used in the present study may be warranted and a dose response study examining this aspect to determine optimum inclusion rates seems justified.

The reasons for the added growth response with WCS cannot be categorically determined from the present results as WCS represents a source of fibre, mainly in the form of lint, of oil (*ca.* 20% of DM), of protein both as rumen degradable and undegraded dietary protein and of phosphorus, and has a high net energy content which will generally increase the caloric density of ruminant diets (Coppock *et al.* 1987). Given the earlier discussion around the low energy content of molasses relative to grains, the contribution of WCS to raising energy density of the mixed MUP-W diet and thus increasing total ME intake would seem a logical explanation of the reduction in the growth gap between the MUP and Bar treatments. Smith *et al.* (1981) estimated the nitrogen digestibility of WCS to be about 74.6% but given the need for mastication and regurgitation of the large seeds prior to passage from the rumen, it is likely that the RDN from WCS will be slowly released into the rumen for microbial uptake. However our diets based on MUP contained a source of both rumen degradable and undegraded dietary protein as urea and copra meal and the need for additional sources of both should have been reduced. As for protein, lipid release from WCS into the rumen is also likely to be slow thereby reducing the often-reported negative effects of oils on fibre digestion (Palmquist and Jenkins 1980). However, given the low-roughage nature of the molasses-based diets used here and the relatively low proportion of WCS in the total diet, it is highly unlikely that diet digestibility was seriously impacted by the feeding of WCS. On balance, it is most likely that the major impact from WCS would be from its effect on energy density of the diet and on total energy intake *per se*.

Intake and digestibility

The effects of increasing intake of the various supplements on hay and total DM intake are shown in Fig. 1 (B) and the equations describing the response curves are included in Table 3. The DMD of the unsupplemented hay diet averaged 40.0% highlighting the very poor quality of this tropical forage. Without supplement, the steers consumed 1.44%W/day of the hay which is similar to the intake determined for young steers on speargrass hay in the previous experiment (1.50%W/day; McLennan *et al.* 2013b). Supplements had a variable effect on both hay and total intake (see Fig. 1B). In general there was a negative associative effect (substitution) between supplement and forage intake. This substitution effect has been well described in the previous experiment (McLennan *et al.* 2013b) and in the literature (Chase and Hibberd 1987; Schiere and de Wit 1995; Dixon and Stockdale 1999). With all the molasses-based supplements except MUP there was a linear reduction in hay intake by the steers as supplement intake increased, the effect being greatest with the MUP-B treatment. At the same time total DM intake, and thus presumably ME intake, increased linearly on these rations, consistent with the growth rate response described above. The quadratic effect of Bar supplement on forage intake suggests an initial small increase at low levels of feeding and then the standard substitution effect. These results are consistent with those reported in the earlier experiments McLennan *et al.* 2013b) but not in the earlier work of our group where there was a depression in hay intake across the full range of barley feeding (McLennan 1997). The difference may be an artefact of the feeding method. In the McLennan (1997) study urea was included in the barley mix whereas in the 2 studies described in this report, urea was fed separate to the barley and with the hay portion of the diet. Feeding the urea separate from the grain may provide more RDN for utilising the roughage component than if its intake is synchronised with starch availability. Thus at low intakes forage intake may be responsive to amelioration of an RDN deficiency in the low quality forage. At higher supplement intakes fibre digestion is likely to be reduced (Chase and Hibberd 1987) and hay intake thereby depressed. The apparent higher depression in forage intake with Bar compared with the molasses-based supplements at high supplement intakes may reflect its higher energy density (MJ/kg DM), as Moore *et al.* (1999) showed an increased negative effect on forage intake when TDN intake from the supplement exceeded about 0.7%W/day. This effect may also explain the higher substitution observed when the barley was included in the MUP ration compared to other rations including MUP. Although total DM intake appears higher for the MUP-based treatments relative to Bar at high supplement intakes, the previously established higher energy content of barley relative to molasses (see above) suggests higher total ME intake with the grain-based ration as reflected in the growth responses described earlier.

Conclusions

The current study reinforced the inferior performance of rations based on molasses compared to a starch source such as barley for cattle on low quality forage diets. However, molasses-based rations will continue to be fed in northern Australia for reasons based on perceived cost advantage and practicality rather than on feeding value. Nevertheless, this sub-optimal performance with molasses rations impacts adversely on the economics of feeding and indicates a need to bridge the performance gap between the different energy sources without increasing the cost of feeding appreciably. Our study has indicated that small additions of WCS, but not grain, to the molasses-based supplements will improve the conversion rate of supplement to additional liveweight gain. The effect of inclusions of higher proportions of grain is open to speculation but given the difference in growth performance between the Bar and MUP rations, it is logical that increasing the barley content in an MUP mixture might increasingly bridge the performance gap between the supplements. However, the optimal inclusion rate would be a function of not only the growth responses to increasing inclusion of barley, and the relative costs of barley and the molasses it replaces in the mix but also the limitations set by the physical nature of the combinations of energy sources and their ease of mixing and feeding under commercial conditions. There appears scope for higher inclusion rates of WCS than were used here before cost are increased significantly or the adverse effects of the oil from WCS impact negatively on animal performance. Identifying the optimal inclusion rate of WCS in molasses-based diets presents a research priority.

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References

Chase CC, Hibberd CA (1987) Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn grain. Journal of Animal Science 65, 557-566.

Coppock CE, Lanham JK, Horner JI (1987) A review of the nutritive value and utilization of whole cottonseed, cottonseed meal and associated by-products by dairy cattle. *Animal Feed Science and Technology* **18**, 89-129.

Dixon RM, Stockdale CR (1999) Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research* **50**, 757-773.

Fordyce G, Coates R, Debney M, Haselton S, Rebgetz R, Laing AR, Cooper NJ, Hall R, Holmes WE, Doogan V (2009) A systems evaluation of high-input management using fortified molasses for beef production in Australia's dry tropics. *Animal Production Science* **49**, 177-191.

Hunter RA (2012) High-molasses diets for intensive feeding of cattle. *Animal Production Science* **52**, 787-794.

Johnson RR (1976) Influence of carbohydrate solubility on non-protein nitrogen utilization in the ruminant. *Journal of Animal Science* **43**, 184-191.

Lindsay JA, Dyer RM, Gelling BA, Laing AR (1996) Finishing Bos indicus crossbred cattle on northern speargrass pastures using molasses or grain based supplements. *Proceedings of the Australian Society of Animal Production* **21**, 89-91.

Lindsay JA, Cooper NJ, Batterham I. (1998) A molasses based production feeding system for Brahman cattle. *Animal Production in Australia* **22**, 119-121.

McLennan SR (1997) 'Developing profitable strategies for increasing growth rates of cattle grazing tropical pastures'. Project DAQ.100 Final Report. (Meat Research Corporation, Australia)

McLennan SR, Leng RA, Nolan JV (1998) Whole cottonseed supplements for cattle given a molasses-based diet. *Animal Production in Australia* **22**, 141-144.

McLennan SR, Fordyce G, Bowen MK, Cherry D, Enchelmaier K, Campbell J, Dawson K, Poppi DP (2013a) Consequences of changes to post-weaning growth path due to supplements and leucaena on growth and carcass characteristics of steers in the seasonally-dry tropics of Australia. In 'Optimising the growth paths of cattle for increased profitability'. Project B.NBP.0391 Final Report to Meat and Livestock Australia (this report, in preparation)

McLennan SR, Campbell J, Poppi DP, Dawson K, Kidd JF (2013b) Effect of stage of maturity of cattle on responses to supplements fed with low quality forages. In 'Optimising the growth paths of cattle for increased profitability'. Project B.NBP.0391 Final Report to Meat and Livestock Australia (this report, in preparation)

Moore JE, Brant MH, Kunkle WE, Hopkins DI (1999) Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. *Journal of Animal Science* **82**, 122-135.

Offer NW, Axford RFE, Evans RA (1978) The effect of dietary energy source on nitrogen metabolism in the rumen of sheep. *British Journal of Nutrition* **40**, 35-44

Palmquist DL, Jenkins TC (1980) Fat in lactation rations: review. *Journal of Dairy Science* **63**, 1-14.

Schiere JB, de Wit J (1995) Feeding urea ammonia treated rice straw in the tropics.II. Assumptions on nutritive value and their validity for least cost ration formulation. *Animal Feed Science and Technology* **51**, 45-63.

Smith NE, Collar LS, Bath DL, Dunkley WL, Franke AE (1981) Digestibility and effects of whole cottonseed fed to lactating cows. *Journal of Dairy Science* **64**, 2209-2215.

Sniffen CJ, Robinson PH (1987) Symposium: protein and fiber digestion, passage, and utilization in lactating cows. *Journal of Dairy Science* **70**, 425-441.

Winks L (1984) 'Cattle growth in the dry tropics of Australia'. (Australian Meat Research Committee Review no. 45)

Table 3. Effect of supplement type and intake, expressed as %W/day (X), on average daily gain and on hay and total dry matter (DM) intake of steers fed a basal diet of speargrass hay in pens

Treatment abbreviations are: Bar, barley mix; MUP, molasses-urea-protein meal mix; MUP-B, MUP plus barley; MUP-W, MUP plus whole cottonseed; MUP-BW, MUP plus barley plus whole cottonseed; and details are provided in the text.

P-values are given for the linear (Lin.) and quadratic (Quad.) coefficients in the regression equations; *, ** and *** represent *P*<0.05, 0.01 and 0.001, respectively; –, *P*>0.05.

Where there was no significant difference (*P*>0.05) between response relationships for different supplements a combined regression equation is given (Combined) and the degree of fit of the various treatments to that combined relationship is given separately

Y	Treatment	Equation	R^2	RSD	Lin.	Quad.
Average daily gain (kg)	Bar	$Y = -0.094 + 0.748 X$	0.95	0.115	***	–
	Combined	$Y = -0.094 + 0.477 X$			***	–
	MUC		0.90	0.091		
	MUC-B		0.90	0.103		
	Combined	$Y = -0.094 + 0.584 X$			***	–
	MUC-W		0.93	0.108		
	MUC-BW		0.91	0.114		
Hay DM intake (%W/day)	Bar	$Y = 1.438 + 0.590 X – 0.782 X^2$	0.73	0.182	0.06	**
	MUC-B	$Y = 1.438 – 0.371 X$	0.20	0.200	***	–
	Combined	$Y = 1.438 – 0.188 X$			**	–
	MUC-W		-0.10	0.234		
	MUC-BW		-0.01	0.210		
Total DM intake (%W/day)	Bar	$Y = 1.466 + 1.525 X – 0.749 X^2$	0.87	0.198	***	**
	Combined	$Y = 1.466 + 0.830 X$			***	–
	MUC		0.85	0.237		
	MUC-W		0.85	0.240		
	MUC-BW		0.85	0.227		
	MUC-B	$Y = 1.466 + 0.603 X$	0.81	0.212	***	–

13.5 Detailed Report 5: Validation of an intake prediction decision support tool

Prediction of herbage intake of cattle from animal performance, using the Australian feeding standards

S.R. McLennan, D.P. Poppi and J. Campbell

[Prepared for submission to Animal Production Science]

General introduction

The performance of grazing livestock is ultimately dependent on their intake and utilisation of nutrients derived from the available pasture sward. Of these, accurate determination of intake remains the most elusive especially under the extensive grazing conditions experienced in tropical northern Australia. Intake measurement or estimation remains a key factor for defining the nutrient status of grazing livestock, for meeting their nutrient requirements including the need for supplementary feed, for predicting animal performance and forecasting enterprise profitability, and for feed budgeting and thus setting realistic stocking rates for a particular land area. In recent times it has also become important for predicting environmental outcomes such as methane emissions and carbon balance (Gonzalez *et al.* 2012).

Several authors have reviewed the prediction of herbage intake by grazing ruminants (e.g., Poppi 1996; Peyraud 1997; Coleman 2005) and identified the influence on this of a number of feed- and animal-related factors. Most of the predictions based on the feed-related factors centre around establishing direct relationships between intake and single or multiple feed characteristics, for instance between intake and digestibility of the diet or, for instance, intake and content of protein or fibre components such as ADF or NDF. These relationships have met with varying success and the best predictions seem to occur with the data sets used in their establishment (Poppi 1996).

Quite apart from the variable accuracy of the predictions, a major limitation is being able to mimic the diet of grazing animals with any accuracy by sampling the pasture to which the animal has access. If this cannot be achieved, and the consensus seems to be that it cannot with any reasonable success, the errors associated with sampling the diet amplify those of the relationship between diet quality and intake, and lead to inaccurate predictions. In terms of animal-related measures, these tend to centre around determination of faecal output which, when coupled with an estimate of digestibility, allows calculation of intake of the grazing animal. Both direct collection of the total faeces using collection bags attached to the animal, and indirect estimates using techniques based on the dilution of indigestible markers in the digestive system, are used but still have limitations related to modification of the normal behaviour of the grazing animal or incomplete recovery of the marker, and are mainly suited to use in research rather than for commercial application. Inert markers such as chromium oxide, ytterbium and more recently the long chain alkane waxes (Dove and Mayes 1991) have been used. Detailed reviews of these methodologies have been published (e.g., Langlands 1987; Parker *et al.* 1990) and will not be discussed further here.

The emergence of the faecal near infrared spectroscopy (faecal.NIRS) technique (Lyons and Stuth 1992; Dixon and Coates 2005, 2009) whereby diet quality is estimated from a NIRS scan of the faeces voided by animals grazing that pasture, seems to overcome one of these limitations, that of accurately determining nutrient concentration in the diet. It provides a simple, rapid and relatively inexpensive estimate of the quality of the diet of animals grazing the pasture and has considerable potential for use under extensive grazing conditions. Most importantly, it removes the need to sample the pasture in order to mimic the diet of the grazing animals; they collect their own samples.

The GrazFeed decision support system has been especially designed to predict the performance of grazing ruminants (Freer *et al.* 1997). It computes the quality of the diet selected by grazing animals on the basis of user inputs on the total herbage mass, pasture height and the proportions and CP content and DMD of the green and dead components of the pasture. Intake is predicted from a relationship with diet quality aspects, particularly DMD, and animal performance is subsequently predicted from the computation of nutrient intake. The GrazFeed package has been quite widely and successfully used in the southern states of Australia. In fact it represents the only real attempt to apply feeding standards to the grazing situation by including an intake estimation as a key first step. However, applicability of the GrazFeed method of characterising the diet selected by ruminants grazing tropical (C4) grasses, with different scope for selective grazing, different sward structure and wider differences between leaf and stem DMD than for temperate pastures, has been questioned (Freer 2002) and it is not generally used for these reasons in northern Australia.

Coleman (2005) pointed out that because the various methods to estimate intake are expensive, laborious and lack both precision and accuracy, they are unsuited for use by consultants or producers under commercial conditions and are generally used only in a research environment. Whilst a high degree of accuracy is desirable for research endeavours aimed at understanding the relationship between nutrient intake and its utilisation for productive purposes, the same level of accuracy is not critical for developing feed budgets under extensive grazing conditions. Feed budgeting matches the supply of herbage with the demands of the animal over a specified period of time and incorporates aspects of pasture growth, trampling and selection of desirable species together with a desired utilisation rate for the period of interest. Its importance lies in the recognised impact of utilisation rate on pasture composition and quality and their sustainability over the longer term. In general, feed budgets will allow a ‘margin for error’ especially where longer term forecasts are made in the absence of accurate long-term climate forecasts.

An alternative approach to estimating herbage intake by grazing ruminants is to use an energy balance method linked to some measure of the performance of the animals and an estimate of the energy value of the consumed herbage. In short, where the energy requirements of the animal for the observed performance, i.e., for maintenance, production and activity (exercise), can be deduced by reference to the feeding standards, the intake of herbage can be derived by dividing this energy requirement by the energy concentration of the selected diet. In effect this represents a reversal of the normal use of the feeding standards whereby animal performance is predicted from known intake of nutrients such as that collected in pen feeding situations. Production may include growth of meat and fibre as well as gestation and lactation. In its simplest form with growing, non-reproducing cattle, the production trait need only be the liveweight change of the animal. The use of supplements can be accommodated by subtracting the energy ingested from this source from the total energy requirements, as supplement intake can be measured and its energy concentration determined by analysis.

This approach is not new; its use has been recommended by several workers (e.g., Cox *et al.* 1956; Logan and Pigden 1969; Baker 1982, 2004). Baker (1982) applied the feeding standards described by MAFF (1975) but later updated this (Baker 2004) by using those of AFRC (1993). Minson and McDonald (1987) used a similar approach but in view of the difficulties associated with estimating the energy content of the pasture selected by the grazing animals, they used a modification to the above technique by assuming that the liveweight gain of cattle was linearly related to the dry matter digestibility (DMD) of the pasture eaten and that DM was non-limiting. Thus for liveweight gains increasing progressively from 0 to 1.0 kg/day in 0.25 kg/d increments, assumed DMD increased from 50 to 70% in 5% increments. Applying the ARC (1980) feeding standard equations, they established a relationship described by a simple equation whereby herbage (both temperate and tropical) intake of cattle could be predicted from their liveweight and liveweight gain with a coefficient of variation of 8.7%.

A similar energy balance approach to estimating herbage intake of cattle is evaluated in this paper. In our study the Australian feeding standards of SCA (1990) and its successor CSIRO (2007) have been used based on local scientist's familiarity with those standards and to provide direct application to the Australian grazing scene. The relevant equations from these standards have been incorporated into a Microsoft Excel® spreadsheet calculator named 'QuikIntake' (QI; SR McLennan and DP Poppi, unpublished) to facilitate their ease of use by scientists, extension specialists, commercial advisors and cattle producers. It is proposed that either a measured or historical liveweight change is used as the key input into the spreadsheet, where the latter may represent the expected change based on past records and an assessment of current climatic conditions. Baker (2004) suggested that the precision of the estimate of herbage intake by this method was dependent on the adequacy of the energy standards, the accuracy of the herbage energy measurement and on the ability to measure animal production accurately. These are valid considerations and need to be addressed in this paper. We are confident that for many pasture communities in northern Australia the F.NIRS approach described earlier can be used to provide a reliable estimate of diet quality and in particular of energy density with grazing cattle, and it provides the link between the estimates of energy requirements and herbage intake.

The adequacy of the feeding standards is more difficult to assess and has been assumed in the cited attempts to use energy balance for intake predictions, although validation studies have usually been carried out to compare predicted and observed intakes. We have previously evaluated the equations of the SCA standards in a desk-top study in which the observed liveweight gains of steers confined to pens were compared with those predicted using both the SCA and the Cornell Net Carbohydrate and Protein System (CNCPS; Fox *et al.* 2004). This study included 240 individually-fed steers from 6 pen experiments where intake, digestibility and liveweight gain were measured. The SCA equations provided a reasonable prediction of liveweight gain, as reported earlier (Dove *et al.* 2010; McLennan and Poppi 2012), and thus provided confidence in their reverse application to predict intake from measured liveweight performance. Nevertheless, there was considerable variation around the regression line relating observed and predicted gains. In this paper we describe the equations used in QuikIntake and discuss potential problem areas. In addition, a validation study has been carried out to assess the accuracy and precision of the estimates of intake made.

Recently the designers of GrazFeed have established a web-based spreadsheet calculator called ME requirements (www.pi.csiro.au/grazplan; CSIRO) similar to the one described here. The main differences are that QI is focused primarily on tropical grazing systems, has undertaken validation as described below and has been enhanced to accommodate the use of supplements in the grazing system.

Description of QuikIntake and incorporated equations

As alluded to above the equations included in QI have been taken from the SCA feeding standards and updated where required using its successor, the CSIRO (2007) standards and also with reference to a web-based technical paper by Freer *et al.* (2012). This latter paper is based on the original paper of Freer *et al.* (1997) which describes the GRAZPLAN animal biology model and the GrazFeed decision support tool. GrazFeed incorporates the equations of SCA and CSIRO (2007) into a user-friendly interface with the feeding standards. The technical paper (Freer *et al.* 2012) is regularly updated to describe changes made to GrazFeed. From hereon, reference will be made solely to SCA except where equations have been updated, when CSIRO (2007) or Freer *et al.* (2012) will be cited. Animal production in this paper is restricted to growing, non-reproductive cattle and the emphasis is on intake predictions for non-supplemented cattle. The spreadsheet lends itself to inclusion of reproducing animals and their followers and to the inclusion of supplements.

Calculation of intake

Intake was calculated by dividing the total metabolisable energy (ME) intake of the animal by the energy density of the diet it selected, as indicated in equations 1. The total ME intake (MEI) is the sum of the ME used for maintenance of the animal (ME_m), i.e., non-productive energy, and the ME available over and above the maintenance requirements, for productive purposes (equation 2). With non-reproducing animals, the latter component is the ME for liveweight gain (MEgain).

$$DM\,\mathrm{int}\,ake = \frac{Total\ ME\,\mathrm{int}\,ake}{M/D} \qquad (1)$$

$$Total\ ME\,\mathrm{int}\,ake = ME_m + MEgain \qquad (2)$$

where:
DM intake = DM intake of herbage (kg/day);
Total ME intake is expressed in MJ/day;
M/D = energy density of the diet (MJ/kg DM);
ME_m = the amount of ME used for maintenance (MJ/day);
MEgain = the amount of ME available for gain after the maintenance requirements are met (MJ/day).

The methods of determining these various factors are described in the following sections.

Energy value of the diet (M/D)

The F.NIRS technique gives a point-in-time estimate of the DMD of the diet selected by grazing ruminants, and we propose that this technique be used to sample the diet of cattle grazing tropical and sub-tropical pastures in northern Australia. This obviates the need to mimic the diet of extensively grazed cattle using samples cut from the available sward which is usually extremely heterogeneous in species composition and plant components. In the most recent update of the original Freer *et al.* (1997) paper describing the GrazFeed decision support model, based on SCA, Freer *et al.* (2012) recommend using equation 3 to estimate the energy density of the diet (M/D; MJ/kg DM) for roughage feeds (hand-fed forages). However, in the absence of comparable data for grazed pasture, they suggest using the original equation provided in SCA, i.e., equation 4. Nevertheless, because QI can be used in both situations, we have used equation 3 to calculate the M/D in the QI spreadsheet.

Where ‘energy feeds and protein supplements’ are included in the diet, Freer *et al.* (2012) recommend using equation 5 which includes the ether extract (EE) content of the supplement.

$$M / D = 17.2\,DMD - 1.71 \tag{3}$$

$$M / D = 17.0\,DMD - 2.0 \tag{4}$$

$$M / D = 13.3\,DMD + 23.4\,EE - 1.71 \tag{5}$$

where:
DMD = DM digestibility of the diet (g/100 g);
EE = ether extract content of the diet (g/g).

Changing from equation 3 to 4 has a marked effect on the estimation of energy density with flow-on effects on the efficiencies of use of energy for maintenance and production and the estimation of maintenance requirements. For instance, for DMD values over the range of 0.45 – 0.65, calculated M/D varied from 6.0 – 9.5 MJ/kg DM using equation 3 and from 5.7 – 9.1 MJ/kg DM using equation 4. Accordingly, using equation 4 instead of 3 can substantially increase the predicted intakes at the same DMD value. The same argument would apply if equations from other feeding standards were used in the calculations and it is important therefore to be consistent in the equations used.

Energy requirements for maintenance (ME_m)

Equation 6 (below), taken from SCA, was used to calculate the maintenance requirements of the animal (ME_m). In simplistic terms, the energy available to the animal can be separated into that used for maintenance (ME_m) and that in excess of maintenance that is used for production (ME_p). The SCA uses an approach that tends to differ from some other standards, e.g., ARC (1980), in that ME_m is not considered a constant but varies with the amount of ME used for production (ME_p). Thus as animal production increases, maintenance requirements of the animal also increase under this system of calculation. Also in contradiction of other standards, the efficiency of use of this ME_p (k_g) is treated as a constant within SCA whereas it varies with changing diet quality in other standards. Thus whilst k_g varies with M/D of the feed consumed (see below), for any particular feed (constant M/D) it is constant across the full range of feeding levels (SCA; CSIRO 2007).

$$ME_m = \frac{KSM\,(0.28W^{0.75}\exp(-0.03A)}{k_m} + 0.1MEgain + \frac{Egraze}{k_m} + Ecold \tag{6}$$

where:
K = 1.2 for *B. indicus*, 1.4 for *B. taurus* and intermediate values for crossbreds;
S = 1.0 for females and steers (castrates) and 1.15 for bulls;
M = 1 + (0.23 x proportion of DE from milk);
W = liveweight (kg), unfasted;
A = age in years, with a maximum value of 6.0;
k_m = net efficiency of use of ME for maintenance;

MEgain = the amount of dietary ME (MJ) used directly for production;
Egraze = additional energy expenditure in grazing relative to a similar housed animal;
Ecold = additional energy expended in cold stress by animals when below critical temperature.

Ecold has been set at zero in QI for 2 reasons. First, QI was designed for use in northern Australia where the incidence of temperatures below critical values is less common, both on a seasonal and diurnal basis, compared with temperate environments. Second, but consistent with the location aspect of reason 1, QI is not designed for precise energy balance studies but instead for longer term application such as feed budgeting and establishing appropriate carrying capacities, where less accuracy is required and short-term effects of low temperature will be markedly diluted over an extended period.

In contrast to Ecold, Egraze operates on a daily basis and needs to be included in determination of energy used for non-productive functions. As the name suggests it includes the energy cost to the animal in obtaining its food from the pasture sward and varies with the nature and quality of the forage on offer. These energy costs will be much higher than for a similar confined animal receiving pre-harvested diets. For animals fed under confined conditions, Egraze is considered by SCA to be zero as the distances travelled are negligible by comparison with grazing counterparts and the ME_m calculation (equation 6) already allows for the energy used in standing, ruminating and eating under these conditions. This results from an allowance for these functions in the estimation of the k_m term used in the calculation of ME_m. The reduction in k_m with decreasing M/D (and DMD; see below) is associated with the higher muscular work expended in consumption of more fibrous forages. Thus as forages decline in digestibility, k_m declines and ME_m increases. Equations 7 and 8 from SCA and Freer *et al.* (2012) are used in QI to calculate Egraze.

$$Egraze = 0.0025 x W x I \ (0.9 - DMD) + Emove \qquad (7)$$

$$Emove = 0.0026 \ x \ D \ x \ S \ x \ W \qquad (8)$$

where:
I = intake of herbage + seed (kg DM);
DMD = DM digestibility (g/100 g);
Emove = energy expenditure in walking for grazing, watering etc.;
D = distance travelled (km);
S = steepness of the land (scale of 1-2).

An explanation of the derivation of these equations is given in SCA and the accompanying manuscript (Freer *et al.* 2012). Intake and DMD are included in equation 7 in recognition of the effect of pasture availability and digestibility on the rate and intake of the diet and thus their impact on energy expenditure. The Emove term has been simplified from the functions shown in Freer *et al.* (2012), for extensive grazing situations where the stocking density will almost always be less than 5 stock/ha and the proportion of green and dead material are difficult to assess and their proportions in an extremely heterogeneous sward scenario are likely to have different effects on diet selection than for more intensive operations. Thus the horizontal distance travelled is multiplied by a slope factor (scale of 1 to 2; level to steep) to give a horizontal equivalent distance travelled, which is multiplied by the energy cost for horizontal walking (0.0026 MJ/km).

Inclusion of the intake term in equation 5 introduces an immediate problem in that intake is the function ultimately being predicted by QI. An estimate of intake is made using the approach of SCA of determining the potential and relative intakes of the animals. Potential intake is the amount eaten by an animal when given unrestricted access to a feed with a DMD of at least 80% and thus represents an upper threshold for intake. The relative intake is the proportion of the potential intake that the animal achieves and is influenced by the availability of the pasture and its ingestibility. A detailed description of these terms and their derivation is given in SCA but due to its minor significance here, it will not be further explained in this text. The simplified equations used to calculate potential and relative intake are equations 9 and 10, updated in CSIRO (2007) and Freer *et al.* (2012) from those originally presented in SCA.

$$PI = 0.025\, x\, SRW\, x\, Z\,(1.7 - Z) \tag{9}$$

$$RI = 1 - 1.7\,((0.80 - 0.16) - DMD) \tag{10}$$

where:
PI = potential intake (kg DM/day);
SRW = standard reference weight of the animal (kg);
Z = relative size, i.e., the ratio of liveweight to SRW (max. 1.0);
RI = relative intake; the proportion of the PI that is actually consumed by the animal;
DMD = DM digestibility (g/100 g).

The estimated DM intake of the animal (kg DM/day) is the product of the RI and PI values from equations 9 and 10. These relate to a growing, non-reproductive bovine animal grazing a C4 pasture with no legume content. An additional function can be included if legume is present in the pasture but has not been included here for simplicity of calculation. This calculation of intake also assumes that pasture is not limiting (at least 3 t DM/ha for cattle). If pasture was limiting the above calculations would give an over-estimation of intake.

To reiterate, the reason for calculation of intake in this way is simply to provide a value which can be used in the calculation of the energy expenditure for grazing (Egraze). Small errors in intake prediction here will have a small flow-on effect on the Egraze term and the errors will be further diminished in the calculations of ME_m and eventually in predicting the intake from the liveweight gain of the animal. If precise measures of intake of animals could be made using calculations of the potential and relative intakes in extensive, heterogeneous pasture situations there would be no need to predict intake from liveweight change.

The calculation of MEgain is described below and represents the ME available over and above that required for maintenance.

Efficiency of energy use for maintenance (k_m)

The k values represent the efficiency of conversion of ME into net energy (NE) for various functions, including maintenance (k_m) and growth (k_g). There are 2 possible approaches to setting the value for k_m, the efficiency of use of ME for maintenance. The first is to use equation 11 below from SCA, which has not changed in CSIRO (2007) or in Freer *et al.* (2012). However, use of this equation for feeds with an M/D less than 7 (*ca.* 51% DMD) is questioned in SCA on the basis that derivation of the equation did not include feeds with M/D this low. The alternative suggested in SCA and CSIRO (2007) is to use a fixed value for k_m of 0.72 for cattle, as used in MAFF (1984), although with the qualification that using this fixed value may overestimate k_m for low quality forages encountered in the tropics of Australia.

A fixed value for k_m of 0.72 is used in QI, as it is also in *MErequirements*. This means that for all diets with DMD <73% (M/D = 10.8) the k_m value is higher than would be the case if equation 11 was used. The predicted intake declines with increasing k_m value so for most tropical forages consumed predicted intake is lower than would be the case if equation 11 was applied. The DMD of diets selected by cattle grazing tropical (C4) pastures would rarely exceed 73%.

$$k_m = 0.02 M/D + 0.5 \tag{11}$$

Energy requirements for growth (MEgain)

The energy requirement for growth is calculated via a step-wise process which ultimately involves determining the NE retained by the animal (energy retention; ER) and converting this to ME required as expressed in equation 12. The energy retained is calculated, as shown in equation 13, from the empty body weight gain (liveweight gain (LWG) x 0.92) of the animal and the energy value of that gain (EVG) which is a function of the composition of gain in terms of fat and protein content. The energy value of the gain is in turn calculated from a knowledge of the stage of maturity of the animal, i.e., the current weight in relation to its mature body weight (standard reference weight, SRW) with an adjustment for the rate of gain or loss (see equations 14, 15 and 16). The parameter ‘b’ in equation 14 is used in the calculation of the EVG changes with body type; it is 20.3 for all breeds of cattle except *Bos indicus* and large European breeds such as Charolais, Blonde d’Aquitane, Limousin, Chianina, Maine Anjou and Simmental, where the factor 16.5 is substituted in recognition of the lower fat and higher protein content of gain for these lean breeds of cattle. For crosses between these animal types, an intermediate value for ‘b’ of 18.4 is suggested (CSIRO 2007). The *B. indicus* cattle were previously grouped with the non-European *B. taurus* breeds (SCA; CSIRO 2007) and their inclusion with the lean European breeds is a recent change (Freer *et al.* 2012).

$$MEgain = \frac{ER}{k_g} \tag{12}$$

$$ER = LWG\,x\,0.92\,x\,EVG \tag{13}$$

$$EVG = (6.7 + R) + \frac{b - R}{1 + \exp\left(-6(P - 0.4)\right)} \tag{14}$$

$$P = \frac{CurrentW}{SRW} \tag{15}$$

$$R = \frac{EBC}{4\,x\,SRW^{0.75}} - 1 \tag{16}$$

where:
MEgain = ME requirements for gain (MJ);
ER = energy retained or net energy required for weight gain (MJ);
k_g = efficiency of use of energy for gain;
LWG = liveweight gain of the animal (kg), converted to empty weight gain by multiplying by 0.92;
EVG = energy content of the empty weight gain (MJ/kg);
b = parameter used for predicting EVG; b = 16.5, 18.4 or 20.3 according to animal type (see text above);
SRW = standard reference weight (kg);
CurrentW = current liveweight of the animal (kg);

P = current weight as a proportion of the SRW;
R = adjustment for rate of gain or loss;
EBC = empty body change (g/day), or liveweight gain x 0.92;

The SRW for a breed and/or sex of cattle is defined in SCA as the liveweight that would be achieved when skeletal development is complete and condition score is mid-range, e.g., 5 in range 1-9. Employing this concept for defining the stage of maturity of an animal, i.e., liveweight relative to its SRW, allows calculations for cattle (and sheep) from all breeds and maturity types (frame sizes) to be computed using single equations. Whilst this concept is sound workers often find difficulty in defining the SRW of the animals for their particular situation. The rate at which animals achieve their mature size could influence determination of SRW so that comparable animals following different growth paths could have different SRWs. Indicative values for SRW for different breeds are tabulated in SCA and CSIRO (2007) but these should be treated as indicative only and users should determine their own values according to the prevailing conditions under which the cattle are grown (M. Freer, pers. comm.). Indicative values for SRWs are included in QI as well as a range of values for *B. indicus*-type cattle ranging from 450-550 kg for females to allow the user some flexibility to change the SRW to suit the situation. The SRW for females has been multiplied by 1.2 and 1.4 to provide values for steers and bulls, respectively. More discussion on this subject is provided later.

Efficiency of energy use for growth (k_g)

The appropriate equation to use to calculate the efficiency of use of energy for growth and fattening (k_g) is not clear-cut but as a critical component of equation 12 in the calculation of MEgain, its selection is of considerable importance. The original suggestion from SCA (equation 1.41) has been changed in CSIRO (2007) where it is suggested that equation 17 be used for grazed tropical pasture. Allowance can be made for differences in latitude or time of year and for varying legume content in the pasture, but for simplicity in QI equation 17 is used.

$$k_g = 0.043M/D \tag{17}$$

Where animals are losing weight they use energy from catabolism of body protein and fat but this energy is not used with 100% efficiency. It has been determined in SCA and CSIRO (2007) that under these conditions the value used for k_m should be 0.80.

Inputs and outputs of QuikIntake

The information that the user needs to enter into QI includes: the DMD of the diet selected; the breed, sex and age of the animal; the current liveweight of the animal or the average over the period of interest; the SRW for that breed and sex of animal in the current environment; the daily liveweight change; and the distance walked daily with a description of the terrain.

As discussed earlier we suggest that for tropical grazing systems in Australia, the best estimate of diet DMD will be provided by F.NIRS. Commercial analytical systems are currently available to provide this service. As suggested earlier, the liveweight change can either be a measured value, although this represents the change for the lead-up period, or a historical value based on previous experience under comparable climatic and grazing conditions. Small errors in this estimate will not be of major consequence where the calculator is being used for feed budgeting purposes or to design supplement programs in extensive systems. Regular adjustments can be made as the season progresses.

Including a value for the distance walked daily is highly subjective but a reasonable estimate will be double the distance from the watering point to where the cattle are observed furtherest from that point, if cattle are known to water daily. Cattle are known to graze out distances of up to 10 km from watering points under extensive grazing conditions in northern Australia (S Petty, pers. comm.), i.e., 20 km/day walking. In a QI simulation using a 250 kg *B. indicus* crossbred steer gaining 0.5 kg/day on a 60% DMD selected diet, the estimated ME_m increased by 36 and 51% (from 30.4 MJ/day) for level and undulating (1 and 1.5 in a scale 1-2) terrain and estimates of DM intake increased by 22 and 31% (from 5.7 kg/day), respectively. Thus the increased maintenance costs associated with Egraze averaged about 3.6 and 5.1 MJ/km travelled, respectively. These effects are illustrated in Fig. 1. The energy requirements will change according to the liveweight of the animals as well. SCA suggests an increase in ME_m of between about 10 and 50% for grazing with non-cold-stressed animals, depending on the grazing conditions and terrain and in the spreadsheet calculator *ME requirements* (M. Freer, pers. comm) the option is provided to the user to nominate a percentage increase in MEm to account for these extra energy requirements of the grazing animal.

The information provided by QI includes the predicted ME intake and DM intake (kg/day and %W/day).

Validation of QuikIntake for predicting intake

Introduction

In order to have confidence in the use of the QI spreadsheet for use in predicting intakes of grazing cattle it was first necessary to validate the spreadsheet using data from controlled experiments with confined cattle where exercise was restricted and where intake and digestibility of the diets and growth rate of the cattle were measured. Such data including all 3 measurements are difficult to find in the literature; many studies include only 2 of the 3 and can therefore not be used to validate this calculator. Consequently, specifically-designed experiments were set up and data were obtained from these experiments (Set A) as well as from previous pen feeding experiments of our own (Set B studies; McLennan 2005; McLennan *et al.* 2012, 2013). It was intended that a considerable number of different forages, primarily C4 types, ranging widely in quality be used to provide a sound database encompassing the full range of diet qualities likely to be experienced under natural grazing conditions. A third set of data (Set C) from studies of our research group using mainly higher-quality C3 species was also included but for reasons which become apparent later, these were kept separate from Set A and Set B simulations. For these validations the intakes predicted using QI were compared with those observed.

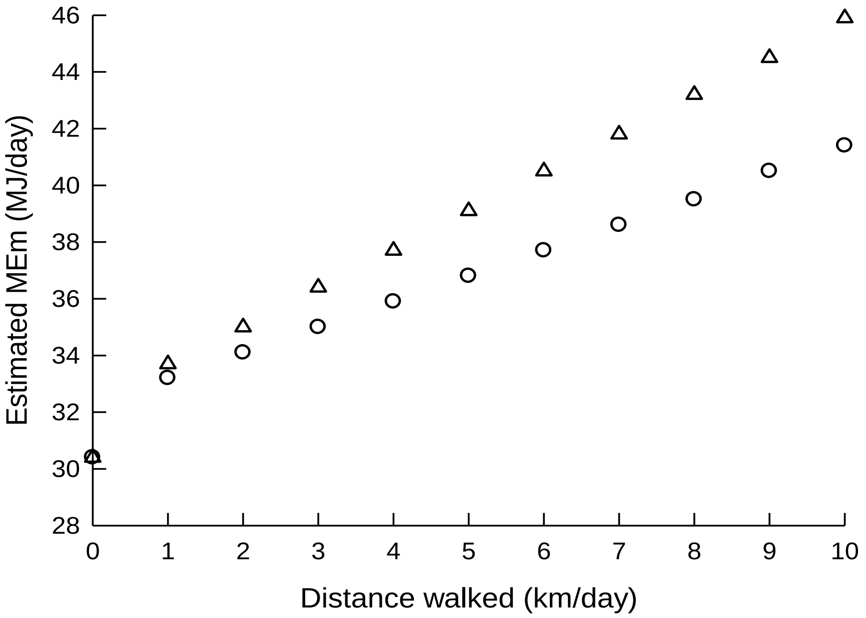

Fig. 1. Effects of distance walked on level (circle) or undulating (triangle) terrain on estimates of the maintenance requirements (MEm) of a 250 kg steer, as calculated using the QuikIntake spreadsheet calculator.

Materials and methods

Set A: Animals, treatments and experimental design

Two runs of the forage evaluation experiment were carried out at “Brian Pastures” Research Station between May and October 2009. Commercial Brahman crossbred weaner steers (50-75% *B. indicus*) from a local source were approximately 6-8 months of age at time of purchase. The steers were vaccinated against tick fever in March, and bovine ephemeral fever in April/May. They also received an application of Cydectin® Pour-On to reduce any parasitic burdens both prior to commencement of the experiment and again in August between experimental runs.

The intended experimental design was 2 runs of a randomised complete block each involving 7 forage treatments with 6 steer replicates. In fact, the number of replicates varied for treatments from the intended 6 to between 3 and 7 where some forages were rejected by steers leading to low replicate numbers for those treatments whilst other forages were allocated an additional replicate. The forages used in Run 1 included 2 lots of Rhodes grass (*Chloris gayana*; A and B) which were cut from the same site but at slightly different stages of maturity, Bisset bluegrass (*Bothriochloa inscupta cv.* Bisset), wheat straw (*Triticum aestivum*), lucerne A (*Medicago sativa;* source A), forage sorghum (*Sorghum spp.* hybrid) and peanut hay (*Arachis hypogaea*). Those used in Run 2 included Dolicos (*Lablab purpureus*), 2 lots of Mitchell grass (*Astrebla* spp*.,* A and B) cut at different stages of maturity, millet (*Pennisetum glaucum*), barley (*Hordeum vulgare*) and lucerne A and B, where A was the same as used in Run 1 and B was from another source. All forages were fed *ad libitum* apart from lucerne A in Run 2 which was fed at a restricted intake of 1.4% liveweight (W)/day, calculated on an ‘as fed’ basis. Steers were housed in individual pens. Pens were blocked according to their position within the pen complex and forage treatments were randomly allocated to pens within this block design. The steers used in Run 2 comprised some used in Run A and some that had not previously been used.

Set A study: Procedures

Runs 1 and 2 of the experiment each consisted of a 7 day pre-trial equilibration period followed by a 42 day growth study, which included a 7 day faecal collection period, and was concluded with a 7 day post-trial equilibration period. The steers were returned to the paddock for a period of 34 day between Runs 1 and 2. Due to a shortage of feed the growth study period for the Mitchell grass B treatment was only 35 days. During the pre-trial equilibration periods the steers were fed Rhodes grass hay *ad libitum* in group pens with 3 steers per pen. The steers were weighed full and fasted (24 h off feed, 16 h off water) at the end of this equilibration period and allocated to treatments by stratified randomisation on the basis of this fasted LW (Day 0).

During the growth study the various forages were fed once daily. Prior to feeding the forages were chaffed using a tub grinder, with the following exceptions: millet and lucerne were chaffed using a feed wagon fitted with horizontal blades in order to minimise leaf loss, and Dolicos lablab and peanut hay were fed un-chaffed due to the woody nature of their stem material and the risk of losing leaf material during chaffing. Residues were generally collected once weekly. The exception was where relatively inedible material such as thick stems from Dolicos and peanut hay or dust and seed from millet accumulated; these were collected 2 or 3 times weekly as required. Otherwise, a bunk assessment was conducted at 0800 h each morning to assess the amount of hay remaining. From this assessment forage was allocated to each steer at a level estimated to provide 15% in excess of its intake on the previous day, in order to maintain *ad libitum* intake, with the exception of lucerne B in Run 2 (see above) for which steers were fed at 1.4%W/day, re-calculated on a weekly basis after weighing the steers. Sub-samples of the forages, collected and stored daily and bulked weekly, and residue feeds were dried to constant weight at 60^{o}C to determine dry matter (DM) content. Separate samples of the forages were taken daily and bulked over the 42 day growth study for later chemical analysis.

During the growth study, steers were weighed, unfasted, once weekly at 0800 h (before feeding) on the day residues were collected. The height of the steers was measured at the hip and body condition score determined at the beginning and end of the growth phase.

During the fifth week of the growth studies total faeces was collected from each steer from the concrete floor of the pen for 7 days. Faeces were collected daily at approximately 0700, 1200 and 1600 h, bulked for each steer at 1 or 2 day intervals, weighed and mixed using a Hobart mixer. A sub-sample of 10% of total was taken and frozen. On the final day of faecal collection these frozen samples were thawed, bulked for each steer and mixed in a Hobart mixer and duplicate representative sub-samples each of *ca.* 500 g were taken and dried to constant weight at 60^{o}C for DM determination. The samples were then ground through a 1 mm sieve prior to chemical analysis. On the final day of the faecal collection, which corresponded with the day residue hay was collected, representative sub-samples of the residue hay were collected, ground through a 1 mm screen and analysed for OM content and for N content in the case of lucerne A and B and Dolicos. These later samples were used to assess the extent of selection by the steers for higher quality material, e.g. leaf.

At the conclusion of the growth study the steers were weighed full and fasted and were then returned to their pens for the final equilibration period when they were fed, *ad libitum*, the same Rhodes grass hay as used in the pre-experiment equilibration.

This phase was included to equilibrate gut-fill between treatment groups. The steers were then again weighed full and fasted at the end of this phase.

Data from other studies

Set B. Data from unsupplemented steers of 6 other pen feeding studies (A-F), established in a similar way to that described above but with growth periods of 70 days duration, were included in the test group. These studies all used C4 forages of relatively low quality (<6% CP; see Table 1 below). The steers in each trial were Brahman crossbreds (50-75% *B. indicus*) which were mostly aged *ca.* 10-12 mo but some mature steers *ca*. 36 mo old were included in 2 experiments (D and E). The average liveweight of the steers during the growth period were: A. 198 kg; B. 177 kg; C. 242 kg; D. 198 and 433 kg; E. 208 and 420 kg; F. 184 kg. The procedures used in determining intake, DMD and liveweight change were similar to those described above.

Set C. Data were obtained from 3 other pen feeding experiments which used higher quality rations than most of those above, mainly based on temperate species. The first used either Friesian (average 15 mo, 293 kg) or *B. indicus* crossbred (average 10 mo, 231 kg) steers which were given lucerne chaff either *ad libitum* or at a restricted intake over 3.5 mo. In the second experiment *B. indicus* crossbred steers of average age either 12 or 36 mo and liveweight 224 and 496 kg, respectively, were given ryegrass haylage either *ad libitum* or at restricted intakes which, over a 75 day feeding period, averaged (DM) 1.08, 1.49, 1.82 and 2.15%W/day for the young steers and 0.97, 1.29, 1.62 and 1.76%W/day for the older steers. In the third experiment, pellets containing varying concentrations of P were fed *ad libitum* to *B. indicus* crossbred steers (15 mo, 339 kg), supplemented with 0.5 kg/day of Mitchell grass hay to maintain rumen motility, over 122 days. The intake predictions from this set of data have been kept separate from those of the Set A and B for comparative purposes. Intake was determined in a similar manner to that described above and DMD was measured in metabolism cages where total faecal collections over 7 days was determined.

Prediction of intake using QuikIntake

Data from the above studies, namely digestibility and liveweight change together with a description of the steers, were used as inputs into QI. The treatment averages, not individual animal data, were used. The liveweight change used was that over the total feeding period of the growth study (excluding any equilibration periods) on a full liveweight basis. Intakes predicted using QI were compared with those measured during the growth studies.

Statistical methods

In the process of validating QI, intakes predicted using the spreadsheet calculator were compared by linear regression with observed values. Several statistical tests were applied, as have been described by Mayer and Butler (1993). The ‘goodness of fit’ of the data to the regression line for predicted vs observed values was expressed as an R^2 with a residual standard deviation (RSD) indicating the variance from this line, and an F-test was also applied for slope = 1 and intercept = 0. The overall model performance was measured as the modelling efficiency (EF) which, like the R^2 described above, provides a measure of the proportion of variation explained relative to the line of ‘perfect fit’ or Y=X; a perfect fit would result in an EF of 1 (Mayer and Butler 1993). Hence the R^2 for the fitted line could be quite high but the EF value low indicating poor prediction of a measurement relative to observed values. The bias, which is calculated as the Y mean (observed) minus the X mean (predicted) divided by the X mean, expressed as a percentage, was also determined.

Attempts were made to improve predictions by changing the prediction equations in 2 ways, viz., by re-calibration or optimisation. Proportionate re-calibration was carried out to correct for bias by re-calculating the X values as: $X_i * (1/\text{average } (X_i/Y_i))$. Model optimisation was performed using the 'Solver' function in Excel which optimises the model coefficients to minimise the residual sum of squares (RSS).

Results and discussion

Chemical composition of the forages

The composition of the forages used in the Set A and B studies, is shown in Table 1. The aim in assembling the feed sources for the Set A study was to provide forages with as wide a range in quality attributes as possible, which would translate through to widely varying intakes and growth rates to test the intake calculator. This was difficult to achieve with C4 forages alone as the nature of these plants is for them to mature rapidly after the start of the growing season, as a survival mechanism, so that their quality declines rapidly as well. Thus C4 harvested forages in the mid to high range of quality are not easily sourced. Consequently, some C3 forages such as lucerne had to be included to increase the quality range. However, there was generally a dominance of lower quality forages with 10 of the 19 forages having CP content <6 and NDF content >65.0 g/100 g DM. Nevertheless, there was a reasonably wide range in nutritive value of the forages used as indicated by crude protein (CP) content (3.4-21.1% DM).

Table 1. Chemical composition of the forages

OM = organic matter; CP = crude protein (nitrogen x 6.25); NDF = neutral detergent fibre; ADF = acid detergent fibre; EE = ether extract; nd = not determined

	OM	CP	NDF	ADF	EE
			(g/100 g DM)		
Set A study					
Lucerne A	90.1	21.1	37.9	28.0	1.9
Lucerne B	89.1	18.4	35.3	24.8	1.4
Forage sorghum	83.0	10.0	54.8	31.1	1.3
Barley	87.9	13.3	55.3	31.8	1.4
Millet	86.9	6.0	61.2	34.7	1.0
Dolicos	90.6	8.3	46.0	34.8	1.4
Rhodes A	90.9	6.7	64.1	33.7	1.8
Rhodes B	90.7	6.3	64.2	32.8	2.0
Bisset bluegrass	90.5	5.3	71.3	44.0	1.3
Peanut hay	90.2	7.9	42.3	35.3	1.8
Mitchell A	90.0	3.4	67.5	39.3	1.3
Mitchell B	90.7	4.5	65.1	38.6	1.2
Wheat straw	89.8	5.4	72.2	44.8	0.9
Set B studies					
A. Pangola grass	94.4	5.7	72.9	37.2	nd
B. Green panic grass	89.9	5.7	69.8	39.8	1.4
C. Speargrass	91.1	3.3	68.9	40.3	nd
D. Pangola grass	94.2	4.2	65.1	36.4	nd
E. Speargrass	93.0	3.1	70.9	40.7	nd
F. Speargrass	90.0	1.9	70.9	41.8	1.2

Animal performance

A summary of the intake, digestibility and LW change over the growth periods is shown in Table 2. The values are averages for the full 42 day growth periods in the Set A study, except that only the first 35 days was used for Mitchell B as the hay supply ran out after this time, and for 70 days for the Set A trials included in the data set. It was considered that 42 days was sufficient time to establish the growth rates of the steers on the various forages especially with regular (weekly) weighings taking place. The use of a standard preliminary equilibration period also ensured that the steers on different forages started the growth period with a similar gut-fill status. Inclusion of a post-trial equilibration period did not change the ranking of forages in average daily gain so the growth rates over the main experimental period (growth phase) was used.

Across the Set A and B studies, intakes varied from a very low 0.95%W/day (wheat straw) to a high of 2.44%W/day (lucerne), with corresponding LW changes of -0.47 to 1.04 kg/day whilst DMD ranged from 43.4 (wheat straw) to 65.1% (lucerne A, restricted intake). The relationships between these various parameters of animal performance were compared in Fig. 2. Although DM intake appeared to increase directly with DMD, the relationship was not close (R^2=0.21) and there was high variability associated with it (RSD=0.38%W/day) which seemed to be uniform across the full range of digestibility values. Similarly, there was a direct but weak relationship between LW change and DMD with similarly low R^2 (0.25) and large variability (RSD=0.32 kg/day). The premise upon which the Minson and McDonald (1987) equation and accompanying table for converting information on LW and LW change to DM intake is based is that the growth rate of cattle is linearly related to the DMD of the forage consumed, with growth rate increasing by 0.05 kg/day for every unit increase in DMD. Whilst our results indicate that this general relationship does exist, the actual slope is much less (0.026 kg/day per unit increase in DMD) than that assumed by Minson and McDonald (1987) and, as indicated above, there is considerable variability around the trend line between these attributes. The closest relationship of those we explored was between LW change and the intake of digestible DM (DDMI; see Fig. 2A; R^2=0.70) which is not surprising as DDMI is analogous to energy intake upon which the feeding standards are based. Once again though there was considerable variability around the relationship trend line (RSD=0.20 kg/day) which is of concern where such a relationship represents the foundation upon which predictions of intake are to be made.

Table 2. Input data for QuikIntake simulations, including liveweight (LW) and LW change, dry matter digestibility (DMD) and observed intake expressed in absolute terms or as a proportion of liveweight (W)

	Average LW	LW change	DMD	Observed DM intake	
	(kg)	(kg/day)	(%)	(kg/day)	(%W/day)
Set A studies					
Lucerne A	264	0.49	62.9	4.91	1.88
Lucerne B	266	1.04	56.3	5.73	2.44
Lucerne A (restricted)[A]	231	-0.10	65.1	2.87	1.21
Forage sorghum	245	0.01	57.1	3.62	1.51
Barley	254	0.84	64.7	4.81	2.00
Millet	232	-0.13	59.5	4.23	1.55
Dolicos	238	0.13	54.3	4.21	1.79
Rhodes A	246	-0.15	59.7	4.00	1.63
Rhodes B	241	0.04	60.8	3.96	1.67
Bisset bluegrass	246	-0.25	56.3	3.69	1.51
Peanut hay	240	-0.37	48.7	2.83	1.16
Mitchell A	238	-0.24	46.0	3.43	1.46
Mitchell B	242	0.08	47.1	4.25	1.65
Wheat straw	231	-0.47	43.4	1.85	0.95
Set B studies					
A. Pangola grass	198	0.17	49.7	3.66	1.66
B. Green panic grass	177	0.20	55.0	4.03	2.28
C. Speargrass	242	-0.20	47.1	2.78	1.15
D. Pangola grass	198	0.06	54.2	3.21	1.62
	433	0.08	56.8	5.19	1.20
E. Speargrass	208	-0.01	51.1	3.02	1.45
	420	-0.25	46.8	5.23	1.25
F. Speargrass	184	-0.16	40.0	2.24	1.22

[A] Intake restricted to 1.4%W/day.

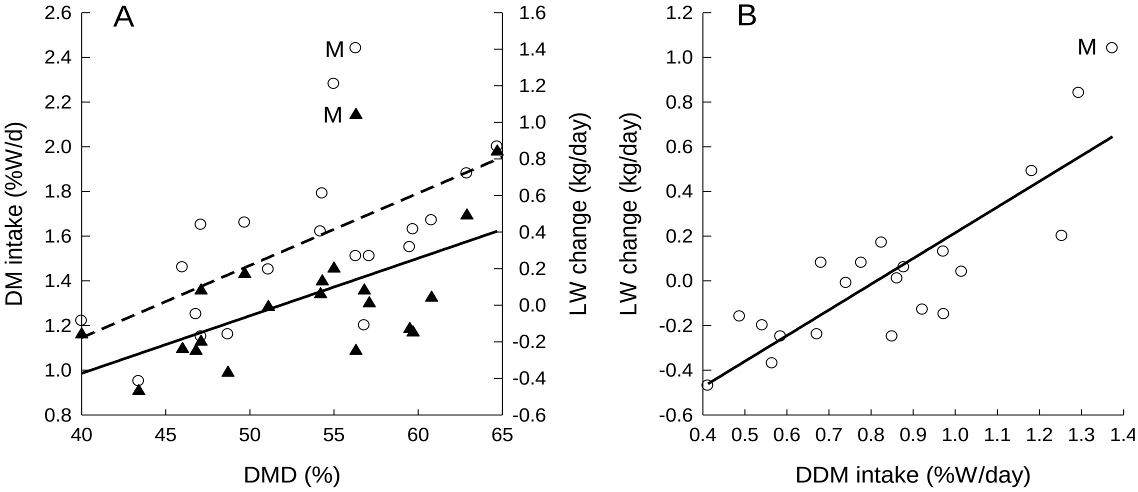

Fig. 2. A. The relationship between dry matter digestibility (DMD%) and DM intake (circles) or liveweight (LW) change (triangles) and B. the relationship between digestible DM (DDM) intake and LW change. The respective linear relationships are: Y = -0.148 + 0.032 X (R^2 = 0.34; RSD = 0.309); Y = -1.632 + 0.032 X (R^2 = 0.32; RSD = 0.312); and Y = -0.935 + 1.150 X (R^2 = 0.70; RSD = 0.207). One outlier is indicated by the letter M and is discussed further in the text.

Intake predictions

The relationships between the intakes predicted using QI and those observed in Studies A and B combined are shown in Fig. 3. In the initial simulations (Model_O (original)) the equations used were those from the SCA, updated by CSIRO (2007) and Freer *et al.* (2012), applying key parameters relating to the type of animal used in the different studies as suggested in the standards. For these simulations, a SRW of 600 kg was used for the *B. indicus* crossbred steers (SRW=500 kg for females) based on evidence from the Growth Paths grazing trial (McLennan 2013; see this report) where steers of similar breed-type appeared to be reaching maturity, as defined by maximum frame size, when liveweight was around this value. As alluded to earlier, choosing the appropriate SRW is a task generally found difficult by users of these feeding standards. Accordingly, predictions were compared using the same input data but varying the SRW between 540 and 630 kg in 30 kg increments which resulted in only very minor changes to the predicted intakes in this case, with the slope of the regression lines varying between 0.46 and 0.47 for the different SRWs.

As shown in Fig. 3A, the linear relationship applied using Model_O indicated that QI markedly over-predicted intake and that there was considerable variability around this prediction line as indicated by the low R^2 (0.36) value and high RSD (0.78 kg/day). In the regression presented, 1 outlier (Fig. 3A, point M; lucerne diet), shown to have high leverage value, was omitted whereas 2 other values with large standardised residuals (points N and P) were not. Omitting this data point is a concern as it represents one of the few data points relating to higher quality forage and high steer growth rate; the data is otherwise heavily biased towards the lower quality range and low growth rates of steers. In view of this, further discussion around this data is provided below. Visually, it appeared that the best predictions were made when observed intakes were low, i.e., when growth rates were around or below maintenance. The slope of the regression line was different to 1 (*P*<0.01) and intercept different to 0 (*P*<0.05). Further, the bias was large at -22.6% and the modelling efficiency (EF) was -1.33 which, being less than zero, indicates that the model is of little value for predicting intakes (Mayer and Butler 1993).

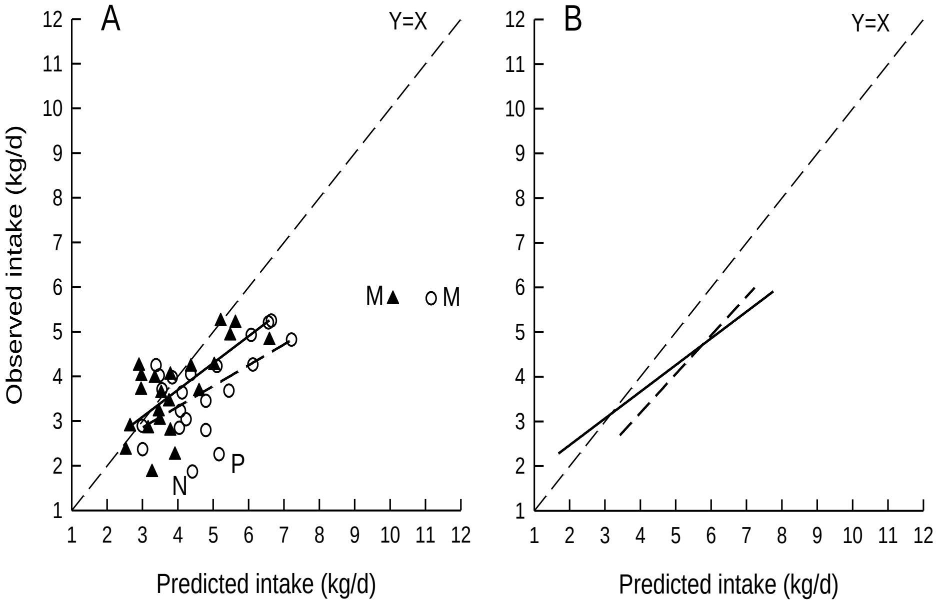

Fig. 3. The relationship between the intake observed in feeding trials and that predicted with (A) the QuikIntake spreadsheet calculator using Model_O (circles, dashed line) or Model_R (triangles, solid line), or with (B) the equation derived by Minson and McDonald (1987; dashed line) or by Gonzalez *et al.* (2012; (solid line). The respective linear relationships are: Y = 1.461 + 0.465 X (R^2 = 0.36; RSD = 0.78; EF = -1.45; bias = -22.6%); Y = 1.289 + 0.602 X (R^2 = 0.47; RSD = 0.70; EF = 0.21; bias = -7.0%); Y = -0.278 + 0.867 X (R^2 = 0.73; RSD = 0.54; EF = -0.09; bias = -19.2%); and Y = 1.273 + 0.598 X (R^2 = 0.63; RSD = 0.64; EF = 0.21; bias = -13.0%). Optimisation of the equations used in B resulted in both fitted lines aligning with Y=X, with slope not different to 1 (*P*>0.05) and intercept not different to 0 (*P*>0.05) The letter M indicates an outlier with high leverage and N and P are values with high residuals; these are discussed in the text. For regressions shown in A, the outlier M is omitted.

The reasons for these over-predictions of intake are unclear but several factors could singularly or collectively contribute. From the equations presented above, reductions in intake predictions would result firstly if the estimate of total ME intake was reduced, where ME intake is derived from the sum of the ME_m and MEgain. With confined animals, the only variables open to manipulation within the equation for calculating ME_m (equation 6) are the "K" parameter relating to species of cattle, where indices of 1.2 and 1.4 are suggested for *B. indicus* and *B. taurus* cattle, respectively, with intermediate values for crosses between these, and the k_m efficiency value. The lower K value for *B. indicus* cattle reflects their lower maintenance requirements relative to *B. taurus* cattle (Frisch and Vercoe 1984) Reducing K and/or increasing k_m would reduce ME_m and also total ME intake. In initial predictions (Model_O) a K value of 1.3 was used for the *B. indicus* crossbred steers but it is feasible that this could be reduced to 1.2 in line with straight-bred *B.*

indicus cattle. Although logical, there does not appear to be any justification in the literature for the higher K value, and hence higher maintenance requirements, of crossbred compared with straight-bred *B. indicus* cattle. In relation to the k_m calculation, equation 11 was used in Model_O predictions but in the spreadsheet program *ME requirements* (CSIRO) a fixed value of 0.72 is used for k_m rather than that calculated using equation 11 above except where cattle are losing weight and a value of 0.80 is used for the efficiency of use of body reserves for maintenance.

Other factors that would contribute to lower estimates of ME intake include reducing the energy value of the gain (EVG) or increasing the k_g efficiency value, both of which contribute to lower MEgain according to equations 12, 13 and 14 above. Within equation 14 defining EVG, only the “b” parameter is open to manipulation where the recommendation is for this to be set at 16.5 for lean breed types such as the large European breed and *B. indicus* cattle, 20.3 for other, primarily, *B. taurus* breeds and 18.4 for crosses between these types. In the initial simulations (Model_O) a b value of 18.4 was used but reducing this to 16.5 common with *B. indicus* cattle reduces the EVG and eventually predicted total ME intake. Under the guidelines presented in SCA, equation 17 is recommended for calculation of k_g for use with grazed tropical forages and there is no real justification for an increase in k_g according to these standards. In fact, the k_g values measured by Tudor and Minson (1982) with tropical forages were lower at 0.28 and 0.17 for pangola (*Digitaria decumbens;* DMD=59.1%) and setaria (*Setaria sphacelata;* DMD=58.1%) than the calculated values of 0.36 for both grasses using equation 17, respectively.

To test the sensitivity of intake predictions to changing some of the factors described above, a series of simulations were set up in QI using a reference steer of liveweight 250 kg, age 12 mo and SRW 600 kg but with varying DMD of the diet and liveweight change. Case studies A to C used diets with DMD of 65, 60 and 50% and corresponding liveweight changes of 0.8, 0.5 and 0 kg/day and predicted DM intakes using Model_O were 6.89, 6.43 and 5.05 kg/day, respectively. Changing the K index in equation 6 for estimating ME_m from 1.3 to 1.2 reduced intake prediction, respectively, by 3.8, 4.5 and 7.5%; changing the b parameter in equation 14 for calculating EVG from 18.4 to 16.5 reduced it by 3.0, 2.5 and 0%; and changing k_m to a constant of 0.72 reduced it by 2.2, 3.9 and 11.3%. The respective effects of all 3 changes combined represented a reduction in predicted intake of 8.9, 10.7 and 18.2%, or 0.61, 0.69, 0.92 kg/day, thereby having a greater proportional and absolute effect as growth rate decreased. This conflicts with the apparent need to increase intake predictions at the higher end of the range (Fig. 3). Increasing the k_g efficiency value to, say, 0.6 would have a large effect on predicted intakes especially with faster growing animals, being 16.3, 15.4 and 0% (k_g = 0.8 for weight loss) reductions for the respective case studies above. However, there appears no justification to make this change.

A new model (Model_R (revised)) was set up in which the changes above were implemented, with k_m set at 0.72, and the K and b parameters set at 1.2 and 16.5, respectively. The relevant regression line is illustrated in Fig. 3A. Once again the outlier point omitted in Model_O was not used in this simulation. These changes resulted in some improvement in the prediction of intake compared with Model_O. The R^2 (0.47) of the regression line was slightly higher but the RSD was still relatively large (0.70 kg/day). In this case the slope of the line (0.60) was different to 1 ($P<0.05$) and the intercept (1.29 kg/day) was different to 0 ($P<0.05$). The bias was lower than for Model_O at -7.0% but still indicative of a slight over-prediction of intake whilst the EF of the line was 0.21 which, although low (relative to a maximum of 1), is at least positive and suggests that the model need not be discarded. On balance it is apparent that the changes to the equations described above have improved the predictions of QI but there is still considerable variability around the regression line.

The sensitivity of Model_R relationship to further change in the calculation of ME_m was tested by omitting the term "0.1MEgain" in equation 6 but this was found to have minimal effect over the range of feeding scenarios tested, only altering the slope of the regression line from 0.60 to 0.63. Irrespective, the rationale for this change is not justified as the logic behind maintaining k_g as a constant is that ME_m changes with MEgain and thus with the production level of the animal.

With both models 1 outlier with considerable leverage has been omitted. This point derived from a group receiving lucerne *ad libitum* and is highlighted in Fig. 3 (letter M adjacent) and indicates a very high predicted intake (11.18 and 10.08 kg/day with Model_O and Model_R, respectively) relative to the observed value (5.73 kg/day). This data set is also highlighted in Fig. 2 (letter M adjacent) which indicates that the steers had a high growth rate (1.04 kg/day) and intake (2.44%W/day) but relatively low DMD (56.4%) of the diet, suggesting a rapid passage rate of digesta through the digestive tract. Because of the high liveweight change for low DMD and thus low M/D, QI calculated that a high DM intake was required to produce the necessary ME to support the high growth rate. Irrespective of the reason, this aberrant combination of DMD and intake for this treatment has had a major bearing on the reliability of the prediction of intake and is significant in that it represents one of the few high quality diets generating high growth rate in this data set.

For comparison, intakes were also predicted using the equation derived by Minson and McDonald (1987; equation 18) and the results are illustrated in Fig. 3B. In this case there were no obvious outliers and all data points are included in the analysis. For instance, in relation to the outlier point M from Fig. 3A where the observed intake was 5.73 kg/day, the predicted value using the Minson and McDonald (1987) equation was 6.43 kg/day. The regression line indicates a systematic small over-prediction of intake where the slope (0.87) was not different to 1 (P>0.05) and the intercept (-0.28 kg/day) was not different to 0. Thus in this case the over-prediction of intake appeared to be relatively uniform across the full range of intakes and cattle growth rates. The proportion of the variation explained by the regression line was relatively high (R^2 = 0.73) and the variance around this line was moderate (RSD = 0.54 kg/day). However, the bias was -19.3% and the negative EF (-0.09) suggested that the model could not be recommended for use (Mayer and Butler 1993) without some re-calibration. After optimisation in Excel, application of the revised equation (equation 19) accounted for slightly more of the variation about the fitted line (R^2 = 0.78; RSD = 0.49) but more importantly, the EF was high at 0.78 and the slope of the line (1.02) was not different to 1 and intercept (-0.07 kg/day) not different to 0 (Fig. 3B). The fitted regression of observed (Y) against predicted (X) was: Y = -0.072 + 1.017 X.

$$Intake = (1.185 + 0.00454\,xW - 0.0000026\,xW^2 + 0.315\,xG)^2 \qquad (18)$$

$$Intake = (1.026 + 0.00454\,xW - 0.00000357\,xW^2 + 0.422\,xG)^2 \qquad (19)$$

where:
Intake is expressed in kg DM/day;
W = liveweight (kg);
G = liveweight gain (kg/day).

Gonzalez *et al.* (2012) have also recently developed regression equations to predict intake based on the liveweight of the animal and some aspect of forage quality, including *in vivo* DMD, N in forage or the diet, and ADF or NDF in the forage. Predicted intake was determined using their equations incorporating liveweight and DMD (equation 20), as shown in Fig. 3B, or liveweight and diet N content. Using *in vivo* DMD, the regression line for the comparison of predicted with observed intakes had an R^2 of 0.63 but a relatively large RSD of 0.64 kg/day; the slope (0.60) was significantly different to 1 (P<0.001) and the intercept (1.27 kg/day) was different to 0 (P<0.05). The EF for this model was 0.21, so need not be rejected, and the bias was -13.0% indicating general over-prediction of intakes. In effect this model was similar to that of Minson and McDonald (1987) who assumed a relationship between liveweight and DMD and then used liveweight and liveweight gain to predict intake. Application of the other model including liveweight and N content of the diet (not shown) produced some very large predicted intakes corresponding to high dietary N concentrations. When N content was 3.4 and 2.9%DM (lucerne diets), predicted intakes were 11.3 and 10.2 kg/day compared to observed intakes of 4.9 and 5.7 kg/day, respectively. Although the data used to derive the models was not provided in their paper, it is likely that Gonzalez *et al.* (2012) did not encounter such high N contents where the main feed types were tropical forage hays. This model had a highly negative EF of -3.1 and could not be accepted. After optimisation of equation 20 in Excel, application of the revised equation (equation 21) resulted in little change in the R^2 (0.64) or RSD (0.63 kg/day) of the fitted line, which had a slope of 1.0 and intercept of 0, but the EF increased to 0.65.

$$Intake = -5.85 + 0.017\,x\,W + 0.110\,x\,DMD \tag{20}$$

$$Intake = -2.68 + 0.0093\,x\,W + 0.078\,x\,DMD \tag{21}$$

where:
DMD = dry matter digestibility (g/100 g).

Predictions of intake were also made with Model_R using the Set C data which incorporated higher quality, mainly C3 diets fed either *ad libitum* or at restricted intakes. In this case excellent predictions resulted with the relationship between predicted (X) and observed (Y) intakes described by the equation: Y = -0.048 + 0.99 X (R^2 = 0.94; RSD = 0.64), where the slope was not different to 1 and intercept was not different to 0 (*P*>0.05); the bias was only -1.9%. The closeness of this regression line to the line of best fit (Y=X) suggests that in this case QI predicted with high precision the intake of the steers based on liveweight gain and the M/D of the diet. This was the case even when intake was restricted either by reducing it below *ad libitum* or by limiting the P concentration in the diets below the level of adequacy.

The reasons for the large differences in intake predictions by QI with Set C compared with the combined Set A and B data sets are not readily apparent. As mentioned above, the Set C data was derived mainly from C3 basal diets, either legumes or formulated (pelleted) diets, of high quality but covering a wide range of intakes and cattle growth rates by virtue of varying P content or through restrictions applied by limiting supply below that achievable *ad libitum*. Whilst the majority of diets in Sets A and B were C4 forages of low quality, there were a number of C3 forages represented including lucerne which was also in Set C. In fact, the lucerne from Set A was an outlier with a predicted intake much higher than that observed and so contrasted with similar diets in Set C. Thus it is not logical to delineate the results of QI predictions solely on diet quality or forage type (C3 vs. C4). Other factors obviously apply. A key presumption in using the energy balance approach to intake prediction is that there is a close linear relationship between ME intake and liveweight gain. Where this relationship lacks precision, one of the key factors may be the supply of microbial crude protein and thus metabolisable protein (see CSIRO 2007). However, the mechanisms for this are not fully understood at this stage.

When the Minson and McDonald (1987) or Gonzalez *et al.* (2012) equations (equations 18 and 20) were applied to the Set C data there were large errors associated with diets fed at restricted rates. This is understandable as these predictions both rely on a direct relationship between intake and DMD (Gonzalez *et al.* 2012) or intake and liveweight gain where gain is assumed directly proportional to DMD (Minson and McDonald 1987), and if DMD is not changed markedly under restricted feeding regimes, the prediction of intake will be higher than observed. Thus application of these equations are predicated on unrestricted availability of forage to the animal.

Conclusions

The QI spreadsheet calculator incorporates the equations from the SCA feeding standards, updated with CSIRO (2007) and Freer *et al.* (2012), to describe the utilisation of energy by cattle for growth and to use these equations in the prediction of intake by cattle. In some circumstance (e.g., Set C data) QI seems to give very precise estimates of intake whereas in others the estimates are far less precise (Sets A and B) and large errors in prediction could occur. At this stage we have no way of knowing when the predictions will be good or otherwise. It would be easy to delineate the circumstances of accurate predictions on the basis of photosynthetic pathway (C3 vs C4), which appears to agree with experience in the application of GrazFeed under practical grazing conditions where it is used more widely and apparently more successfully in temperate compared with tropical regions, but this seems a oversimplification which defies logical and energetically-legitimate basis. It would also provide no practical solution for the tropical grazing situation. One of the contributing factors in the variable results might be the interaction of metabolisable protein supply with energy utilisation which may explain the variations around the relationship between energy intake and liveweight gain, which is a cornerstone for the current approach to using energy balance for intake prediction. However these mechanisms are not fully understood as any deficiency in metabolisable protein supply should limit both ME intake and liveweight gain with consequential reductions in intake predictions. It appears that larger data sets are required in order to illuminate the circumstances under which accurate intake predictions can be expected and how to improve the situation where they are not.

At this point QI could be used for feed budgeting purposes where a moderate level of accuracy is sufficient, but it should be recognised that in some scenarios quite large errors could occur. These situations should be obvious if predicted intakes are much greater that would be expected based on diet quality (DMD) and liveweight gain. Nevertheless, further research is required to increase confidence in the predicted intakes.

The alternative approach to intake predication we investigated was the application of simple equations relating intake to liveweight and either diet quality, e.g., DMD or N content (Gonzalez *et al.* 2012) or liveweight gain of the animal (Minson and McDonald 1987). With the data sets available here the predictive value of the equations varied. The Minson and McDonald (1987) equation gave a reasonable prediction of intake, which was improved after optimisation. These predictions appear sufficiently accurate for use in feed budgeting providing herbage mass is not limiting and thereby provide a simple option. However, where liveweight gain is affected independently of DMD errors will occur as the equation is premised on a direct relationship between these factors. Such circumstances include a limitation in herbage mass or deficiencies in some nutrient such as P. The same limitations apply to the equations of Gonzalez *et al.* (2012) where predicted intake is a function of usually a single measure of diet quality, e.g., DMD, and this does not account for other factors such as herbage supply. By contrast, QI is not limited in this way as intake is not predicted directly from diet quality but from liveweight gain which is the embodiment of all the various factors contributing to the animal's intake of energy.

The other advantages of an approach such as that provided by QI is that it can be used with cattle in different physiological states such as pregnancy and lactation as well as growth, if the relevant equations have been included. An example is the *MErequirements* spreadsheet of CSIRO which includes options for both pregnant and lactating cows and their calves. A version of QI is available with these options included but validation becomes much more difficult than with growing cattle especially with lactating animals under grazing conditions. Appropriate data sets for validation are rare.

The other option available in QI, which is not accommodated using the single equation approach, is that of inclusion of a supplement in the diet of the cattle. Provided the intake of supplement and its energy content are known (or can be assessed from feed tables), the ME intake from supplement can be estimated and subtracted from the estimated total ME requirements of the animal to support the liveweight gain observed, and the remaining ME intake is assumed to have come from the pasture. Intake of DM is then determined in the same way as described above for unsupplemented animals. The one limitation to this approach is that high intake of supplement can reduce the digestion of the forage component of the diet (e.g., Dixon and Stockdale 1999) and such an associative effect would need to be accounted for or intake of forage may be under-predicted. Moore *et al.* (1999) have provided equations by which this adjustment could be made.

With increasing emphasis on responsible utilisation of grazing lands and the demands for better forecasting of pasture requirements and appropriate stocking rates, the requirement remains for a simple decision support system to assist in this undertaking. QI provides one option and under some circumstances the equations provided by Minson and McDonald (1987) or Gonzalez *et al.* (2012) could be used. However, in the case of QI further understanding of the conditions under which it does not provide an accurate prediction is required and subsequent refinement is needed to enable it to be reliably applied to extensive grazing situations.

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References

ARC (1980) ‘The nutrient requirements of ruminant livestock’. Technical review by the Agricultural Research Council working party. (Commonwealth Agricultural Bureaux: Farnham Royal, England)

AFRC (1993) ‘Energy and protein requirement of ruminants’. An advisory manual prepared by the AFRC technical committee on response to nutrient.’ (CAB International: Wallingford, UK)

Baker RD (1982) Estimating herbage intake from animal performance. In ‘Herbage intake handbook’. (Ed. JD Lever) pp. 77-93. (British Grassland Society: Hurley, UK)

Baker RD (2004) Estimating herbage intake from animal performance. In ‘Herbage intake handbook’. (Ed. PD Penning) pp. 95-120. (British Grassland Society: Hurley, UK)

Coleman SW (2005) Predicting forage intake by grazing ruminants. In, ‘Proceedings of 2005 Florida Rumninant Nutrition Symposium’. pp 72-90. (United Sates Department of Agriculture)

Cox CP, Foot AS, Hosking ZD, Line C, Rowland SJ (1956) The direct evaluation of pasture in terms of the milk production of individually grazed cows. *Journal of the British Grassland Society* **11**, 107-118.

CSIRO (2007) ‘Nutrient requirements of domesticated ruminants.’ (CSIRO Publishing: Melbourne, Australia)

Dixon RM, Coates DB (2005) The use of faecal NIRS to improve nutritional management of cattle in northern Australia. In “Recent advances in animal nutrition in Australia’. **15**, 65-75.

Dixon RM, Coates DB (2009) Review. Near infrared reflectance spectroscopy of faeces to evaluate the nutrition and physiology of herbivores. *Journal of Near Infrared Spectroscopy* **17**, 1-31.

Dixon RM, Stockdale CR (1999) Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research* **50**, 757-773.

Dove H, Mayes RW (1991) The use of plant wax alkanes as marker substances in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* **42**, 913-952.

Dove H, McLennan SR, Poppi DP (2010) Application of nutrient requirement schemes to grazing animals. In ‘Proceedings of the 4th grazing livestock nutrition conference’. (Eds BW Hess, T DelCurto, JGP Bowman, RC Waterman) pp. 133-149. (Western Section of American Society of Animal Science: Champaign, Illinois)

Fox DG, Tedeschi LO, Tylutki TP, Russell JB, Van Amburgh ME, Chase LE, Pell AN, Overton TR (2004) The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. *Animal Feed Science and Technology* **112**, 29-78.

Freer M (2002) The nutritional management of grazing sheep. In ‘Sheep nutrition’. (Eds M Freer, H Dove) pp. 357-375. (CSIRO Publishing: Collingwood, Vic.)

Freer M, Moore AD, Donnelly JR (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises – II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agricultural Systems 54, 77-126.

Freer M, Moore AD, Donnelly JR (2012) The GRAZPLAN animal biology model for sheep and cattle and the GrazFeed decision support tool. CSIRO Plant Industry Technical Paper (revised December 2012). At www.csiro.au/en/Organisation-Structure/Divisions/Plant-Industry/GRAZPLAN-supporting-documents-and-programs (confirmed April 18, 2013).

Frisch JE, Vercoe JE (1984) An analysis of growth of different cattle genotypes reared in different environments. Animal Production 103, 137-153.

Gonzalez LA, Ramirez-Restrepo C, Coates D, Charmley E (2012) Prediction of feed intake in growing beef cattle fed tropical forages. In, 'Proceedings of the Australian Rangelands Society Biennial Conference'. Poster 4-2. (Australian Rangelands Society: Australia)

Langlands, JP (1987) Assessing the nutrient status of herbivores. In, 'The nutrition of herbivores'. (Eds JB Hacker, JH Ternouth) pp 363-390. (Academic Press: Sydney)

Logan VS, Pigden WJ (1969) Estimating herbage yield from energy intake of grazing ruminants. In 'Experimental methods for evaluating herbage'. Publication 1315. (Ed. JB Campbell) pp 140-151. (Canada Department of Agriculture: Ottawa)

Lyons RK, Stuth JW (1992) Fecal NIRS equations for predicting diet quality of free-ranging cattle. *Journal of Range Management* **45**, 238-244.

MAFF (1984) 'Energy allowances and feeding systems for ruminants.' (Ministry of Agriculture, Fisheries and Food, Technical Bulletin Number 433, Her Majesty's Stationary Office: London)

Mayer DG, Butler DG (1993) Statistical validation. *Ecological Modelling* **68**, 21-32.

McLennan SR (2004) More effective supplements for the northern beef industry. Final Report to Meat and Livestock Australia Ltd - Project NAP3.122. 96 pp.

McLennan SR (2005) Improved prediction of the performance of cattle in the tropics. Final Report to Meat and Livestock Australia Ltd - Project NBP.331.

McLennan SR, Callaghan M, Swain T, Kidd JF (2012) Effect of monensin inclusion in supplements for cattle consuming low quality tropical forage. *Animal Production Science* **52**: 624-9.

McLennan SR, Fordyce G, Cherry D, Enchelmaier K, Campbell J, Dawson K, Bowen MK, Poppi DP (2013) Consequences of changes to post-weaning growth path due to supplements and leucaena on growth and carcass characteristics of steers in the seasonally-dry tropics of Australia. *Animal Production Science* (This report; in preparation)

McLennan, SR, Poppi DP (2012) Application of nutrient requirement systems to grazing cattle, with and without supplements. In 'VIII SIMCORTE, 4th International symposium of beef cattle production, Vicosa, Brazil'. pp. 95-122.

Minson DJ, McDonald CK (1987) Estimating forage intake from the growth of beef cattle. *Tropical Grasslands* **21**, 116-122.

Moore JE, Brant MH, Kunkle WE, Hopkins DI (1999) Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. *Journal of Animal Science* **82**, 122-135.

Parker WJ, Morris ST, Garrick DJ, Vincent GL, McCutcheon SN (1990) Intraruminal chromium controlled release capsules for measuring herbage intake in ruminants – a review. *Proceeding of the New Zealand Society of Animal Production* **50**, 437-442.

Peyraud JL (1997) Techniques for measuring herbage intake of grazing ruminants: a review. In, 'Managing high yielding dairy cows at pasture'. (Eds E Spörndly, E Burstedt, M Murphy) pp 3-23. **(**Uppsala, Sweden: Swedish University of Agricultural Sciences)

Poppi DP (1996) Prediction of food intake in ruminants from analysis of food composition. *Australian Journal of Agricultural Research* **47**, 489-504.

SCA (1990) 'Feeding standards for Australian livestock. Ruminants. (Standing Committee for Agriculture, CSIRO: Melbourne)