final report

Research opportunities for sustainable productivity improvement in the northern beef industry: A scoping study

Abstract

The production and economic context of beef production in northern Australia has been seriously challenged over the last decade. Costs of production have escalated rapidly and beef prices have not increased in real terms since 2004 while productivity improvement, necessary to offset these cost-price pressures, has been slowing. Reversing these trends is imperative for a viable industry over the longer term. This report describes an approach taken to explore options for sustainable development of the industry as a basis for guiding research and development for the next two decades. A range of development scenarios that offer potential to significantly improve industry profitability through productivity gains were developed in consultation with industry and technical experts. The potential effect of these scenarios on productivity and economic and environmental outcomes of northern enterprises was evaluated using a new simulation model of northern beef enterprises. The evaluation was conducted for ten regions spanning Queensland, the Northern Territory and north-western Western Australia. The results suggest that significant gains in productivity and profitability can be achieved by integrating individual technologies that target specific components of the livestock system e.g. genetics, reproduction, nutrition.

Executive summary

Why the work was done?

Adoption of new productivity-enhancing technologies and improved management practices is the keystone to ensuring continued viability of the northern beef industry. Positive trends in key herd productivity indicators, such as beef yield per animal, have slowed over the last decade and many beef enterprises are yielding low to negative economic profits.

Productivity and cost-efficiencies in many enterprises can be improved in the shorter term by adopting existing best management practices in order to operate closer to current productive potential. However, retaining viability over the medium to longer-term requires the productive potential of the industry to be further increased and this will necessarily require further investments in technological developments and innovation.

This project has explored some potential options for sustainable improvement in profitability of northern beef enterprises that are based on technological innovation in order to inform research and development needs for the industry for the next 20 years.

What was done?

Several approaches were employed for identifying potential new technologies and production issues where cutting-edge research might produce significant improvements in productivity for the industry. These involved consulting people within or associated with the northern beef industry including beef producers, extension specialists and technical experts, and reviews of relevant technical and scientific literature. Bio-economic modelling was employed to assess the potential of these pathways for achieving productivity growth of at least 2% p.a. over the next 20 years, while maintaining land condition, reducing greenhouse gas emission intensity and being readily adopted by industry. The production and environmental consequences of both benchmark and the development scenarios were examined for 10 distinctive agro-ecological regions along with the reaction of industry stakeholders to the scenarios. Knowledge gaps were identified along with uncertainties surrounding the scenario analyses to ensure that research, development and extension (R, D & E) options for the future can be assessed with all the information and caveats well understood.

An important legacy of the project is the development and employment of a new analytical capacity (North Australian Beef Systems Analyser) that offers considerable scope for future application to addressing R, D & E impact issues for the northern beef industry. This analytical tool provides in an innovative way the ability to test a diverse range of development and management options and their resource management implications at an enterprise level. Herd productivity (growth, reproduction, mortality) is driven by energy and protein supply from forage and supplements and there are feedback effects of grazing pressure on land condition and animal production.

What was achieved?

The analysis suggests that there is considerable scope for the northern beef industry to apply both new and extant technologies and practices and regain productivity

advances in excess of the present 'terms of trade' impost (~2% per annum cumulative). This will necessarily involve combinations of practices rather than any single practice or technological application alone.

These productivity gains need not be reaped at the expense of important environmental values, in particular land resource condition, although ongoing stewardship and resource monitoring must necessarily go hand in hand with the uptake of these practices.

Beyond improving sector viability, improvements in animal productivity from innovation will have a positive impact on reducing the intensity of greenhouse gas emissions per kilogram of beef produced. The net effect on total greenhouse gas emissions from the sector will depend on overall stock numbers but the analyses suggest that to achieve the desired productivity gains total methane production would increase even though there are significant reductions in methane produced per kg of beef. While not part of the analysis the results indicate that if total methane production was held constant there would still be significant productivity gains.

When will it impact and what's in it for business?

The project has focussed on scoping out where and how future targeted R, D & E may assist the northern beef industry to again realise the magnitudes of productivity gains that have been achieved over the last few decades. The project has reviewed the types of practices and technologies on offer for adoption, or for which technical solutions are yet to be found but do offer realistic scope for economic application. The modelling and analytical approach undertaken in this project is new and needs more testing, and inevitability contains simplifications and caveats, but there is broad confidence in the fundamentals of the approach and the key conclusions.

Scope exists over the shorter term (e.g. to 5 years) for profitable implementation of some of the technologies and practices that are embodied in the regional studies. Sensitivity analysis has revealed that adoption of even modest improvements consistent with current best practice management in husbandry, land management and financial management can greatly improve enterprise profitability. Consultation with producers supports the conclusion that additional profitability can be reaped from adherence to known best-management practice. This is, of course, an extension issue that warrants further investment.

The challenge for reaping longer-term impact is to focus R, D & E on some critical areas for productivity gain that are suited to a wider range of environments than at present. For example, low cost legume augmentation of grass pastures, a technology with some thirty years history, still has potential to increase profitability, assuming effective establishment. Irrigated forages offer some substantial productivity gains where suitable water resources are locally available but the large capital and operational costs involved may limit uptake based on current returns. Both of these feedbase options offer opportunities for finishing turnoff animals and thus providing a wider diversity of market opportunities. Genetic improvements and novel sources of cheap protein offer scope for productivity gains within herds particularly when these can target both animal growth rates and enhanced fertility. Energy deficits remain a primary constraint on herd performance and, while often overshadowed by the search for protein, is a promising target for future R, D & E efforts - rumen modification and genetic improvement of plant digestibility are two candidate areas.

Critically, while individual technology innovations and improved practices offer scope for productivity gains, the largest gain lies in their integration within grazing and

property management systems. For example, pursuing genetic gain in weaning rate in isolation from improving herd management and nutrition will lead to modest gains compared with addressing multiple constraints in unison to exploit production potential. This suggests the need for and opportunity to exploit systems-based approaches to R, D & E practice and the intelligent application of the outcomes.

Who stands to benefit?

The project examined prospective impacts of new or improved practices across 10 agro-ecological regions. Enterprises in all regions have the scope to reap material advantage from the technologies and practices that were investigated. Nevertheless, the magnitude of any potential gain across the various regions is affected by the prevailing resource endowments, climatic factors and state of development of the local enterprises. For example, while further use of legume augmentation offers productivity gains for most regions, it has limited economic benefit for central Australian enterprises due to uncertain yields under the highly variable climate and the high cost of establishment across large areas. Overall, the relative gains in estimated profitability for all of the scenarios that were examined are lower for Queensland enterprises (especially southern Queensland) than for the other regions largely because these enterprises are generally located in more favourable agro-climatic zones and enjoy higher levels of productivity under existing management practices.

Summary

In summary, the project has developed a useful tool for assessing future development options for the northern beef industry. The results point to several areas of worthwhile opportunities to lift future productivity and profitability of beef enterprises through research and development investment. Importantly, this needs to be accomplished in an integrated way in order to maximise benefits to the industry while maintaining the integrity of the underlying resource base.

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1 Background

1.1 The situation in the northern beef industry

Aided by a substantial investment in research, development and extension (R, D & E), the northern beef industry experienced impressive gains in productivity from the 1970s, particularly through the adoption of technological developments, including the wide-scale replacement of *Bos taurus* herds with *Bos indicus* cattle, the use of dietary supplements, pasture development and improved grazing management (Ash *et al*. 1997). However positive trends in key productivity indicators, such as beef yield per animal (Fig. 1) have slowed over the last decade. At the same time, beef prices have declined in real terms since 2004 (Fig. 1) and costs of production have increased (Fig. 2). McCosker *et al*. (2010) noted that direct costs per large stock unit (LSU) have increased by 150% over the last decade, and debt levels per LSU have doubled. Consequently many northern beef enterprises are struggling financially, with McCosker *et al*. (2010) reporting that approximately 50 percent of enterprises spent more money than they actually earned in six of the seven years to 2009. The average return on assets (ROA) was less than 2%, although the top 20% of enterprises were faring better (4-6% ROA; McCosker *et al*. 2010) due to the combined advantage of larger scale operations, lower costs and generally better management.
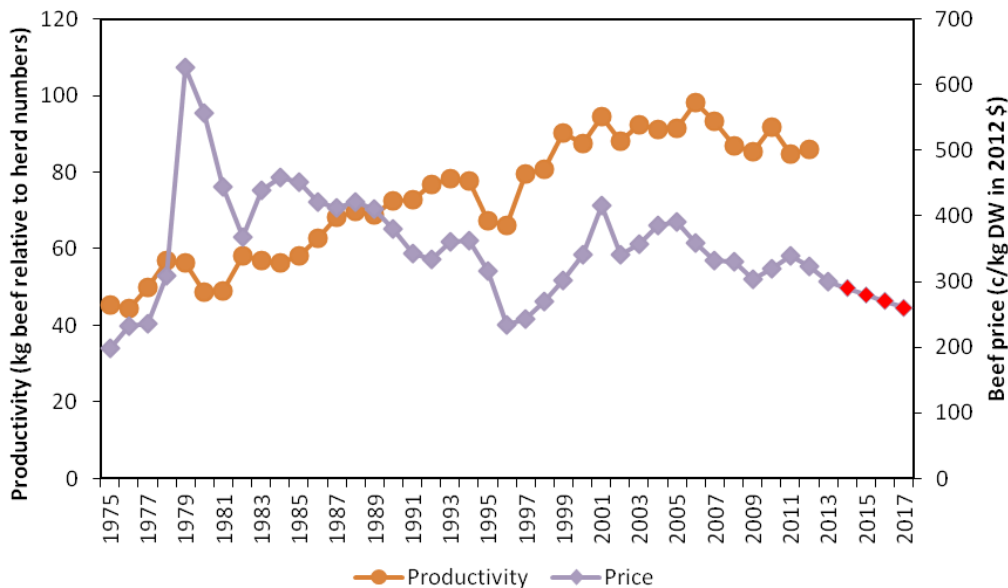
Fig. 1. Trends in productivity of beef production (kg beef produced relative to herd numbers) and prices received (Qld). Beef produced represents the kg of beef from animals slaughtered in Qld plus live export cattle from Qld (adjusted to represent kg dressed weight) relative to total cattle numbers in Qld (based on ABS Statistics; 7218.0.55.001 Livestock and Meat, Australia). Beef price is the saleyard price of beef (ABARES) adjusted for CPI (ABS) so it represents the price of beef in real terms using 2012 as the baseline. Triangles in the beef price series represents future beef prices based on ABARES Outlook statistics (ABARES 2013).

Cost of Production ($/kg meat produced)
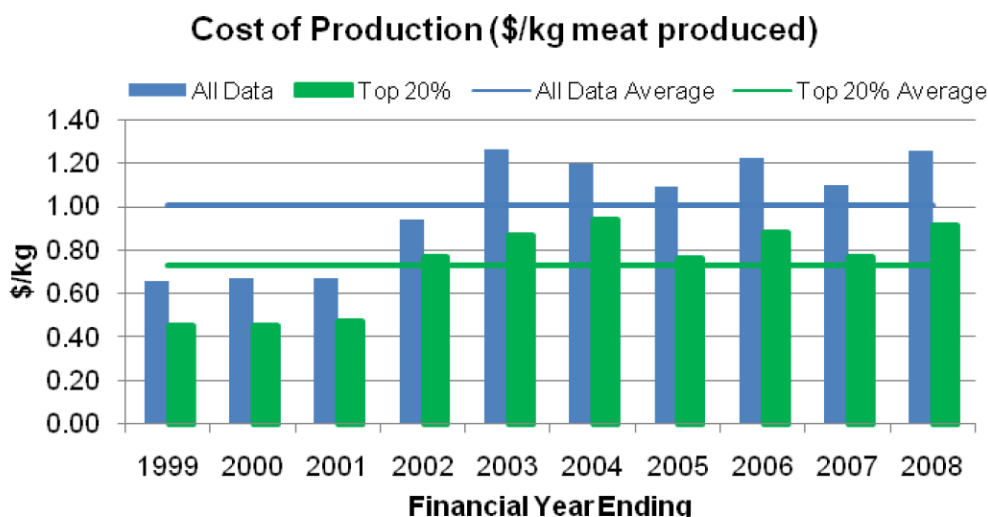
Fig. 2. Costs of production for selected Queensland beef herds. (From McCosker *et al.* 2010).

1.2 Options for improving profitability

The broad drivers of profitability in the northern beef industry include the prices received, costs of production and herd productivity – the last being dominated by breeder fertility and animal growth rates. However, producers effectively have influence over only two of these three drivers – costs of production and herd productivity. While there is scope for increasing cost efficiency through enhanced financial management and larger scales of production, effecting ongoing productivity improvements remains a key path for lifting enterprise profitability sufficient to ensure that the industry remains viable over the longer term. Productivity on many enterprises can be improved in the shorter term by adopting best management practices to operate closer to current productive potential. However, in the medium to longer-term increasing productive potential will necessarily require further technological developments and innovation. The application of new technology can also help to reduce costs. Puig *et al.* (2011) examined potential futures of the pastoral industry in the Northern Territory and from their modelling work and stakeholder interaction identified some key priorities that included: increased research and development to underpin increased productivity and efficiency of production, diversifying markets, and implementing sustainable management practices. This report describes a project that has explored some potential options for sustainable improvement in profitability of the northern beef industry based on technological innovation to inform research and development needs for the industry for the next 20 years.

2 Project objectives

The project had the following core objectives:

1. Identify alternative development pathways for the northern beef industry on a regional basis and assess their likely contribution to:
   - achieving total factor productivity growth of at least 2% p.a. over the next 20 years;
   - maintaining or improving land condition;
   - reducing the intensity of greenhouse gas emissions;
   - being readily adopted by industry.

2. Quantify the likely impacts of alternative futures through bio-economic modelling of a range of development scenarios to capture the production and resource consequences of applicable land management decisions. Scenarios will be constructed for selected regions across northern Australia which reflect expected changes in key aspects of the beef production operating environment (e.g. market conditions, new and emerging policies).

3. Collate and summarise the production and environmental consequences of benchmark and selected scenarios for each study region and the reaction of stakeholders to the scenarios.

4. Identify knowledge gaps and specify uncertainties in the scenario analyses so that R&D options for the future can be assessed with all the information and caveats well understood.

5. Present the findings in a final report that will include the following.
> a. An assessment of the productivity potential of current and alternative herd and land management options at the paddock to property scales for the range of agro-ecological regions of the northern beef industry.
> b. An assessment of the effects on land resource condition and the consequent greenhouse gas (GHG) footprint for each scenario option.
> c. An assessment of systems analysis capability for the northern beef industry developed in the project and associated knowledge gaps.
> d. The reactions of industry stakeholders to the development scenarios.
> e. Identified research opportunities with both short and long-term horizons and possible approaches.

3 Methodology

3.1 General approach

The basic approach of the project was to identify potential new technologies and practices whose adoption may offer benefits to the industry. These technologies and practices were then evaluated for their potential to increase beef productivity and profitability and the effect on the environment for six regions in northern Australia. Initially no limits were imposed on the scope of technologies that could be considered, so they could span the various aspects of the beef production system. The evaluation was supported by the application of a simulation model of northern beef enterprises that was developed for the project, whereby the candidate technologies and practices were incorporated into development scenarios that were simulated in the model. This modelling approach did necessarily impose some constraints on the technologies and development scenarios that could be evaluated.

The project encompassed the beef producing regions of Queensland, the Northern Territory and the Pilbara and Kimberley regions of Western Australia. The development scenarios were evaluated for ten regions which were:
- Katherine (Victoria River District)
- Kimberley
- Pilbara
- Central Australia
- Barkly-NW Queensland
- western Queensland

- north Queensland
- central Queensland
- southern Queensland
- south-eastern Queensland.

3.2 Process for identifying new technologies and development scenarios

Several approaches were employed for identifying potential new technologies and production issues where cutting-edge research might produce significant improvements in productivity for the industry. These involved consulting people within or associated with the northern beef industry including beef producers, extension specialists and technical experts, and reviews of relevant technical and scientific literature. Significant contributions were also made by the project steering committee, which comprised representatives from state agencies (from Queensland, Western Australia and the Northern Territory), Meat and Livestock Australia, the North Australian Beef Research Council and CSIRO.

3.2.1 Consulting beef producers

Consultation with cattle producers was largely undertaken through the Regional Beef Research Committees (RBRCs). In all, individual members of the project team attended meetings of six RBRCs. A standardised approach was used at each meeting to solicit insights from the participants. Using a facilitated discussion, the producers were asked to identify and describe the major constraints that were currently limiting productivity and profitability and that might be amenable to solution through research and development. It was suggested to producers that innovation to increase productivity might be drawn from a range of areas including (but not limited to) nutrition, genetics, grazing and resource management systems, turnoff strategies and interactions between these key drivers. Particular emphasis was given to issues related to herd productivity and production costs which are recognised to be the two major drivers of profitability that producers can directly influence. Participants were encouraged to think about ideas without being constrained by the limits of their current operations.

3.2.2 Expert workshops

Two expert workshops were convened, one specifically directed at cattle reproduction and genetics and the other on cattle nutrition. The objectives of these workshops were to solicit insights from leading scientists on current constraints to production and future opportunities to improve productivity arising from cutting-edge research in reproduction, genetics and nutrition. They also sought to quantify the potential gains that may be possible from technological advances arising from research, and to identify sources of benchmarking data on current performance in the industry.

Reports from these workshops are presented in Appendix 1.

3.2.3 Review of the scientific and technical literature

A search was conducted of the scientific literature and relevant beef industry plans for regions of the world with similar agro-ecological conditions to northern Australia with several objectives. First was the need to assess international trends in beef productivity and identify technological developments elsewhere that may offer

potential to improve production and profitability in northern Australia. It was also important to compare the performance of Australia's northern beef industry with comparable beef production systems elsewhere to provide an international context to production trends in Australia. This review would therefore help to ensure that the development scenarios that were evaluated in the project encompassed all prospects for industry innovation. The report from the literature review is presented in Appendix 2.

3.2.4   Review of improved forages

A review was undertaken of the available agronomic and livestock production literature to explore some potential opportunities for growing and utilising sown pastures and forage crops within northern beef production enterprises. A benchmark assessment was also made of the prospective level of livestock production that might be obtained as verification of the modelling output of various development scenarios that involved improved forages.

The report is presented in Appendix 3.

3.2.5   From new technologies and innovations to development scenarios

The technology and innovation opportunities that were identified through these processes were reviewed by the project team and those regarded as being particularly promising were incorporated into development scenarios for investigation with the enterprise simulation model. For example, further advances in the understanding of rumen microbial ecology may allow the development of improved rumen microorganisms or manipulation of the balance of microorganisms that increase the digestibility of forage. This technology was, therefore, incorporated into a scenario in which forage digestibility during the dry season was assumed to decline at a slower rate and bottomed at a higher digestibility than is currently the case. Another example is improvement in cattle genetics, which was incorporated into scenarios that involve increased levels of reproductive performance or animal growth. Further information on the process of scenario development, and a summary of the scenarios and assumptions used in modelling the scenarios, is presented in the Results and Discussion section.

3.3   Enterprise simulation modelling

3.3.1   The northern beef enterprise model - overview

A new simulation model of northern beef enterprises was developed within CSIRO to evaluate the development scenarios. We examined other modelling approaches to ensure we were not duplicating previous efforts. For example, Puig *et al.* (2011) developed an innovative systems-modelling approach to examine options and trade-offs for development, diversification and land use change in the northern pastoral lands. It took a much broader approach than 'within enterprise' developments and so was not designed to answer the key questions that this project was seeking to answer.

We anticipate that the modelling framework developed in this project will also provide considerable utility for assessing the effect of future research and development work on the northern beef industry beyond this project. The model (Northern Australian Beef Systems Analyser – NABSA) is based on a Microsoft Excel® platform and uses a monthly time step. It integrates livestock, pasture and crop production with labour and land requirements, accounts for revenue and cost streams, and provides

estimates of the expected environmental consequences of various management options (Fig. 3). Simulated animal growth from birth to turn-off is based on energy and protein supply for regional forage conditions, and changes in animal numbers and disposals are tracked.

Northern Beef Systems
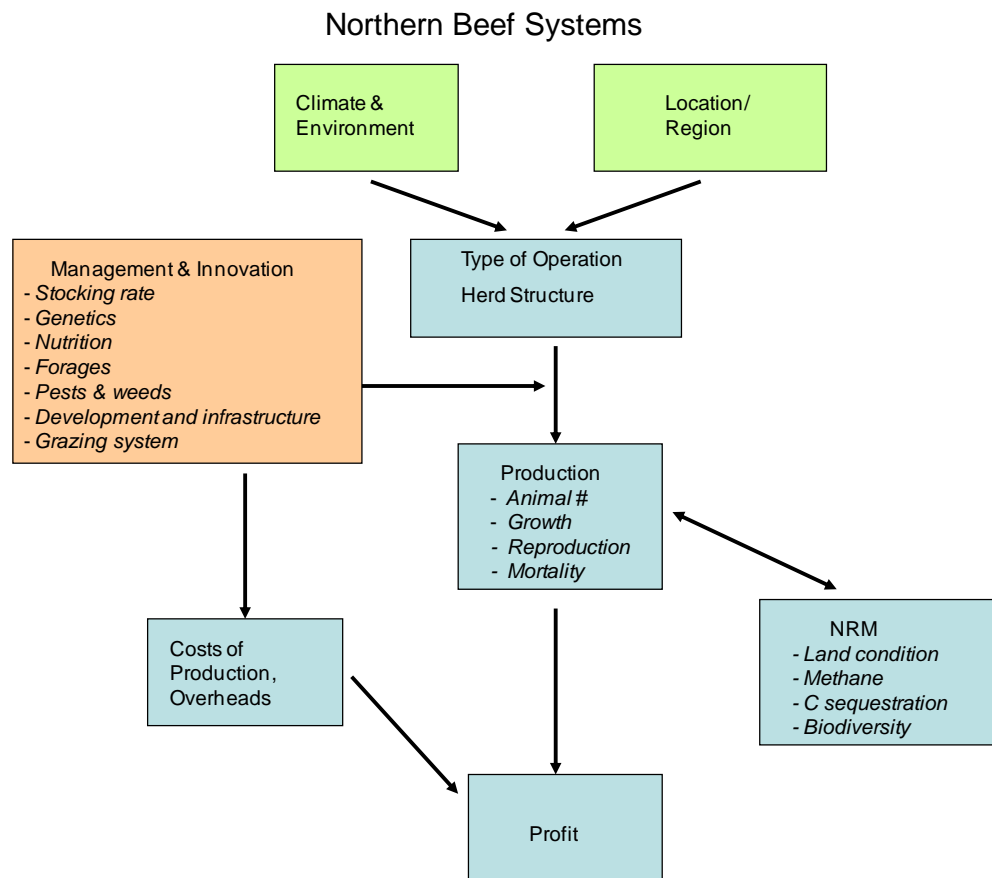
Fig. 3. A schematic illustration of the structure of the northern beef production system, on which the enterprise model was based. Green boxes indicate environmental and geographic inputs that determine type and scale of operation, orange box represents the technology and management interventions and the blue boxes represents how the enterprise (herd dynamics, economics) and resource base responds to the environment and management drivers.

Simulated livestock growth, reproduction relative to body condition, and mortality rates are driven by relationships that are drawn from the literature and from research within northern Australia, and from agreed standards (e.g. Feeding Standards of Australia). Different reproduction curves can be specified for breeders of different ages (e.g. second-calf heifers and mature cows). A variety of supplements or hay can be fed to different animal classes in different months of the year. Criteria associated with selling rules for reducing cattle numbers in response to declining forage availability can also be modified by the user. The model accommodates both pure *Bos indicus* and *Bos indicus* x *Bos taurus* herds.

The model is versatile, being able to accommodate both extensive production systems on unimproved native pasture and mixed enterprises with improved pastures and cropping. Forage and crop production data input to the model are derived from the GRASP (McKeon *et al.* 1990) and APSIM (Keating *et al.* 2003) animal and pasture yield simulation models based on the historical climate record for a given location and the appropriate stocking rate, land/soil type and land condition. A range of forage crops can be simulated for a range of environments, to accommodate scenarios that involve special purpose forage crops (see below for

further details). The model also has the capacity to allocate high value forages to specific classes of animals.

Monthly and annual output is generated for livestock production, enterprise economic performance (including revenues, direct and overhead costs and gross margins) and the environmental effects of different management options. Environmental performance is assessed against attributes of soils and hydrology, vegetation and the atmosphere (i.e. greenhouse gases) using a range of quantitative and qualitative indicators.

The model is parameterised for each region using typical or benchmark data on the characteristics and management of enterprises for the region (e.g. Stockdale *et al.* 2012 for the Kimberley-Pilbara). Testing of the model for these benchmark conditions indicated that the output for key livestock production and economic indicators is consistent with current performance data obtained from secondary sources (e.g. Holmes *et al.* 2011, McCosker *et al.* 2010).

The current version of the user guide for the NABSA enterprise model (initially referred to as IATna) is presented in Appendix 4.

3.3.2 How the model works and key features

3.3.2.1 Setting up an enterprise
The first step in setting up the model for exploring scenarios is to establish the basic features of the enterprise (e.g. property size, land type and condition, approximate stocking rate) to be simulated. These features are set through a single input screen (Fig. 4).

Fig. 4. Screen shot from the model interface to illustrate setting up a property.

The structure of the herd and the main turn-off class of animals and associated direct costs are then set (Figs. 5 and 6). Other dialog boxes allow labour requirements,

overhead costs, the rules for forced sales during the dry season if forage is limited, and other parameters to be set. The model has been built to accommodate a range of ruminant livestock (i.e. cattle, sheep and goats) though in this study the focus is on beef cattle.

Fig. 5. The screen for setting the initial herd structure. The numbers of animals in different classes will vary from year to year in response to growth, reproduction rates and mortality, etc.

Fig. 6. The screen for setting the main features of the cattle operation.

3.3.2.2 Forage quantity and quality

Once an enterprise has been set up a model run is commenced using an historical climate file that permits the natural features of good and poor seasons to grow forages that supply the animals with nutrients. As mentioned above, forage growth for native (unimproved) pasture is modelled separately using the GRASP pasture simulation model and imported into a large database contained within the NABSA model. Fig. 7 shows a typical pattern of forage growth for the past 30 years for the Charters Towers region as simulated by the GRASP model. The one-year El Nino droughts of 1982-83 and 1987-88 are well represented, as is the multi-year drought of the early to mid-1990s. Similarly, high pasture growth in La Nina years (e.g. 1998-2000) is simulated appropriately.

To keep the modelling approach relatively simple, a generic set of soil/land types was used across all regions. This included a sandy soil of low fertility, a duplex soil of moderate fertility and a clay soil of higher fertility. The most appropriate soil/land type was chosen for each region e.g. duplex soil in north Queensland, clay soil in the Barkly. A climate file was generated for each regional study using SILO data (www.longpaddock.qld.gov.au) based on the most relevant climate station within each region.
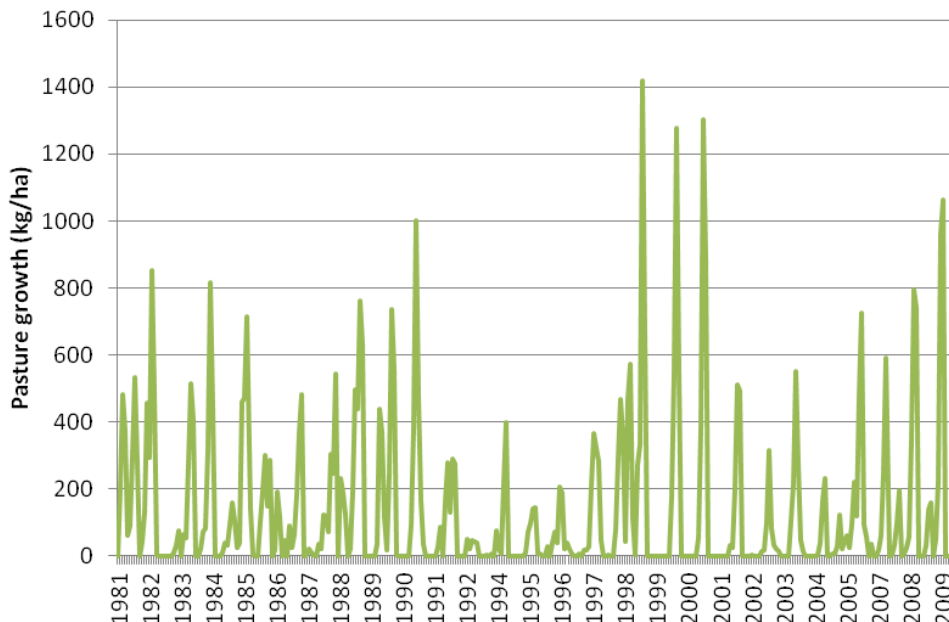
Fig. 7. GRASP simulated pasture growth (monthly time-scale) for the Charters Towers region on a typical duplex soil.

The amount of available forage is only one determinant of animal growth. Forage quality is also a strong driver of growth and is a particularly important issue in northern Australia due to the seasonal protein and energy deficiency that is typically associated with tropical grasses. This is illustrated by Figs. 8a and 8b which show dietary protein and dry matter digestibility as measured in the Wambiana grazing trial over the last 13 years.
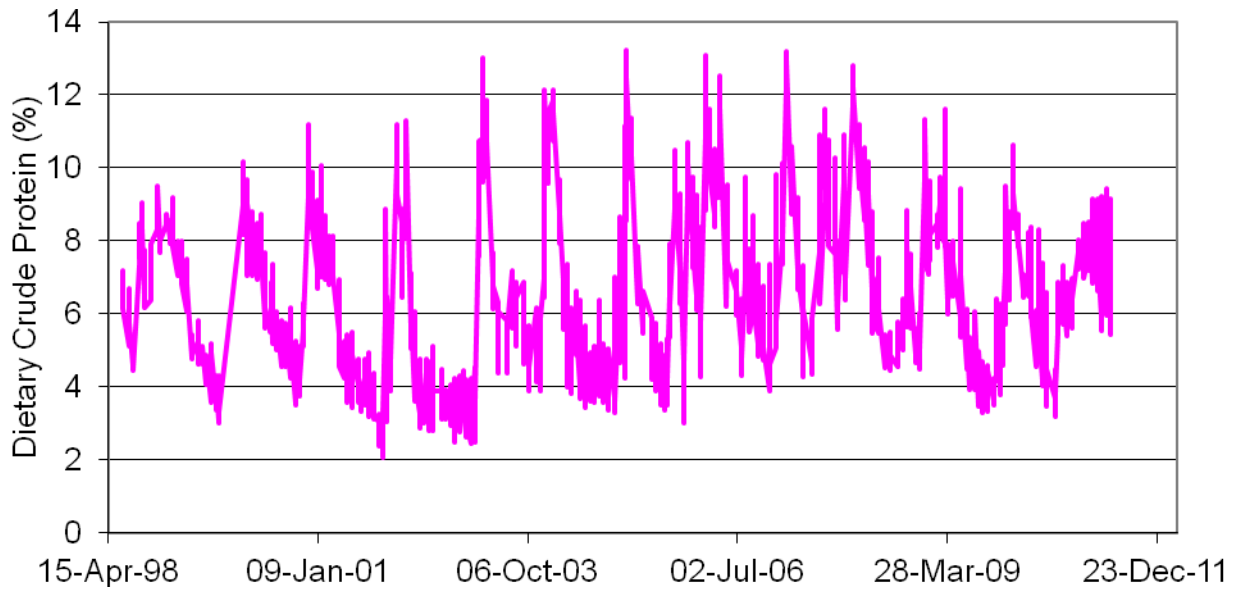
Fig. 8a. Seasonal pattern in dietary crude protein, derived from faecal NIRS, for the Wambiana grazing trial 1998-2011. (Data courtesy of Peter O'Reagain, QDAFF, Charters Towers.)
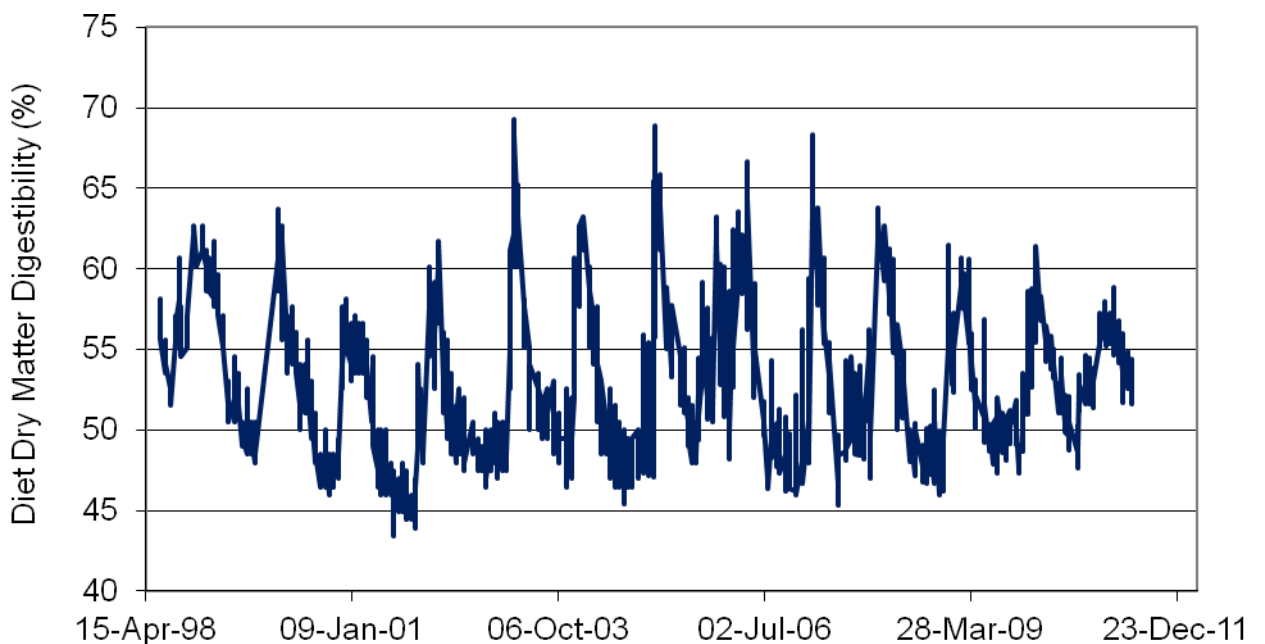
Fig. 8b. Seasonal pattern in dietary dry matter digestibility, derived from faecal NIRS, for the Wambiana grazing trial 1998-2011. (Data courtesy of Peter O'Reagain, QDAFF, Charters Towers.)

Similar patterns of seasonal change and upper and lower limits of protein and digestibility occur across northern Australia, with some variation according to soil type and climate. For example, seasonal decay rates of protein and digestibility are slower for Mitchell grass systems on higher fertility clay soils compared with tropical tallgrass pastures on Tippera red soils near Katherine. The quality of forage from new growth, the decay rate through the season and the minimum quality can be

stipulated within the model. The abundant NIRS data that are now available provide a rigorous basis for setting the upper and lower limits of forage quality and the rates of decay.

The model combines both the growth of forage and its changing quality through the year in twelve monthly forage pools, as illustrated in Fig. 9. When forage growth occurs it enters Pool 1 and then progresses sequentially through subsequent pools in the following months. So in the example in Fig. 9, forage growth in December enters Pool 1 as high quality new growth and what is not consumed or detached enters Pool 2 in January as lower quality forage (as depicted in the decline in forage quality). The percentage of forage that detaches during the year to become litter can be stipulated and forage that carries over into the next year detaches at a much higher rate (which can be varied).

As the season progresses the quality of new growth entering Forage Pool 1 is also reduced to represent the declining availability of nitrogen for new growth (as depicted in Fig. 9). The percentage of each pool of forage that is available to animals can be altered and this, in effect, is used to impose some diet selection rules on the availability of green forage to animals. It is well known that new green growth is not always fully available to animals because it is usually growing into a sward of mature pasture and animals consume both new growth and mature pasture. The nature of the relationship between green forage in the pasture and green in the diet is reasonably well established for tropical pastures in northern Australia (Hendricksen *et al.* 1982).

This approach using forage pools allows a realistic representation of forage quality in different climatic and land type regions of northern Australia. For example, in central Queensland there can regularly be new forage growth (Pool 1) in six months of the year, while in the monsoon tropics the combination of short seasons and poorer soils typically results in new forage growth occurring in only three or four months of the year.
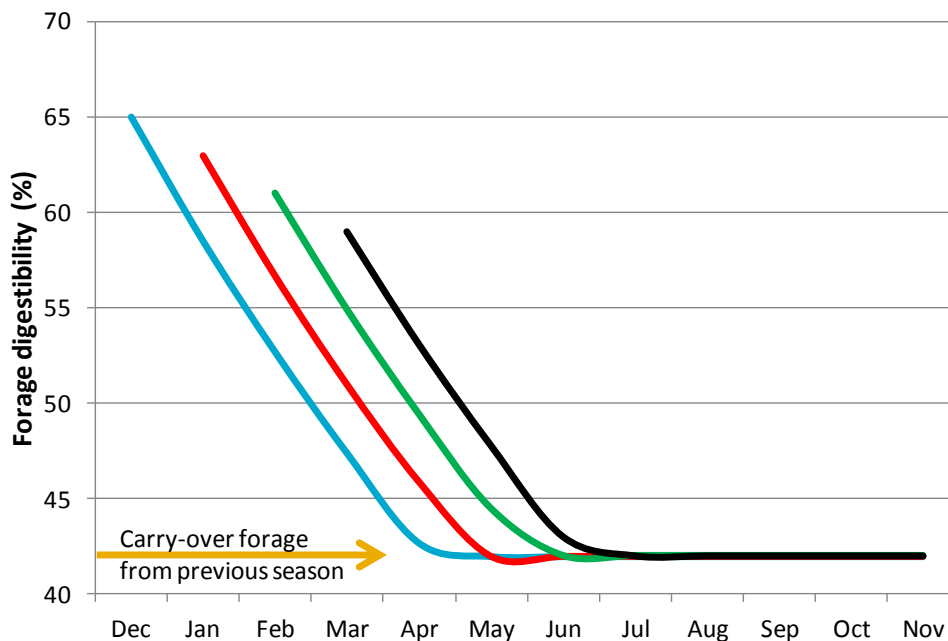
Fig. 9. Conceptual representation of how forage quality declines through the year after entering as high quality forage in the month of its growth. The blue line represents high quality growth produced at the start of the wet season, which then declines in quality through the

year; the red line represents new growth in January that is slightly lower quality than that produced in December, which then declines in quality through the year: the green and black lines follow a similar pattern, with, in this representation, no new growth occurring after April. The orange line at the bottom of the figure represents old, low quality forage carrying over from the previous growing season.

Perennial sown forage, such as buffel grass, can be simulated by choosing a higher basal area than for native pasture, while in some areas of Queensland the GRASP model has been calibrated specifically for buffel grass. This simulates a quicker response in growth to starting rains as well as higher overall growth rates (Fig. 10). Similarly, starting levels of protein and energy and the seasonal rates of decline can be set according to the characteristics of the sown grass. If the sown grass has suffered run down of nitrogen this can be reflected in the starting nitrogen concentration.
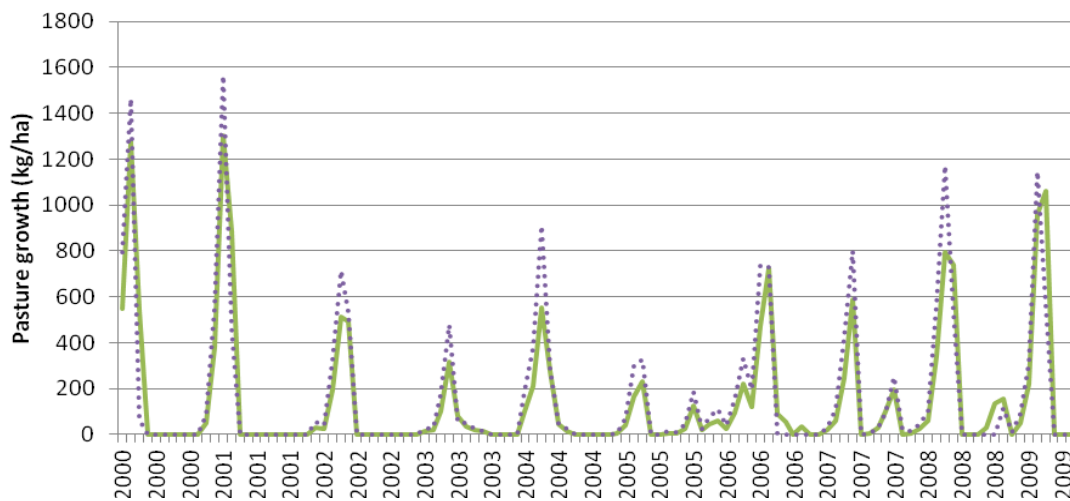
Fig. 10. A representation of growth (kg DM/ha) of a sown pasture such as buffel grass (purple dotted line) compared with native pasture (solid green line).

To test development scenarios involving special purpose forage crops, the APSIM crop simulation model was used to simulate production for a range of dryland or irrigated forage crops (e.g. sorghum, lablab, lucerne and oats) and perennial pastures (Bambatsi, one of the panic grasses; *Panicum coloratum*) in a variety of environments. For example, Fig. 11 shows projected monthly growth for irrigated forage sorghum in the Burdekin region. It should be noted that only a limited amount of empirical data is available and little model validation has been undertaken for forage crops in tropical Australia so there are lower levels of confidence about modelled results for irrigated forage crops.
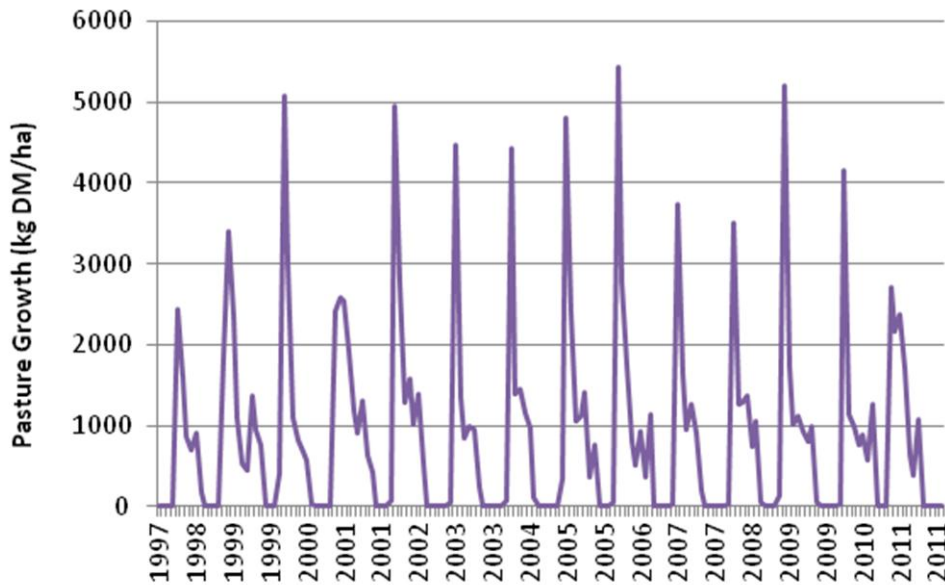
Fig. 11. Simulated growth (kg DM/ha) of Forage sorghum under irrigated conditions in the Burdekin region. Forage sorghum is planted annually and grown for 9 months.

3.3.2.3 Animal growth

Simulation of animal growth from birth to turn-off is based on energy and protein supply from forages and supplements using standard relationships for the nutrient requirements of domesticated ruminants (PISC 2007). This is the first model of cattle growth for northern Australian forage conditions that takes this approach. Previously, models have used more simplistic relationships between feed available, estimates of its quality and animal growth (e.g. McKeon *et al.* 2000). Calf growth is determined by the milk supply from cows which, in turn, depends on the nutritional conditions of lactating cows. Time of weaning can be varied within the model to allow testing of early weaning scenarios. Compensatory growth is not explicitly represented in the model which means late dry season losses and early wet season gains are both underestimated with the expectation that these essentially negate each other.

The model can simulate situations where low forage availability (e.g. due to poor seasons or overstocking) limits animal intake (Fig. 12). The shape of this relationship can be altered for differing pasture conditions. For example, the level of feed availability below which feed intake becomes limiting is greater for dense pasture swards in the sub-tropics (1000 kg/ha) than it is in more open extensive native pastures.
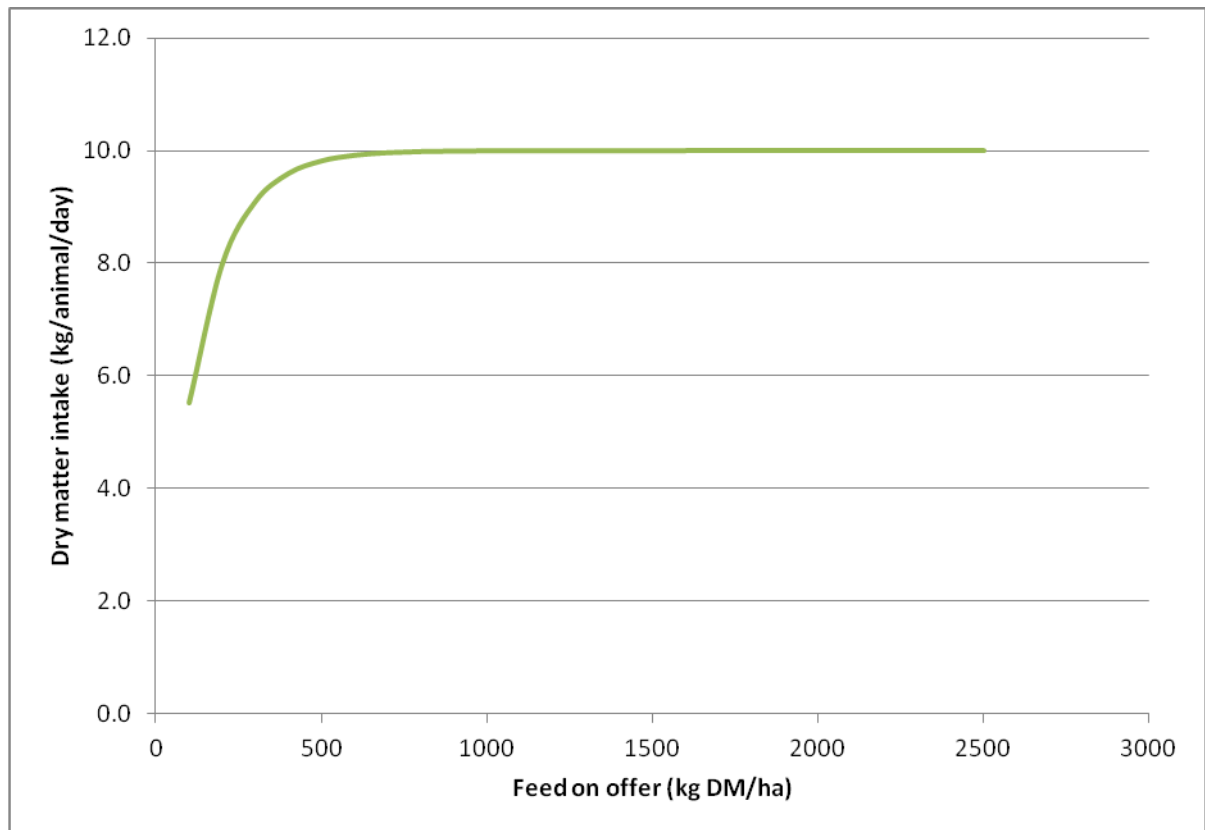
Fig. 12. The relationship between forage availability and potential feed intake in extensive native pasture conditions in the tropics.

3.3.2.4 Reproduction

Conception is determined by the weight of cows relative to a reference weight (the expected weight of an animal in good condition at a given age), which is an effective surrogate for body condition score. The shape of the relationship between body weight in relation to reference weight and conception can be altered (Fig. 13) and different relationships are used for heifers, second-calf heifers and mature cows. As can be seen in Fig. 13, conception rate is highly sensitive to body weight, and relatively small changes in body weight relative to the reference weight can lead to large changes in conception rates. This relationship is based on a range of research results from across northern Australia and is consistent with relationships recently published based on large datasets from across northern Australia (Mayer *et al.* 2012). This approach yields realistic conception and weaning rates, including the lower pregnancy rates typically observed in second-calf heifers in nutritionally stressful environments. Culling of empty cows is a user defined parameter which allows 0-100% percent of empty cows to be retained.
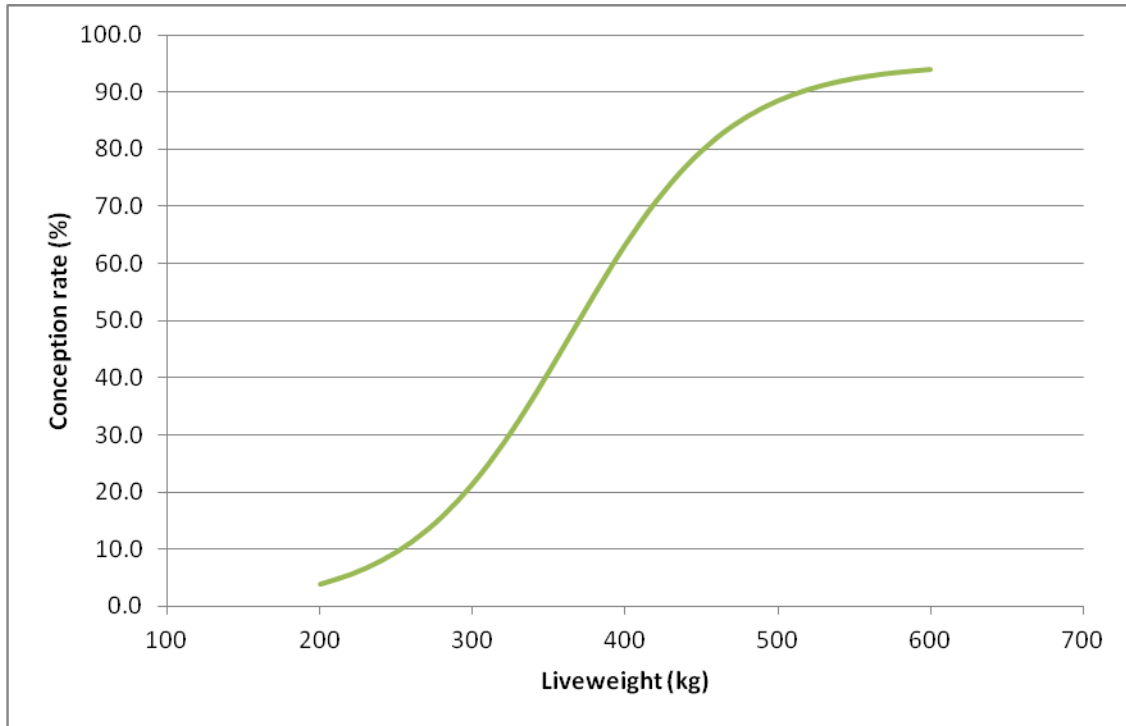
Fig. 13. Example of a relationship between cow liveweight and conception for a mature cow with a standard reference weight of 520 kg. The shape of the relationship can be described by the equation:

Conception rate (%) = A/(1+Exp(k*Cow wt actual/Cow reference wt+C)),

Where A=asymptote maximum conception rate %, k=coefficient function for shape of the curve, and C= constant. Cow wt actual is cow weight at conception.

There is relatively little empirical information available on peri-natal and post-natal mortality rates, but based on the available information (Bortolussi *et al.* 2005) these are determined using standard relationships that are strongly dependent on body weight. Cow mortality rate is determined by body weight relative to the animal's standard reference weight (Fig. 14). In addition a baseline mortality rate can be set that applies across all animal classes and this is based on regionally sourced information.
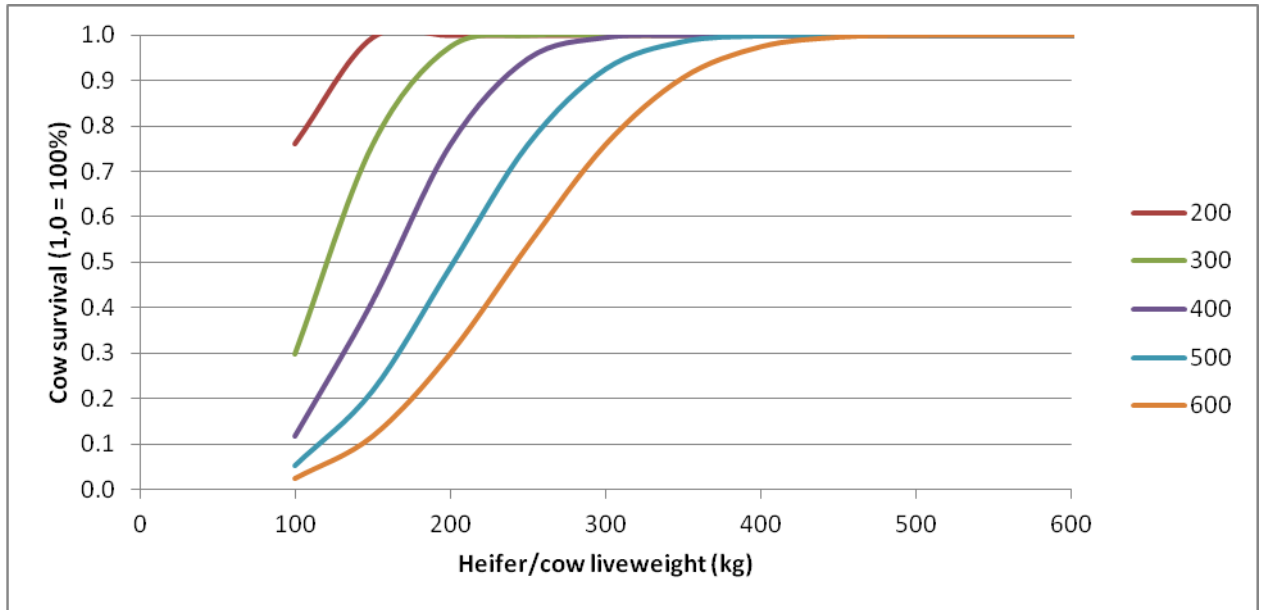
Fig. 14. The relationship between body weight and cow survival rate for a range of heifer/cow reference weights (200,300,400,500,600 kg).

3.3.2.5 Supplementation

Supplements or purchased fodder can be used to maintain or improve animal condition in seasonal nutritional deficits or during drought. A range of different supplements or hay can be fed (e.g. urea, M8U [8% urea:molasses mix], cottonseed meal and sorghum hay) in different months of the year to different animal classes (Fig. 15). More than one supplement can be used at the same time if required.

Supplements add protein and/or energy directly into the nutrient supply of the animal and the benefits can be multiple. For example, feeding urea not only corrects protein deficiency but it can also stimulate feed intake, thereby increasing energy supply.

Phosphorus deficiency and its effects on animal productivity are not represented directly in the current version of the animal model. Animals are assumed to have sufficient phosphorus supply and in areas where phosphorus is deficient it was included as a supplement to reflect costs of production.

Fig. 15. Example of how supplements can be specified to maintain livestock condition.

3.3.2.6 Property economics

Enterprise economic outcomes (except for taxation) for different scenarios are simulated by assessing the revenues from animal turnoff against direct costs of production (animal veterinary costs, transport, commission, etc) to generate gross margins. In addition, overhead costs, labour and interest paid on debts are calculated to generate net profits. Capital costs associated with any development are included as a debt, but there is no annual depreciation charge included in overhead costs.

3.3.2.7 Resource condition

It is possible to simulate some key resource condition outcomes for modelled scenarios. These include land condition, perennial grass basal area, and soil loss (derived from GRASP). The pasture utilisation rate (calculated by the model) determines land condition, and how land condition improves or deteriorates in response to this utilisation rate can be altered for different climate-pasture systems. Qualitative indices that integrate the effects of livestock production across a range of resource condition criteria are also produced by the model. The approach used to produce these indices builds on some earlier work for extensive beef enterprises in northern Australia (MacLeod and McIvor 2006), and is described in Appendix 5.

Within the model land condition is altered using a scale of 0 to 9, based on perennial grass percentage and grass basal area. The grazing land management research and extension community use the ABCD land condition score system (Chilcott *et al.* 2003) and so in the output tables in this report, the quantitative 0-9 land condition index required for the quantitative model is also shown in the ABCD land condition score approach.

3.3.2.8 Methane production

Methane production from cattle grazing pastures is closely related to dry matter intake (Kennedy and Charmley 2012). Given the NABSA model predicts dry matter intake of cattle it is a straight forward regression relationship to derive methane production. We used the relationship developed by Kurihara *et al.* (1999) for tropical pastures, which was amended by Hunter (2007), to estimate methane production as this relationship is used in Australia's greenhouse gas inventory of greenhouse gas emissions (National Greenhouse Gas Inventory Committee 2006). However, in the recent work of Kennedy and Charmley (2012), who used the same techniques and equipment as Kurihara *et al.* (1999) but with a much wider range of tropical forage species, methane production levels were approximately 30% lower than those found by Kurihara *et al.* (1999). So it is possible that methane production levels estimated in this study are too high but the relativity amongst scenarios is still valid and not affected by the published differences in overall methane production.

3.3.3 Assumptions and limitations of the NABSA model

Any model for simulating a complex system across a broad and highly variable range of environments, such as occurs in northern Australia, will necessarily have limitations and rely on simplifying assumptions. While the NABSA model has been developed to test scenarios at an enterprise scale, the current version cannot represent all of the operational diversity and complexities of real beef enterprises in their entirety and the important limitations include the following:

- For this study, generic land type files have been used in GRASP to represent low, moderate and high fertility soils. Climate files for the region being studied were then used in conjunction with the most appropriate land (soil fertility) type for that region.
- Mineral deficiencies are not represented in the animal production model so in regions where mineral deficiencies are an issue, e.g. phosphorus, they are represented as a supplementation cost and it is assumed that the deficiency is corrected.
- Diseases are not explicitly represented in the animal production model but efforts to minimise their effect is represented in veterinary costs e.g. vaccines.
- The model does not allow for variation of individuals within a class of animals. All of the animals within a given class are subject to the same process rates (e.g. they grow at the same rate, consume supplement at the same rate, etc) although this is not the case in reality.
- All animals are born in the same month though it is possible to broadly represent uncontrolled mating via inter-calving interval.
- Where enterprises carry a financial debt, all profit is directed towards paying off the debt as soon as possible, whereas in practice debt repayments are managed in a variety of ways.
- The model does not allow for separate paddocks to be simulated, and does not incorporate spatial issues such as uneven grazing distribution and its effect on intake, diet quality and production. We have also generally assumed a single land type exists on a property. While this assumption generally works well for large extensive operations, it becomes more challenging in the more developed areas of central and southern Queensland where there can be complex mixes of developed and undeveloped country within an enterprise.
- Capital costs of development for various scenarios are currently accommodated by starting a simulation with a negative cash balance to represent the capital investment (the interest rate on the repayment of debt can be altered).

- No additional capital costs beyond those required for development scenarios are included in the model. Maintenance and repairs are included as overheads but imputed costs for depreciation and replacement of capital equipment are not included.
- While it is recognised that debt levels are an important factor affecting profitability, for this study we have assumed no starting debt so that comparisons in profitability could be made. However, a starting debt and interest rates can be included in the model.
- While some development scenarios take many years to fully take effect e.g. improved genetics, we have undertaken model runs without this ramp-up period and assumed that they have been fully implemented or established within the first two years of the 20-25 year simulation i.e. for consistency we are comparing all the scenarios at full implementation.
- A key aspect of implementing the development scenarios was to ensure they could be implemented sustainably. Breeder numbers were adjusted in the model runs to maintain safe utilisation rates and to either maintain or improve land condition over the simulation period.

These types of simplifying assumptions are common to all bio-economic models of complex biological, management and economic agricultural systems. However, we are confident that the key processes in these beef production systems are well represented and the output that we have tested with industry stakeholders is realistic. Some of the limitations identified in the list of points above can be addressed with further model development.

3.3.4 Baseline modelling

In order to assess the potential impact of various technology and innovation scenarios on northern enterprises, it is first necessary to establish a baseline case for a representative enterprise within each region. The baseline includes typical features for an enterprise such as its size, dominant land type, enterprise type and structure, market direction, and input costs etc so that it accurately simulates the livestock production and economic performance that might be currently expected for a typical enterprise. For economy, and in order to maintain consistency and comparability amongst recent projects focussed on the northern beef industry, we initially drew on the collection of representative properties (Table 1) that had previously been developed for the Northern Grazing Systems project (MLA NBP project B.NBP.0578; MacLeod *et al.* 2012). Data were also drawn from several recently published surveys and economic analyses of northern beef enterprises to establish baselines for representative properties, including McCosker *et al.* (2010) and Stockdale *et al.* (2012) as well as ABARES broad-acre industry data (e.g. ABARES 2012). Details of the assumptions for the baseline structure for the representative properties in each region are presented with the scenario results in Section 4.

Table 1. Summary characteristics of regional 'representative' enterprises developed in the Northern Grazing Systems project (J. Scanlan and N. MacLeod, pers. comm.). Ave. condition A = good, D = poor.

Region	Maranoa-Balonne	Burdekin	Duaringa	Western Qld	Southern Gulf	VRD South	Barkly South	Alice Springs	Kimberley
Land area	15,586 ha	24,000 ha	14,230 ha	16,200 ha	1,665 km^2	4,594 km^2	5,000 km^2	3,400 km^2	2,670 km^2
Number of paddocks	7	10	18	15	20	20	20	13	10
Land types	Brigalow/belah Poplar box on duplex Soft mulga on sandplains	Grey clays Yellow earths Red and brown duplex Alluvial	Alluvial brigalow Box flats Narrow-leafed ironbark	Open downs Wooded downs Soft gidyea Boree wooded downs Open alluvial	Open downs Alluvial Red plains Black soils Spinifex ridges	Black cracking clay Good basalt red soil Poor calcareous red soil Spinifex plains	Lateritic red earths Heavy grey earths	Open woodland Mulga Spinifex Alluvial	Pindan Black soils Marine plains
Average condition	B/C (2.5)	B (2.1)	B/C (2.3)	A/B (1.6)	B/C (2.3)	A/B (1.9)	A/B (1.88)	B/C (2.8)	C/D (3.5)
Enterprise type	Breeding cows with steers sold as weaners or yearlings	Breeding cows with steers sold as weaners or yearlings	Breeding cows with steers sold as heavy Ox (3yo)	Breeding cows with steers & heifers sold for trade or live export	Breeding cows with steers & heifers sold for live export	Breeding cows with steers sold for live export	Breeding cows with steers sold for live export	Breeding cows with 60% of steers sold as yearlings and 40% grown out to 2yo	Breeding cows with 25% steers sold as weaners, 25% as yearlings and 50% as 2yo
Total stock carried (AE)	1,600	2,100	1,650	1,500	13,850	10,850	30,000	4,000	6,400
Total value (incl. livestock)	$7.5 m	$7.1 m	$16.0 m	$7.8 m	$27.6 m	$57.2 m	$85.0 m	$7.3 m	$5.9 m

Ten 'representative properties' were modelled to examine the selected array of development scenarios across the ten regions, including coverage of land and vegetation types of contrasting productivity. The combinations of regions and land productivity that were modelled are presented in Table 2. The land productivity (LP) potentials LP1, LP2 and LP3 broadly correspond to sand, duplex and clay soils and represent a trend from low to higher productive potential.

Table 2. The regions and land productivity of representative properties for which development scenarios were modelled.

Region	Location/land potential (LP) of properties
Katherine	Victoria River District: LP 3 (e.g. Wave Hill)
Kimberley	Fitzroy Crossing: LP 2
Central Australia	Alice Springs: LP 2
Pilbara	Wittenoom: LP 2
Barkly-NW Queensland	Donor Hills: LP2
Western Queensland	Longreach: LP 3
North Queensland	Charters Towers: LP 2
SE Queensland	Gayndah: LP 2
Sthn Queensland	Mitchell: LP 2 Duaringa: LP 2
Central Queensland	

3.3.5 Sensitivity analysis

A sensitivity analysis was undertaken prior to testing the various scenarios to determine how herd dynamics and profitability changed in response to the major recognised drivers of herd productivity i.e. weaning rate, mortality and growth rate.

In order to ensure a valid comparison, as the parameters that drive weaning, mortality and growth were altered so too were the total breeder numbers so that herd numbers as measured in adult equivalents remained constant (e.g. as mortality rates were increased, breeder numbers were also increased to maintain adult equivalents at a constant level). For growing animals, only increased growth in the male animals was adjusted to avoid the interaction between altered growth and conception rate in breeding females.

For weaning rate, the cow condition score and conception rate relationships were altered so that the cows could conceive either more or less easily to achieve a range of weaning rates without altering any of the other biological parameters. For the sensitivity analysis for liveweight gain, a protein supplement was fed to male animals at no additional cost.

The results of the sensitivity analysis are shown in Fig. 16 for two contrasting production systems (southern Queensland and northern Queensland). Profitability and turnoff of steers and heifers is sensitive to all three production drivers (weaning, mortality and growth). Although often under-recognised compared with fertility rates, the results especially highlight the sensitivity of projected productivity and profitability outcomes to mortality rates. In the higher productivity systems of southern Queensland, herd mortality rates are typically quite low (1-3%), but they can be

considerably higher in the lower productivity systems of much of northern Queensland (3-5%) and in harsh environments such as the Queensland Gulf region or parts of the Kimberley (Bortolussi *et al.* 2005). Recently, Henderson *et al.* (2013) have undertaken a detailed analysis and modelling of mortality rates across northern Australia and for the harsher regions, breeder and steer mortality rates can be 15-20%.

An interesting aspect of the analysis of production environments was the different response curves to changing production drivers. For weaning rate in north Queensland, relatively larger gains in profit were made moving from an average 55% to 65% weaning than from 65% to 75% weaning. This most likely reflects the ability to consistently maintain a self-replacing herd when increasing weaning rates from lower levels such as 55%. Similarly, increasing mortality rates from 3 to 5% had a relatively much bigger effect on profitability in the north Queensland example compared with south-east Queensland, because combining relatively low weaning rates with high mortality rates greatly restricts the ability to maintain herd size.

Another key driver of enterprise productivity and profitability is the total size of the herd carried. A sensitivity analysis in which the herd size is increased will directly affect productivity, costs and resource condition, so there are many interactions. As herd number is initially increased animal production per head (growth, reproduction) typically declines (Jones and Sandland 1974) although production per hectare and profitability can increase in the short run (Ash and Stafford Smith 1996). However, in the medium to long term, forage deficits and declining resource condition can mean that higher stocking rates are both unproductive and unprofitable (O'Reagain *et al.* 2011).

This type of response is captured in the model because of the interaction between forage production and quality, animal response, utilisation rates and feedback on land condition. As herd numbers initially increase diet quality declines and more frequent forage deficits result in lower animal productivity. As resource condition declines, reliance on supplements and purchased fodder becomes greater and profitability declines.

North Queensland   **South-East Queensland**
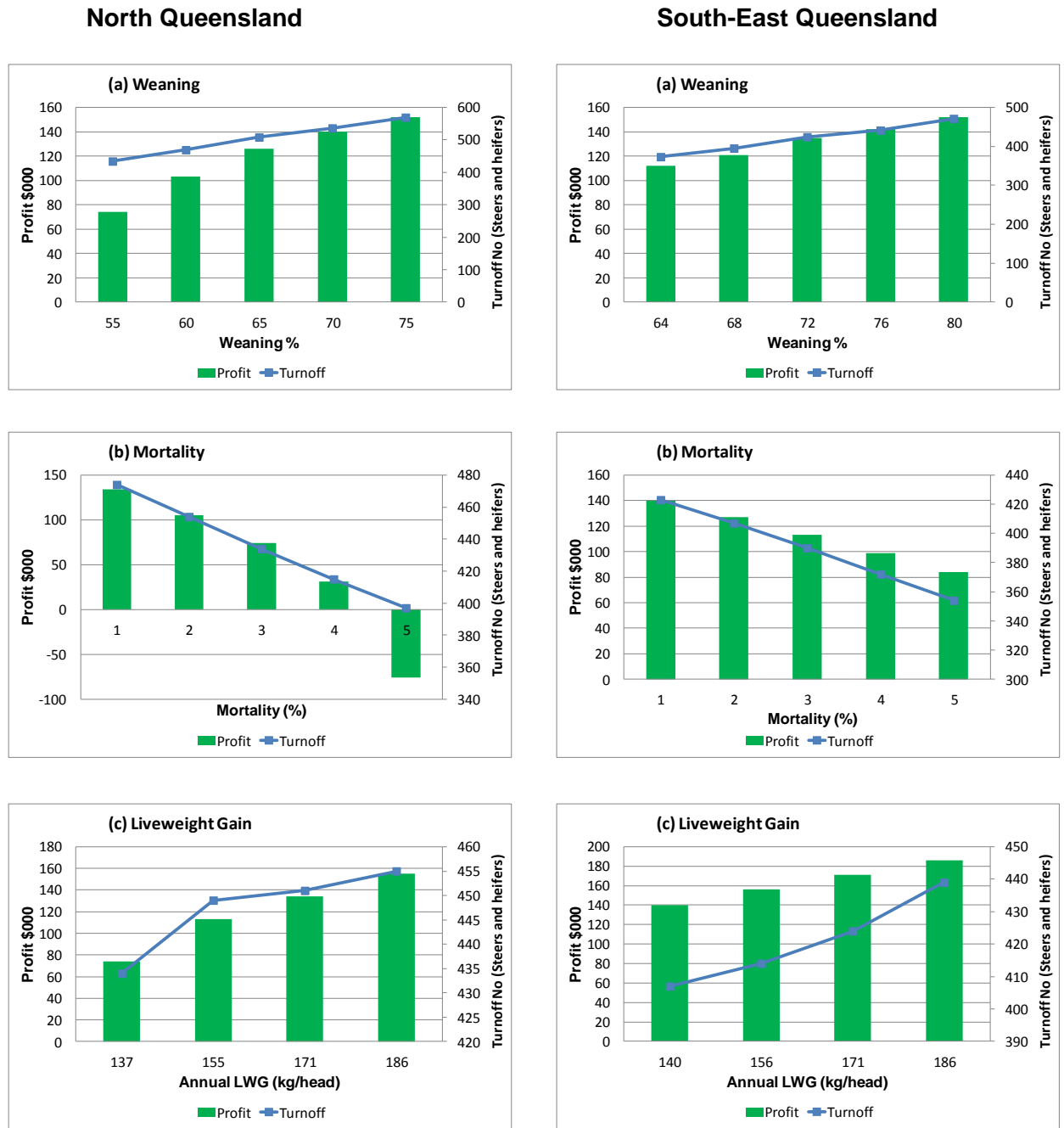
Fig. 16. Sensitivity analysis of the three main drivers of production (weaning, mortality and growth rate) in terms of profitability and turn-off of steers and heifers for high (south-east Queensland, right column) and low-moderate (north Queensland, left column) production systems. Adult Equivalents were held constant as adjustments were made to weaning, mortality and growth rates. Liveweight gain sensitivity is for males only to avoid interaction between increasing liveweight gain and conception rates.

4 Results and discussion

4.1 Scenarios

Consultations with industry representatives and the scientific community revealed a variety of potential development opportunities suggesting productivity benefits for the northern beef industry. However, this was accompanied by a prevailing view that there are no 'silver bullets' for quickly, or cheaply, placing the industry onto a firmer economic footing. Many suggestions related to improving the fundamental aspects of cattle production (e.g. livestock reproduction and growth). While there was some commonality in issues amongst regions, this was not always the case, and within regions not all producers agreed on what were feasible development options.

The issues that were most commonly raised by producers included:
- better pastures (especially to provide more protein in the late dry season)
- improved breeder genetics (especially in relation to re-conception rates)
- faster growth rates (through improved genetics and pastures)
- improved pasture utilisation through better grazing distribution
- reduced labour costs through the development of remote technologies
- more effective options for managing weeds, pests and diseases.

The need for increased adoption of existing best practices was also frequently mentioned. A lack of viable alternative markets and processing facilities in northern Australia were often nominated as major impediments to the further development of the beef industry, but these issues were considered to be beyond the control of producers themselves. Despite the concept of mosaic irrigated agriculture being widely discussed by policy makers and some investors in the context of the development of northern Australia (e.g. Chilcott 2009), this was rarely advanced as a serious option by beef producers. However, when suggested to them many saw its potential for increasing animal growth rates and helping to meet market specifications for sale animals.

In some cases, more than one development scenario could be envisaged for a particular new technology or innovation option. Some scenarios were only relevant to certain regions and niches within regions (for example, some regions do not have access to sufficient water resources to grow irrigated pastures), or required tailoring to suit the agro-ecological and production systems of specific regions. The primary scenarios that have been considered in the project are presented in Table 3.

In this study we focussed on scenarios to increase productivity though it is recognised that reducing costs of production is an important aspect of increasing profitability. Reducing costs of production through scenarios such as greater use of remote management technologies can be represented in the model through reduced labour inputs. There is relatively little published information on the scope of the potential reductions in labour costs (D. Swain, pers. comm.).

Table 3. An overview of the development scenarios being modelled for beef producing regions across northern Australia.

Technology/development	Scenarios
Mosaic farming/irrigation	Steers or weaners grazed on fertilised annual or perennial forage crops to bring to market sooner
Better breeder genetics	Improved breeder conception rates at moderate body condition scores and whilst lactating, resulting in improved calving, branding and weaning percentages
Better genetics for growing	Improved efficiency of energy use
More efficient rumen (better rumen microbes, modified rumen ecology)	Increase in pasture digestibility
Improved pastures or supplement use	**A:** Improved pastures are introduced to areas where they have not been traditionally used, but where their growth is feasible. **B:** Oversow native pastures with legumes
Cheap protein	A cheap high protein source that has both soluble and insoluble protein. This is assumed to be landed on property for $200/tonne compared with existing costs of protein meals ($450-$600/tonne)
Combined scenarios	Combining better breeder genetics, better genetics for growing, rumen modification and cheap protein

4.2 Implementation of scenarios in the enterprise model and associated assumptions

Simulation of the scenarios required specific settings in the model to represent each scenario. The following points summarise the key adjustments and assumptions made for relevant scenarios.

- For scenarios representing increases in reproduction rates coefficients were adjusted for the equation relating animal liveweight to conception rates (generally to increase overall weaning rates by 5%).
- Improvement in the efficiency of energy use (as a result of genetic improvements) was simulated by adjusting the growth efficiency coefficients in the Feeding Standards of Australia to achieve a liveweight growth improvement of about 10%.
- Improvements in rumen function were simulated by reducing the rate at which dry matter digestibility declined each month following pasture senescence i.e. instead of a 10% decline in digestibility per month a monthly decay rate of 8% was used. In addition, the lower limit on digestibility was lifted by three percentage points e.g. 43% to 46% digestibility. This increase in base

digestibility was believed to be feasible based on discussions with ruminant nutritionists.

- The known effect of increased pasture yield from oversowing a native pasture with a legume was simulated by increasing initial perennial grass basal area by 2 percentage points within the GRASP model (e.g. where native grass basal area is 3% this was increased to 5%), which increases forage growth. The monthly nitrogen decay rate was reduced from 30% per month to 10% per month to simulate the year-round higher protein content of pastures. The DMD decay rate was reduced from from 10% to 9%. Most of the benefit in animal production from using sown legumes occurs in the dry season when protein in native pasture becomes limiting and this was represented realistically in the model. Carrying capacity was increased in line with the proportionate increase in forage production and this typically resulted in herd numbers increasing by 20% over baseline scenarios. It was assumed a legume was available for all soil types.

- Since buffel grass was not one of the improved forages specifically included as an option in the model, its use was simulated by increasing the perennial grass basal area (typically by 2% units) of native pasture within GRASP to represent the greater forage growth it produces.

- Two of the scenarios improved the feedbase (legumes and forage crops) and for these scenarios herd numbers were increased to mirror the increased carrying capacity. As indicated above for sown legumes this was typically 20% and for forage crops it was around 10%. For all other scenarios, baseline breeder numbers were initially kept constant but it was anticipated with scenarios that increased productivity through higher weaning rates, better condition cows and increased growth rates would lead to higher AEs. Where necessary, the increase in AEs was constrained to prevent utilisation rates increasing by more than 1 or 2% over baseline utilisation rates.

- For the irrigated forage crop scenarios it was assumed a water source for irrigation was available either through available ground water, pumping directly out of streams/rivers, or via an irrigation scheme. Significant capital costs were assumed to occur in the development of the land for irrigation and in irrigation equipment (e.g. centre pivots and associated pumps etc). Pumping costs were assumed to be $50/ML and cost of water entitlement/access was set at $20/ML.

- Simulation runs were generally undertaken for 30 year periods of historical climate e.g. 1980-2010 to provide the full range of climatic variability. In a few case studies a shorter run of years (c. 20 years) was used because the climate data generated very low pasture growth over a few consecutive years during the historical 40 year record. This made it difficult within the model to sustain a herd of critical mass with flow on longer term implications for herd dynamics. Rather than alter the standard GRASP parameter files used across the regions we instead decided to use a shorter simulation period.

- As the intent was to evaluate scenarios that could lift productivity, it was decided that existing constraints, e.g. lack of abattoirs in the NT and north-west WA regions, should not limit the scenarios to be evaluated. Hence, we assumed that abattoirs were present at or near the major ports. These abattoirs would also be available to process not just finished animals but also surplus heifers and culled cows. This provided a more consistent basis for comparing the baseline with improved scenarios rather than assuming in the baseline that no such slaughtering facilities are present and consequently culled animals have to be transported large distances, which is the current situation in those regions.

4.3   Scenario simulations by regions

4.3.1 Katherine (Victoria River District)-Kimberley

Two case studies were used for this region, one centred on productive cracking clay soils in the Victoria River District (VRD) and the other on moderate productivity soils in the Kimberley. In both these regions the market orientation is towards supplying steers (and excess heifers) to live export (predominantly Indonesia). This market specifies a maximum liveweight of 350 kg. Enterprises in these regions are extensive low input systems based almost entirely on unimproved native pastures.

4.3.1.1 Katherine (Victoria River District) case study

4.3.1.1.1 Assumptions for baseline

The case study enterprise is built on a 5520 sq. km property of which 4416 sq. km are presently accessible for grazing – the balance being undeveloped country without adequate water distribution. Grazing is based entirely on native pasture on open downs country with clay soils. The enterprise has a baseline herd that averages 18,700 AE (average stocking rate of 4.2 AE/sq. km) and seeks to produce young animals (steers and heifers) at about 24 months (<350 kg) for the live export market via Darwin. Other turnoff includes heifers that are surplus to self-replacement requirements, aged cows, and a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement.

The pasture and herd simulations are based on the historical climate sequence of 1971-2009 for both the baseline and scenarios. The starting land condition is B/C condition as rated against a four-category 'ABCD' land condition rating system that is commonly employed by state land management agencies in northern Australia (e.g. Chilcott *et al.* 2003).The herd baseline mortality rate is 5% although this can increase when animals are in poor condition. All animals receive urea lick during the dry season.

The model enterprise is assumed to have a starting cash balance of $500,000 and no ongoing capital development costs to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.1.1.2 Scenario assumptions for the Katherine-VRD case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the VRD case study.

1. Improved pasture: oversow native pasture with legume

- All of the useable area of the property is oversown with a legume.
- The seasonal decline in protein is much less because of the legume.
- Digestibility does not decline as quickly in response to the legume.
- Breeder numbers are kept constant but the average AEs carried increase in response to higher weaning rates and better weight and condition of cows.
- Target market weight was increased to 420 kg by two years of age with these animals being feeder animals for finishing.
- Investment costs are $25/ha (a total of $11m). The capital costs of establishing the pasture are added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal at a cost of $200/tonne landed on the property compared with cottonseed meal at $600/tonne.
- The new protein product is fed to all weaners at 0.3 kg/head/day, at 0.4 kg/head/day for 1-2 year old animals and at 0.5 kg/head/day for all older animals between May and November.
- Additional labour is required to feed out the protein supplement.
- Urea is not provided to any class of animal.

3. Irrigated forage sorghum

- 1000 ha of forage sorghum is grown under irrigation. Existing grazing land is converted to forage crops.
- The crops receives 80 kg N and 30 kg MAP per hectare.
- All yearling and older steers go on to the forage sorghum.
- Surplus heifers are grazed on native pasture and sold
- The maximum number of breeders is reduced by 500 compared to the baseline.
- Selling weight and age are increased to 580 kg and 42 months, respectively.
- The capital costs of establishing the pasture, associated plant and machinery and installing the irrigation infrastructure is $5000/ha (a total of $5m) which is added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time. Recurrent costs of additional labour and maintenance are included in annual gross margin analysis.

4. Genetic reproduction efficiency increase

- Genetic improvement leads to an increase in the weaning rate of 5% above the baseline.
- The maximum number of breeders is not increased but the average AEs carried increases slightly in response to the higher weaning rate.
- It is assumed that the growth rate of animals is not changed over the baseline performance levels.

5. Genetic growth efficiency increase

- Genetic improvement leads to increased growth efficiency in all animals in the herd, but no change in frame size.
- This positively affects the growth of steers, heifers and cows and both liveweight gain and weaning rate increase over the baseline level.
- The selling weight is maintained at 350 kg but the selling age is reduced to 18 months.

6. Rumen modifier

- This technology is simulated by slowing slightly the normal seasonal decay in digestibility and increasing the minimum digestibility by two percentage points (from 43 to 45% digestibility).
- This has a positive effect on the growth of all animals leading to improvements in liveweight gain and weaning rates.

- Selling weight is increased from 350 kg to 420 kg in a shift from live export to trade animals for finishing.

7. Combined scenarios

- This scenario combines the elements of the genetic breeder fertility improvement, genetic growth efficiency, rumen modifier and cheap protein supplement scenarios.
- It does not include the elements of any of the improved pastures scenarios, so there is no change in the underlying baseline feed base.
- The selling weight is increased from 350 kg to 420 kg in a shift from live export to trade animals for finishing.

4.3.1.1.3 Summary of results for the Katherine-VRD case study

The projections of the main production, economic and resource indicator variables from the simulation runs for the baseline and scenarios are summarised in Table 4.

The baseline scenario produced a profit of approximately $900,000 per annum over the 38-year period 1971-2009. The target market for this case study was the live export trade with a target weight not exceeding 350 kg by 24 months of age. This was achieved in just under half of the years; in poorer years animals reached weights of about 280-300 kg at 24 months.

Average utilisation rates were approximately 9% and this allowed the land to improve from B/C condition to A condition over the 38-year simulation run. This reflects an overall level of pasture utilisation lower than what would have occurred to achieve a starting condition of B/C.

All improvement scenarios resulted in increased productivity and profitability over the baseline though there were some differences in profitability and its stability from year to year amongst the scenarios.

The improved pasture scenario produced a substantial increase (20%) in adult equivalents as the increased pasture productivity allowed an increase in carrying capacity. Profitability for this scenario was relatively high (more than double the baseline) as a result of increased animal numbers and a moderate increase in both weaning rate and liveweight gain. Animals reached the target liveweight of 420 kg by 24 months in about 25% of years; in other years they reached 350-400 kg by 24 months. The marginal return on the capital invested in oversowing with legumes was quite low at 9%.

The irrigated forage sorghum scenario was aimed at the Jap Ox market rather than the Indonesian live export market targeted in the baseline because in most years animals were capable of reaching a target weight of 580 kg by about 30 months; in poorer years they required another three to five months to reach market weight. Although the maximum number of breeders was reduced by 500 (because males were being kept longer and to limit the increase in utilisation rate) the overall number of AEs increased slightly. Revenue increased by almost $1m but profit increased only by $100,000 over the baseline. Since capital costs were very high ($5m) the marginal return on the investment was low (2%) relative to the risks associated with the capital development, as the model assumes a productive forage crop is grown in all years i.e. no operational, disease or pest constraints are imposed. There were operating losses, particularly in the early years, as a result of servicing the capital debt. Also,

losses were recorded in some financial years because a cohort of animals reached market specifications in June of one year and the next cohort not until July of the following year i.e. significant revenue did not occur within a financial year but this was followed by a year with high revenue and profit because of two cohorts being sold.

Weaning rate increases of 5 percentage points (i.e. 51% to 56%) in the improved breeder genetics scenario led to a 25% increase in profit. This was lower than for some other scenarios because the outcome was simply an increase in calf numbers rather than any impact on the growth of animals in the herd.

The three scenarios focussed on increasing animal growth (i.e. genetic gains in growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) had significant effects on productivity and profit (40-90% increase) because both weaning rate and growth rates were higher than in the baseline scenario. In particular, the rumen modifier resulted in a significant improvement in profitability through much improved liveweight gain and a substantial increase in herd size.

The low average utilisation rates for all scenarios meant that land condition recovered to be in good condition by the end of the 38 year simulation period.

The combined scenarios of genetic reproductive improvement, genetic growth efficiency improvements, a cheap protein source and improved digestibility via a rumen modifier resulted in much increased profitability (176% increase). This was due to both improved weaning rates (69%) and increased annual liveweight gains (175 kg/head). A 25% increase in adult equivalents also contributed to the additional profit. This increase in AEs was a result of a modest increase in herd numbers but was mostly a result of animals, particularly the breeding herd, being in better condition and having increased efficiency of production. Utilisation rate increased from 9% to 11% compared with the baseline but this did not trigger a decline in land condition.

Total methane production was about the same as the baseline for the two genetic improvement scenarios though methane intensity was lower, and significantly so (15%) for the improved growth efficiency scenario. For the improved nutrition scenarios (legume oversowing, cheap protein, forage crop) total methane production increased by 10-20% but methane intensity decreased by about 15%. For the combined scenarios, total methane production increased by 20% but methane intensity was reduced by 27%.

Table 4. Summary table of mean production, economic and resource management projections for the Katherine-Victoria River District case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated forage sorghum	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Animal equivalents (AE)	18,721	22,723	21,159	20,835	19,149	18,566	21,836	23,341
Gross margin per AE ($)	101	135	121	103	112	126	125	151
Gross margin per ha ($)	3	6	5	4	4	4	5	6
Profit ($)*	912,766	1,911,540	1,556,365	1,012,548	1,151,676	1,345,925	1,748,586	2,518,827
Percentage of years in which a loss occurred (%)	27	5	16	27	22	3	0	16
Marginal return on scenario capital investment (%)		9		2				
Turnoff (no. head)	5290	6703	6834	5097	5846	6075	6284	7508
Beef turned off (kg)	1,878,068	2,716,907	2,583,052	2,461,940	2,044,545	2,171,352	2,474,519	3,155,812
Beef turned off per AE (kg)	100	120	122	118	107	117	113	135
Weaning rate (%)	51	63	63	51	56	55	59	69
Weaning weight (kg)	164	177	176	170	163	165	176	176
Liveweight gain (kg/hd/yr)[+]	125	157	141	171	125	141	150	175
Utilisation (%)	8.8	10.4	9.6	9.8	9.2	8.6	10.2	10.8
Land condition (ABCD)	A	A	A	A	A	A	A	A
Methane (kg/ha/yr)	3.0	3.7	3.4	3.39	3.1	2.9	3.4	3.6
Methane intensity (g/kg beef)	877	751	723	762	830	737	767	638

*Profit before tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.1.2 Kimberley case study

4.3.1.2.1 Assumptions for baseline

The case study enterprise is built on a 2797 sq. km property of which 2181 sq. km are presently available for grazing – the balance being either undeveloped country without adequate water distribution or low value country. Grazing is based entirely on native pasture on moderate productivity (duplex) soils. The enterprise runs a maximum of 11,000 breeding cows and seeks to turn off steers at about 24 months (<350 kg) for the live export market via the Wyndham or Broome ports, although actual marketing weight is approximately 280 kg. The baseline herd averages 11,370 AE (average stocking rate of 4 AE/sq. km). Other turnoff includes heifers that are surplus to self-replacement requirements and a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement. Aged culls are retained on the property as there currently is no market for them (9-10 year-old cows were given a nominal value of 20c/kg in the baseline and all scenarios). To ensure consistency in comparisons, all scenarios used the same approach for cull cows even though in the future there may be better markets for culled animals.

The pasture and herd simulations are based on the historical climate sequence of 1993-2009 for both the baseline and scenarios. The starting land condition is C condition ('fair') as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003). The herd baseline mortality rate is 9% although this can increase when animals are in poor condition. No animals receive dietary supplements.

The model enterprise is assumed to have a starting cash balance of $145,000 and no ongoing capital development costs to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries an 8.5% interest rate. This interest rate figure is higher than for other regions but was used based on expert input suggesting the greater risks in operating in this region attracted higher interest rates.

4.3.1.2.2 Scenario assumptions for the Kimberley case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the Kimberley case study.

1. Improved pasture: oversow native pasture with legume

- All of the useable area of the property is oversown with a legume.
- The seasonal decline in protein is much less because of the legume.
- Digestibility does not decline as quickly in response to the legume in the pasture.
- Breeder numbers are kept constant but the average AEs carried are allowed to increase through higher weaning rates and condition of cows to reflect the increase forage production and carrying capacity.
- Average market weight was increased to 320 kg (from 280 kg for the baseline) after two years so that the live export trade remained the primary target market.
- Investment costs are $25/ha for the useable area of the property (a total of $5.5m). The capital costs of establishing the pasture are added to the overall

balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal at a cost of $200/tonne landed on the property.
- The new protein product is fed to all weaners at 0.3 kg/head/day, at 0.4 kg/head/day for 1-2 year old animals and at 0.5 kg/head/day for all older animals between May and November.
- Additional labour is required to feed out the protein supplement.
- Urea is not provided to any class of animal.

3. Irrigated forage sorghum

- 500 ha of existing grazing land is converted to forage sorghum under irrigation.
- The crop receives 80 kg N and 30 kg MAP per hectare.
- All yearling and older steers go on to the forage sorghum.
- The maximum number of breeders is reduced by 500 compared to the baseline.
- Selling weight and age are increased to 580 kg and 42 months, respectively.
- The capital costs of establishing the pasture, associated plant and machinery and installing the irrigation infrastructure is $5000/ha (a total of $2.5 m) which is added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

4. Genetic reproduction efficiency increase

- Genetic improvement leads to an increase in the weaning rate of 5 percentage points above the baseline.
- The maximum number of breeders is not increased but the average AEs carried increases slightly in response to the higher weaning rate.
- It is assumed that the growth rate of animals is not changed over the baseline performance levels.

5. Genetic growth efficiency increase

- Genetic improvement leads to increased growth efficiency in all animals in the herd, but no change in frame size.
- This positively affects the growth of steers, heifers and cows and both liveweight gain and weaning rate increase over the baseline level.
- The selling weight is increased from 280 kg to 320 kg.

6. Rumen modifier

- This technology is simulated by slowing slightly the normal seasonal decay in digestibility and increasing the minimum digestibility by three percentage points (from 42 to 45% digestibility).
- This has a positive effect on the growth of all animals leading to improvements in liveweight gain and weaning rates.
- Selling weight is increased from 280 kg to 320 kg.

7. Combined scenarios

- This scenario combines the elements of the genetic breeder fertility improvement, genetic growth efficiency, rumen modifier and cheap protein supplement scenarios.
- It does not include the elements of any of the improved pastures scenarios, so there is no change in the underlying baseline feed base.
- The selling weight is increased from 280 kg to 320 kg.

4.3.1.2.3 Summary of results for the Kimberley case study

The projections of the main production, economic and resource indicator variables from the simulation runs for the baseline and scenarios are summarised in Table 5.

The baseline scenario produced a profit of approximately $100,000 per annum over the 17-year period from 1993 to 2009, which is consistent with the estimate of enterprise performance for this region reported by Stockdale *et al.* (2012). The target market for this case study was the live export trade with a target weight not exceeding 350 kg by 24 months of age. This was achieved in about 90% of years, although turnoff weight for steers and heifers averaged only 288 kg.

The average utilisation rate was 12.5% and this allowed the land to improve from its starting C condition to A condition over the 17-year simulation run.

All improvement scenarios apart from the irrigated forage sorghum scenario resulted in increased productivity and profitability over the baseline, with some scenarios showing a substantial increase in profitability (up to a ten-fold increase for the combined scenario).

The improved pasture scenario produced a substantial increase (19%) in AEs as the increased pasture productivity allowed an increase in carrying capacity. Profit for this scenario was more than seven times the baseline profit as a result of increased animal numbers, marked increases in both weaning rate and liveweight gain and a 40% increase in the number of animals turned off annually. Animals reached the target liveweight of 320 kg by 24 months in all but one year. The marginal return on the capital invested in oversowing with legumes was modest at 12%. We accept that given current technologies this scenario of improved pastures would be very difficult to implement. However, the study highlights that were the technology to be available, through improved R&D investment, the potential benefits would be substantial.

The irrigated forage sorghum scenario was aimed at the Jap Ox market rather than the Indonesian live export market because animals were capable of reaching their target weight of 580 kg by 42 months, and in approximately 60% of years they reached this weight by about 30 months of age. Although the maximum number of breeders was reduced by 500 (because males were being kept longer and to limit the increase in utilisation rate) the overall number of AEs increased by 15%. Revenue increased by $425,000 per year but annual profit declined by $84,000 because of the ongoing costs of growing the crop (planting, fertiliser, pumping costs etc) and large capital costs ($2.5m) which generated significant interest and capital debt reduction payments. Consequently the marginal return on the investment was -3%. On the basis of this analysis investment in irrigated forage sorghum that is grazed would appear to be uneconomic in this region.

An increase in the weaning rate of 5 percentage points in the improved breeder genetics scenario resulted in a doubling of annual profit. This in itself is an impressive

outcome but because there was no effect on the growth of animals in the herd the benefit is relatively modest in comparison to certain other scenarios.

The three scenarios focussed on increasing animal growth (i.e. genetic gains in growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) had significant effects on productivity and profitability because both weaning rate and growth rates were greater than in the baseline scenario. In particular, the rumen modifier resulted in a significant improvement in profitability through much improved liveweight gain and a modest increase in herd size (and a cost advantage over the cheap protein scenario – which had similar productivity to the rumen modifier).

The modest average utilisation rates for all scenarios meant that land condition recovered to be in good condition by the end of the 17 year simulation period.

As mentioned above, the combined scenarios of genetic reproductive improvement, genetic growth efficiency improvements, a cheap protein source and improved digestibility via a rumen modifier resulted in a ten-fold increase in profit. This was due to both improved weaning rates (70%) and increased annual liveweight gains (164 kg/head). A 30% increase in AEs also contributed significantly to the additional profit but this increased utilisation rate by only 2 percentage points from 12.5% to 14.7% and did not affect land condition.

Total methane production was about the same as the baseline for the two genetic improvement scenarios though methane intensity was lower. For the improved nutrition scenarios (legume oversowing, cheap protein, forage crop) total methane production increased by about 20% but methane intensity decreased by up to 25%. In the combined scenarios, total methane production increased by 25% but methane intensity was reduced by 35%.

Table 5. Summary table of mean production, economic and resource management projections for the Kimberley case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated forage sorghum	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Animal equivalents (AE)	11,370	13,527	13,068	13,058	11,465	12,129	12,991	14,769
Gross margin per AE ($)	65	116	83	66	74	79	103	119
Gross margin per ha ($)	3	6	4	3	3	3	5	6
Profit ($)*	101,620	734,946	437,231	17,796	224,202	322,877	705,542	1,110,159
Percentage of years in which a loss occurred (%)	35	12	6	47	35	29	6	0
Marginal return on scenario capital investment (%)		12		-3				
Turnoff (head)	2,952	4,153	4,153	2,437	3,182	3,109	3,774	5,058
Beef turned off (kg)	938,247	1,480,235	1,352,756	1,231,245	991,940	1,065,159	1,319,074	1,813,725
Beef turned off per AE (kg)	83	109	104	94	87	88	102	123
Weaning rate (%)	47	60	60	47	52	51	56	70
Weaning weight(kg)	161	178	177	169	161	163	176	191
Liveweight gain (kg/hd/yr)[+]	105	143	130	156	105	123	133	164
Utilisation (%)	12.5	13.8	13.4	14.2	12.6	13.0	14.0	14.7
Land condition (ABCD)	A	A	A	A	A	A	A	A
Methane (kg/ha/yr)	3.6	4.3	4.1	4.2	3.6	3.7	4.0	4.5
Methane intensity (g/kg)	1,074	822	852	959	1,027	984	852	690

*Profit before tax and assumes no capital costs apart from development scenarios. [+]Liveweight gain of yearling animals (steers and heifers)

4.3.2 Pilbara-Central Australia

Two case studies were used for this region, one centred on the Pilbara region of north-west WA and one centred on Alice Springs in Central Australia. These regions are characterised by high rainfall variability, with frequent extended dry periods interspersed with less common above-average seasons. Both regions are considerable distances from markets and this and high seasonal variability strongly influence the nature of beef enterprises.

4.3.2.1 Central Australia case study

4.3.2.1.1 Assumptions for baseline

The case study enterprise is built on a 4473 sq. km property of which 3265 sq. km are presently available for grazing – the balance being either undeveloped country without adequate water distribution or low value country. Grazing is based entirely on native pasture on moderate productivity (duplex) soils. The enterprise runs a maximum of 3500 breeding cows (*B. taurus*) and seeks to turn off steers and bullocks at up to 600 kg with animals going to the Adelaide market. The baseline herd averages 4541 AE (average stocking rate of 1.4 AE/sq. km). Other turnoff includes heifers that are surplus to self-replacement requirements and a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement.

The pasture and herd simulations are based on the historical climate sequence of 1971-2001 for both the baseline and scenarios. The starting land condition is C condition ('fair') as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003). The herd baseline mortality rate is 3% although this can increase when animals are in poor condition. All animals receive urea lick during the dry season.

The model enterprise is assumed to have a starting cash balance of $180,000 and no ongoing capital development costs to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.2.1.2 Scenario assumptions for the Central Australia case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the Central Australia case study. No irrigated forage scenarios were included for this region because there is limited available surface water for irrigation and recharge of groundwater supplies are dependent on irregular flood events (Harrington *et al.* 2001).

1. Improved pasture: oversow native pasture with legume

- All of the useable area of the property is oversown with a legume.
- The seasonal decline in protein is much less because of the legume.
- Digestibility does not decline as quickly in response to the legume in the pasture.
- Breeder numbers are kept constant but the average AEs carried are allowed to increase in response to increased forage production and carrying capacity.
- Investment costs are $25/ha (a total of $8.1m). The capital costs of establishing the pasture are added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal at a cost of $200/tonne landed on the property.
- The new protein product is fed to all weaners at 0.3 kg/head/day, at 0.4 kg/head/day for 1-2 year old animals and at 0.5 kg/head/day for all older animals between May and November.
- Additional labour is required to feed out the protein supplement.
- Urea is not provided to any class of animal.

3. Improved breeder genetics

- Genetic improvement leads to an increase in the weaning rate of 5 percentage points above the baseline.
- The maximum number of breeders is not increased but the average AEs carried increases by approximately 8% in response to the higher weaning rate.
- It is assumed that the growth rate of animals is not changed over the baseline performance levels.

4. Genetic growth efficiency increase

- Genetic improvement leads to increased growth efficiency in all animals in the herd, but no change in frame size.
- This positively affects the growth of steers, heifers and cows and both liveweight gain and weaning rate increase over the baseline level.
- The maximum number of breeders remains unchanged but the average AEs carried increases by about 6% in response to the improved weaning rate.

5. Rumen modifier

- This technology is simulated by slowing slightly the normal seasonal decay in digestibility and increasing the minimum digestibility by three percentage points (from 44 to 47% digestibility).
- This has a positive effect on the growth of all animals leading to improvements in liveweight gain and weaning rates.
- Breeder numbers were initially held constant and herd size (AEs) was allowed to increase in response to improved weaning and growth rates. However, to constrain increases in utilisation and declines in land condition, the maximum number of breeders was reduced by 500 (to 3000) compared with the baseline. As a result herd numbers increased only by 4% over the baseline.

6. Combined scenarios

- This scenario combines the elements of the genetic breeder fertility improvement, genetic growth efficiency, rumen modifier and cheap protein supplement scenarios.
- It does not include the elements of any of the improved pastures scenarios, so there is no change in the underlying baseline feed base.
- Breeder numbers were initially held constant and herd size (AEs) was allowed to increase in response to improved weaning and growth rates. However, to constrain increases in utilisation and declines in land condition, the maximum

number of breeders was reduced by 500 (to 3000) compared with the baseline. As a result herd numbers increased only by 4% over the baseline.

4.3.2.1.3 Summary of results for the Central Australia case study

The projections of the main production, economic and resource indicator variables from the simulation runs for the baseline and scenarios are summarised in Table 6.

The baseline scenario produced a profit of approximately $235,000 per annum over the 31-year period from 1971 to 2001, which is consistent with the estimate of enterprise performance for this region reported by McCosker *et al.* (2010). The target market for this case study was the southern bullock trade with a target weight of 600 kg by 48 months of age. This was achieved (or close to it) in about 50% of years, including approximately 20% of years where the target weight was achieved by 2-3 year-olds. In the other 50% of years turnoff weight at the desired marketing age of 48 months averaged approximately 500 kg. The arid climate of central Australia resulted in highly variable returns with losses occurring in nearly half of the years in the baseline scenario.

The average utilisation rate was 16% and this allowed the land to improve from C condition to A condition over the 31-year simulation run.

All development scenarios apart from the improved pasture scenario resulted in increased productivity and profitability over the baseline, although there was some variability amongst the scenarios). However, variability in returns remained high in all scenarios with financial losses occurring in around half of the years.

The improved pasture scenario produced a substantial loss ($346,000) despite a 14% increase in adult equivalents and increases in both weaning rate and liveweight gain as a result of the increased pasture productivity. The loss reflects the huge development cost associated with oversowing such a large land area, relative to number of stock carried and the relatively modest improvements in productivity.

Increasing weaning rates by 5 percentage points in the improved breeder genetics scenario resulted in a 15% increase in annual profit. However, the lack of benefit for animal growth in this scenario meant the gain in profit was the smallest of all development scenarios (apart from the improved pasture option).

In comparison, because both growth rates and weaning rates were greater in the three scenarios focussed on increasing animal growth (i.e. genetic gains in growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) these produced larger gains in productivity and profitability, although the gains were relatively modest except for the rumen modifier scenario. This scenario generated a 37% improvement in profit through much increased productivity.

Despite a couple of years with very high pasture utilisation rates (reflecting poor seasons), average utilisation rates over the 30-year simulation period were modest for all scenarios so that land condition recovered to good condition by the end of the simulation runs.

The combined scenarios of genetic reproductive improvement, genetic growth efficiency improvements, a cheap protein source and improved digestibility via a rumen modifier resulted in the greatest increase in profitability (67%) of any of the scenarios, although this was only marginally greater than the use of the rumen modifier on its own. The combined scenarios had a substantial increase in both

weaning rate (67%) and annual liveweight gain (205 kg/head), but only a small (4%) increase in the number of AEs carried.

For most scenarios, total methane production and methane intensity were similar to the baseline, reflecting smaller changes in animal productivity in response to the technology and management interventions compared with other regions. The combined scenarios resulted in a 20% reduction in methane intensity and no increase in overall methane production.

Table 6. Summary table of mean production, economic and resource management projections for the Central Australia case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Animal equivalents (AE)	4,541	5,177	5,175	4,914	4,836	4,734	4,730
Gross margin per AE ($)	151.0	158.8	142.1	150.3	153.5	163.2	179.9
Gross margin per ha ($)	1.53	1.84	1.64	1.65	1.66	1.73	1.90
Profit ($)*	235,374	-346,149	277,581	270,207	292,359	322,676	394,018
Percentage of years in which a loss occurred (%)	48	69	52	48	52	43	41
Marginal return on scenario capital investment (%)		-7					
Turnoff (head)	1211	1371	1337	1321	1275	1259	1382
Beef turned off (kg)	536,732	636,481	615,660	578,592	578,060	589,965	665,389
Beef turned off per AE (kg)	118	123	119	118	120	125	141
Weaning rate (%)	55	61	59	60	57	61	67
Weaning weight (kg)	133	138	139	134	135	140	139
Liveweight gain (kg/hd/yr)[+]	141	167	162	142	157	169	205
Utilisation (%)	16.3	17.6	17.9	17.5	16.8	16.8	16.8
Land condition (ABCD)	A	A	A	A	A	A	A
Methane (kg/ha/yr)	0.9	1.0	1.0	1.0	0.9	0.9	0.9
Methane intensity (g/kg)	748	726	748	756	723	707	619

*Profit before tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.2.2 Pilbara case study

4.3.2.2.1 Assumptions for baseline

The case study enterprise is built on a 2695 sq. km property of which 1698 sq. km are presently available for grazing – the balance being undeveloped country without adequate water distribution or low value country. Grazing is based entirely on native pasture on moderate productivity (duplex) soils. The enterprise runs a maximum of 5500 breeding cows (*B. taurus x B. indicus*) and seeks to turn off steers and excess heifers at less than 350 kg for the Indonesian live export market. The baseline herd averages 6747 AE (average stocking rate of 3.9 AE/sq. km). Other turnoff includes a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement.

The pasture and herd simulations are based on the historical climate sequence of 1984-2009 for both the baseline and scenarios. The starting land condition is B/C condition as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003). The herd baseline mortality rate is 4% although this can increase quite significantly when animals are in poor condition. All animals receive urea lick during the dry season.

The model enterprise is assumed to have a starting cash balance of $560,000 and no ongoing capital development costs to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries an 8% interest rate.

4.3.2.2.2 Scenario assumptions for the Pilbara case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the Pilbara case study. An irrigated forage scenario was included for this region based on the possibly availability of water from the dewatering of mines in the region.

1. Improved pasture: oversow native pasture with legume

- All of the useable area of the property is oversown with a legume.
- The seasonal decline in protein is much less because of the legume.
- Digestibility does not decline as quickly in response to the legume in the pasture.
- Breeder numbers are kept constant but the average AEs carried can increase in response to improved weaning and growth rates and improved cow condition.
- Target selling weight increased to 420 kg by two-years of age.
- Investment costs are $25/ha (a total of $4.2m). The capital costs of establishing the pasture are added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal at a cost of $200/tonne landed on the property.
- The new protein product is fed to all weaners at 0.3 kg/head/day, at 0.4 kg/head/day for 1-2 year old animals and at 0.5 kg/head/day for all older animals between May and November.

- Additional labour is required to feed out the protein supplement.
- Urea is not provided to any class of animal.

3. Irrigated forage sorghum

- 500 ha of forage sorghum is grown under irrigation.
- The crop receives 80 kg N and 30 kg MAP per hectare.
- All yearling and older steers go on to the forage sorghum.
- The maximum number of breeders is reduced by 500 compared to the baseline to reflect the change in herd structure with more cohorts of growing steers.
- Selling weight and age are increased to 580 kg and 42 months, respectively.
- The capital costs of establishing the pasture, associated plant and machinery and installing the irrigation infrastructure is $5,000/ha (a total of $2.5 m) which is added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

4. Improved breeder genetics

- Genetic improvement leads to an increase in the weaning rate of 5% above the baseline.
- The maximum number of breeders is not increased but the average AEs carried can increase in response to the higher weaning rate.
- It is assumed that the growth rate of animals is not changed over the baseline performance levels.

5. Genetic growth efficiency increase

- Genetic improvement leads to increased growth efficiency in all animals in the herd, but no change in frame size.
- This positively affects the growth of steers, heifers and cows and both liveweight gain and weaning rate increase over the baseline level.
- The maximum number of breeders remains unchanged but the average AEs carried can increase in response to improved weaning rates and better condition cows.

6. Rumen modifier

- This technology is simulated by slowing slightly the normal seasonal decay in digestibility and increasing the minimum digestibility by three percentage points (from 42 to 45% digestibility).
- This has a positive effect on the growth of all animals leading to improvements in liveweight gain and weaning rates.
- The maximum number of breeders remains unchanged but the average AEs carried can increase in response to improved weaning rates and better condition cows.

7. Combined scenarios

- This scenario combines the elements of the genetic breeder fertility improvement, genetic growth efficiency, rumen modifier and cheap protein supplement scenarios.
- It does not include the elements of any of the improved pastures scenarios, so there is no change in the underlying baseline feed base.

- The maximum number of breeders remains unchanged but the average AEs carried can increase in response to improved weaning rates and better condition cows.

4.3.2.2.3 Summary of results for the Pilbara case study

The projections of the main production, economic and resource indicator variables from the simulation runs for the baseline and scenarios are summarised in Table 7.

The baseline scenario produced a profitability of approximately $128,000 over the 25-year simulation period, which is consistent with the estimate of enterprise performance for this region reported by Stockdale *et al.* (2012). The target market for this case study was the live export trade with a target weight of 350 kg by 24 months of age. This was achieved in approximately 40% of years; in poorer years animals reached an average of 280 kg at 24 months. Inter-annual profitability was highly variable with losses recorded in nearly half of all years.

The average utilisation rate was 25%, which would appear to be reasonably high for this environment. The stocking rates used in the scenarios are reasonably conservative based on existing grazing management practice. The GRASP model has not had extensive calibration for the Pilbara region and it may well be that pasture growth is under-estimated, resulting in higher than anticipated utilisation rates.
All development scenarios apart from the improved pasture scenario resulted in increased productivity and profitability over the baseline, but there was considerable variability amongst the scenarios). The percentage of years with financial losses remained high for most scenarios though it was reduced to 25% of years for the rumen modified and combined scenarios.

The improved pasture scenario produced a substantial (74%) increase in profit due to increases in animal numbers, weaning rate and liveweight gain as a result of the increased pasture productivity. Consequently there was an 18% increase in the number of head turned off annually. Animals reached the target liveweight of 420 kg by 24 months in only 28% of years. In other years animals reached an average weight of 340 kg by 24 months (range of 171-418 kg). The marginal return on the capital invested in oversowing with legumes was very low at just 2%.

The irrigated forage sorghum scenario was aimed at the Jap Ox market rather than the Indonesian live export market targeted in the baseline because animals had the potential to reach market specifications. In approximately 30% of years animals reached their target weight of 580 kg by about 30 months; in most other years they required between 38 and 42 months to reach market weight. In two years they had reached between 460 and 480 kg at the desired selling age of 42 months. Although the maximum number of breeders was reduced by 500 (because males were being kept longer and to limit the increase in utilisation rate) the overall number of AEs increased slightly. Revenue increased by about $260,000 but the scenario generated an average annual loss of $560,000 due to high costs and interest payments.

Increasing weaning rates by 5 percentage points in the improved breeder genetics scenario resulted in a substantial (46%) increase in annual profit.

The cheap protein scenario produced a 40% increase in profit, the genetic improvement in growth efficiency an 83% increase and the rumen modifier a 186% increase in profit as a consequence of improved growth rates and weaning rates. The

rumen modifier scenario also had a 17% increase in AEs (which increased the annual pasture utilisation rate by 4 percentage points compared to the baseline).

Average annual pasture utilisation rates were on the high side for this region (25-30%) for all scenarios including the baseline. Utilisation rates were very high (50-100%) in poor seasons for some scenarios. The high average rates and frequency of poor seasons meant that land condition declined for most scenarios over the 25-year simulation period.

Combining genetic reproductive improvement, genetic growth efficiency improvements, a cheap protein source and improved digestibility via a rumen modifier resulted in a 291% increase in profitability. Both weaning rate (69%) and annual liveweight gain (174 kg/head) improved substantially compared to the baseline, and there was a 23% increase in the number of AEs carried.

Compared with the baseline, all scenarios resulted in an increase in overall methane production of between 10 and 20%. However, methane intensity was reduced in the scenarios by about 10%, with the exception of the combined scenarios, which showed a decline in methane intensity of 24%.

Table 7. Summary table of mean production, economic and resource management projections for the Pilbara case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated forage sorghum	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Animal equivalents (AE)	6,747	8,062	7,489	7,449	6,944	7,318	7,908	8,284
Gross margin per AE ($)	100	119	98	85	105	107	115	127
Gross margin per ha ($)	3	4	3	2	3	3	3	4
Profit ($)*	127,996	223,050	179,801	-559,962	186,377	234,751	366,625	500,830
Percentage of years in which a loss occurred (%)	46	33	46	92	42	42	25	25
Marginal return on scenario capital investment (%)		2		-28				
Turnoff (head)	2083	2519	2459	1915	2250	2201	2451	2843
Beef turned off (kg)	730,126	985,423	891,861	886,039	777,709	822,342	951,323	1,163,198
Beef turned off per AE (kg)	108	122	119	119	112	112	120	140
Weaning rate (%)	53	66	64	53	58	55	64	69
Weaning weight (kg)	133	161	159	139	133	135	161	170
Liveweight gain (kg/hd/yr)[+]	120	150	134	159	120	138	148	174
Utilisation (%)	25.3	29.1	28.0	26.6	25.8	26.4	29.7	29.7
Land condition (ABCD)	B	C	B/C	B/C	B	B/C	C	C
Methane (kg/ha/yr)	2.2	2.7	2.5	2.5	2.3	2.4	2.6	2.7
Methane intensity (g/kg)	825	751	756	765	795	775	742	625

*Profit before tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.3 Barkly-NW Queensland

4.3.3.1 Barkly-NW Qld case study

4.3.3.1.1 Assumptions for baseline

The case study enterprise is built on a 5000 sq. km property all which is accessible for grazing, reflecting the current trend for properties in the region to improve water distribution to make the majority of land on a property accessible to cattle. Grazing is based entirely on native pasture on open downs country with clay soils. The enterprise runs a maximum of 22,000 breeding cows and seeks to turn off steers at about 24 months (<350 kg) for the live export market via Darwin. In this region many animals also flow down through Queensland to be fattened but for this study we chose the live export market as the baseline. The baseline herd averages 27,995 AE (average stocking rate of 5.6 AE/sq. km). Other turnoff includes heifers that are surplus to self-replacement requirements, aged cows, and a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement.

The pasture and herd simulations are based on the historical climate sequence of 1990-2010 for both the baseline and scenarios. The starting land condition is C condition ('fair').The herd baseline mortality rate is 3% although this can increase when animals are in poor condition. All animals receive urea lick during the dry season.

The model enterprise is assumed to have a zero starting cash balance and no ongoing capital development costs to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.3.1.2 Scenario assumptions for the Barkly case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the Barkly case study. An irrigated pasture scenario was not included for this region as it was determined that no suitable water resources are available to support such developments.

1. Improved pasture: oversow native pasture with legume

- All of the property is oversown with a legume.
- The seasonal decline in protein is much less because of the legume.
- Digestibility does not decline as quickly in response to the legume.
- Breeder numbers are kept constant but the average AEs carried increase by 9.5%; utilisation increases only by 1%.
- Target market weight was increased to 420 kg after two years.
- Investment costs are $25/ha (a total of $12.5m). The capital costs of establishing the pasture are added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal at a cost of $200/tonne landed on the property.
- The new protein product is fed to all weaners at 0.3 kg/head/day, at 0.4 kg/head/day for 1-2 year old animals and at 0.5 kg/head/day for all older animals between May and November.

- Additional labour is required to feed out the protein supplement.
- Urea is not provided to any class of animal.

3. Irrigated forage sorghum

- 1500 ha of forage sorghum is grown under irrigation.
- The crop receives 80 kg N and 30 kg MAP per hectare.
- All yearling steers go on to the forage sorghum.
- Selling weight and age are increased to 580 kg and 42 months, respectively.
- The capital costs of establishing the pasture, associated plant and machinery and installing the irrigation infrastructure is $5000/ha (a total of $2.5 m) which is added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

4. Improved breeder genetics

- Genetic improvement leads to an increase in the weaning rate of 5 percentage points above the baseline.
- The maximum number of breeders is not increased but the average AEs carried increases slightly in response to the higher weaning rate.
- It is assumed that the growth rate of animals is not changed over the baseline performance levels.

5. Genetic growth efficiency increase

- Genetic improvement leads to increased growth efficiency in all animals in the herd, but no change in frame size.
- This positively affects the growth of steers, heifers and cows and both liveweight gain and weaning rate increase over the baseline level.
- The maximum number of breeders remains unchanged but the average AEs carried increases in response to the improved weaning rate and cow condition.
- The selling weight is increased from 350 kg to 420 kg in a shift from live export to trade animals for finishing.

6. Rumen modifier

- This technology is simulated by slowing slightly the normal seasonal decay in digestibility and increasing the minimum digestibility by three percentage points (from 45 to 48% digestibility).
- This has a positive effect on the growth of all animals leading to improvements in liveweight gain and weaning rates.
- The maximum number of breeders remains unchanged but the average AEs carried increases in response to the improved weaning rate and cow condition.
- Selling weight is increased from 350 kg to 420 kg in a shift from live export to trade animals for finishing.

7. Combined scenarios

- This scenario combines the elements of the genetic breeder fertility improvement, genetic growth efficiency, rumen modifier and cheap protein supplement scenarios.

- It does not include the elements of any of the improved pastures scenarios, so there is no change in the underlying baseline feed base.
- The maximum number of breeders remains unchanged but the average AEs carried increases in response to the improved weaning rate and cow condition.
- The selling weight is increased from 350 kg to 420 kg in a shift from live export to trade animals for finishing.

4.3.3.1.3 Summary of results for the Barkly-NW Qld case study

The projections of the main production, economic and resource indicator variables from the simulation runs for the baseline and scenarios are summarised in Table 8.

The baseline scenario produced a profit of approximately $1.8m over the 20-year simulation period. The target market for this case study was the live export trade with a target weight of 350 kg by 24 months of age. This was achieved in just 20% of years; in other years animals reached an average weight of 300 kg (range 246-339 kg) at 24 months. This profit was relatively higher than for other regions. A feature of this case study region was that profits were recorded in all years i.e. variability in production and profit was much lower than for other regions.

Average pasture utilisation rates were approximately 12% and this allowed the land to improve from C condition to A condition over the 20-year simulation run for both the baseline and all other scenarios.

All improvement scenarios resulted in increased productivity and profitability over the baseline. The improved pasture scenario produced a 10% increase in AEs as the increased pasture productivity allowed an increase in carrying capacity, whereas profit was 31% greater than for the baseline as a result of the combined effect of increased animal numbers and increases in both liveweight gain (up 20 kg) and weaning rate (up 5%). Animals reached the target liveweight of 420 kg by 24 months only in approximately 10% of years; in other years the average weight at 24 months was 344 kg (range 285-405 kg). The marginal return on the capital invested for this scenario was only 4%.

The irrigated forage sorghum scenario involving a major capital investment of over $7m associated with the development of 1500 ha for irrigation produced some profitability gains. This scenario involved shifting from live export of light animals to production of Jap Ox animals. This was attempted by placing all the yearling steers on to irrigated forage sorghum. The increase in liveweight gain allowed animals to reach a target liveweight of 580 kg by 42 months of age in most years. Prices received for finished animals of this age were assumed to be less than for animals finished by 24-36 months age. Revenue for this scenario exceeded that for the baseline by $1.2m but large capital and running costs meant profit increased by only $77,000. Thus, the marginal return on this investment was just 1%, making such a large capital investment unattractive. Forage sorghum was grown from the late dry/early wet season through to the middle of the following dry season, which is the typical pattern of growth for forage sorghum. It is possible that a scenario where the forage sorghum is planted immediately after the wet season, when the soil becomes trafficable, and grazed over the May-December period would return better animal gains and profits compared with the baseline.

There was a relatively modest profit gain of 10% as a result of a 5% improvement in weaning rates in the improved breeder genetics scenario, reflecting the benefit of this

scenario being limited to an increase in calf numbers rather than an improvement in the growth of animals.

The three scenarios focussed on increasing animal growth (i.e. improved growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) also increased weaning rates and so produced modest to substantial increases in profit over the baseline. In particular, the rumen modifier resulted in a 67% improvement in profit, which was helped by a 17% increase in adult equivalents.

The combined scenarios of genetic reproductive improvement, genetic growth efficiency improvements, a cheap protein source and improved digestibility via a rumen modifier resulted in a 120% increase in profit. This was due to both improved weaning rates (72%) and increased annual liveweight gains (174 kg/head). A 32% increase in adult equivalents also contributed significantly to the additional profit, but utilisation rate increased from 12 to 15%. However, land condition was not affected.

Compared with the baseline, most scenarios resulted in an increase in overall methane production of between 10 and 20%. The exception was the combined scenarios which showed an increase in methane production of 28%. Methane intensity was reduced in the scenarios by about 10%, with the exception of the combined scenarios, which showed a decline in methane intensity of 20%.

Table 8. Summary table of mean production, economic and resource management projections for the Barkly-NW Qld case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated forage sorghum	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Animal equivalents (AE)	27,955	30,624	30,428	31,005	28,846	29,841	32,718	36,954
Gross margin per AE ($)	114	128	120	110	117	121	134	144
Gross margin per ha ($)	6	8	7	7	7	7	9	11
Profit ($)*	1,786,189	2,333,258	2,228,230	1,863,591	1,967,578	2,220,373	2,983,557	3,923,559
Percentage of years in which a loss occurred (%)	0	0	0	4	0	0	0	0
Marginal return on scenario capital investment (%)		4		1				
Turnoff (head)	9,252	10,268	10,528	8497	9,987	9,969	11,011	12,515
Beef turned off (kg)	3,294,472	3,910,166	3,923,168	4,059,832	3,489,012	3,676,285	4,323,213	5,359,739
Beef turned off per AE (kg)	118	128	129	131	121	123	132	145
Weaning rate (%)	56	61	62	57	61	60	65	72
Weaning weight (kg)	137	142	143	139	136	138	147	155
Liveweight gain (kg/hd/yr)[+]	123	143	135	144	123	138	149	174
Utilisation (%)	12.0	13.0	12.8	13.0	12.5	12.6	13.9	15.1
Land condition (ABCD)	A	A	A	A	A	A	A	A
Methane (kg/ha/yr)	5.0	5.6	5.4	5.7	5.2	5.2	5.8	6.4
Methane intensity (g/kg)	759	710	693	700	742	712	674	600

*Profit before tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.4 Western Queensland

4.3.4.1 Western Queensland (Longreach) case study

4.3.4.1.1 Assumptions for baseline

The case study enterprise is built on a 15,000 ha property of which 14,000 ha are available for grazing – the balance being undeveloped country without adequate water distribution or low value country. Grazing is based entirely on Mitchell grass pastures on fertile, cracking clay soils. The baseline herd size is 1500 AE, consisting of breeding cows and growing trade steers to 400 kg weight by about 24 months. Other turnoff includes heifers that are surplus to self-replacement requirements and a proportion of the breeders that are culled early for fertility, culled for age (10 years) or sold as a drought destocking requirement. There is an average stocking rate of an AE to about 10 ha, which gives a utilisation rate of 25-30%.

Calves are weaned at 8-9 months and females receive urea blocks during the dry season.

The pasture and herd simulations are based on the historical climate sequence of 1985-2005 for both the baseline and scenarios. The starting land condition is B condition as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003). The herd baseline mortality rate is 3% although this can increase when animals are in poor condition.

The model enterprise is assumed to have a $0 starting cash balance, no debt and no ongoing capital development costs to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.4.1.2 Scenario assumptions for the Western Queensland (Longreach) case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the Western Queensland case study.

1. Improved pasture: legume + improved grass

- All of the property is oversown to legumes.
- Seasonal decline in protein is much less because of legumes.
- Digestibility does not decline as quickly in response to the oversown legume.
- Breeder numbers increased by about 100 in response to additional forage growth i.e. higher carrying capacity.
- Investment costs of $30/ha or $450,000.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal but assumes $200/tonne cost landed on the property.
- Fed to all weaners at 0.3 kg, 0.4 kg for 1-2 year olds and 0.5 kg/head/day to all older animals between May and November.
- Some extra labour is required for feeding out protein.

3. Irrigated forage oats

- 200 ha of irrigated forage oats receiving 80 kg N per hectare.
- Target market of 500 kg steers by 24 months of age i.e. steers on oats over winter to reach target weight in Sept/Oct.
- All weaner and yearling steers go on to irrigated oats when it becomes available for grazing (usually in April/May after sowing in March).
- Capital costs of development and irrigation approximately $5000/ha or $1m and this a cost incurred to the overall balance sheet at the start of the simulation run and the debt paid off over time using profits.

4. Improved breeder genetics

- The weaning rate is lifted by 5 percentage points over the baseline.
- Breeder number not actively increased but AEs increases slightly in response to higher weaning rates.
- No change to growth of animals.

5. Genetic growth efficiency increase

- Increase in growth efficiency of all animals (not an increase in frame size).
- Positively affects growth of steers, heifers and cows so both liveweight gain and weaning rate increase.
- No deliberate increase in breeder number but AEs increase slightly in response to improved weaning rate.

6. Rumen modifier

- Assumes normal seasonal decay in digestibility slows slightly and minimum digestibility increases by three percentage points (43 to 46% digestibility).
- This has a positive effect on growth of all animals improving weaning and liveweight gain. As a result herd numbers increase slightly but there is no deliberate increase in breeder numbers.

7. Combined scenarios

- Assumes no change in feed base (no improved pasture or forage crop) but it combines the breeder genetics, growth efficiency, rumen modifier and cheap protein scenarios.
- No deliberate increase in breeder number but numbers can increase in response to improved productivity.

4.3.4.1.3 Summary of results for the Western Queensland (Longreach) case study

Table 9 shows a summary of the main production, economic and resource management variables for the baseline and scenarios for Western Queensland (Longreach).

The baseline scenario produced a modest profit, in line with benchmarking estimates for the region (e.g. McCosker *et al.* 2010). The target market for this case study was trade steers with a target weight of 400 kg by 24 months of age. This was achieved in most years.

Average utilisation rates were 27% and this allowed land to remain in the starting B condition for the 20 year simulation run.

All improvement scenarios resulted in increased productivity and profitability over the baseline though there were significant differences amongst the scenarios.

The improved pasture (legume) scenario resulted in a significant change in animal numbers as the increased pasture productivity allowed an increase in carrying capacity of 25% from 1500 AEs to 1800 AEs. Profit for this scenario was relatively high as a result of increased animal numbers and a moderate increase in both weaning rate and liveweight gain. Because of increased growth rates the target weight was lifted to 450 kg with animals reaching this weight by 21-24 months. The marginal return on the capital invested in oversowing with legumes was 30%.

To take best advantage of the irrigated oats in winter and spring steers were taken from native pasture in April and fattened to 500 kg by September or October i.e. no later than 2 years old. With a significant number of animals able to utilise oats, carrying capacity could be lifted by 20% without causing any deterioration in land condition. Capital costs were relatively high ($1.0m) and the increase in profit of approximately $24,000 per year meant that the marginal rate of return on capital investment was low at 2%.

An increase in the weaning rate of 5 percentage points in the improved breeder genetics scenario led to modest increases in profit because the outcome was an increase in calf numbers rather than any impact on the growth of animals in the herd.

In contrast, the three scenarios that increased animal growth (genetic gains in growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) all had more significant effects on productivity and profitability because both weaning rate and growth rates were higher than in the baseline scenario. However, these gains were not as great in relative terms as in some other regions because the baseline liveweight gains in winter and spring on this better clay soil country were better than most other regions, where animals lost or just maintained weight in winter/spring. AEs went up by 5-10% in these scenarios.

The combined scenarios of better breeder genetics, increased growth efficiency through genetic gain, a cheap protein source and improved digestibility via a rumen modifier resulted in much increased profitability. This was due to both a highly productive herd with weaning rates at 76% and annual liveweight gains at 186 kg/head. Some of the additional profit was also due to a modest increase in herd numbers (15%) and it was evident that this increased utilization was shifting land condition towards B/C by the end of the 20 year run.

Compared with the baseline total methane production increased by less than 10% for all scenarios with the exception of the improved pasture scenario, which showed a 25% increase. Methane intensity was lower for all scenarios than in the baseline, with the reductions in the order of 10% for all scenarios except the combined scenario, which declined by 21%.

Table 9. Summary table of mean production, economic and resource management projections for the Western Queensland (Longreach) case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated oats	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Animal equivalents (AE)	1502	1890	1599	1638	1520	1567	1662	1710
Gross margin per AE ($)	167	201	172	184	185	175	189	220
Gross margin per ha ($)	17	25	18	20	19	18	21	25
Profit ($)*	148,319	275,599	173,135	172,668	179,362	171,070	212,492	274,483
Percentage of years in which a loss occurred (%)	15	15	15	20	15	15	15	10
Marginal return on scenario capital investment (%)		30		2				
Turnoff (head)	543	650	586	605	587	575	617	699
Beef turned off (kg)	214,924	283,388	235,362	303,823	234,217	229,877	256,773	300,492
Beef turned off per AE (kg)	143	150	147	186	154	147	155	176
Weaning rate (%)	64	69	68	66	69	67	71	76
Weaning weight (kg)	197	206	199	205	198	200	205	208
Liveweight gain (kg/hd/yr)[+]	143	169	150	218	144	156	159	186
Utilisation (%)	27.3	26.4	24.2	29.2	29.0	23.4	25.3	25.5
Land condition (ABCD)	A/B	B	A	B/C	B	A	A/B	A/B
Methane (kg/ha/yr)	9.0	11.3	9.5	9.9	9.2	9.1	9.9	9.9
Methane intensity (g/kg)	630	597	605	490	592	595	575	496

*Profit before tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.5 North Queensland

4.3.5.1 North Queensland (Charters Towers) case study

4.3.5.1.1 Assumptions for baseline

The case study enterprise is built on a 30,000 ha property of which 27,000 ha are available for grazing – the balance being undeveloped country without adequate water distribution or inaccessible country. Grazing is based on native pastures (bluegrasses, golden beard grass, speargrass, wiregrass) on mostly moderately productive soils. The baseline herd size is 2900 AE consisting of breeding cows and growing and fattening heavier steers for the meatworks in Townsville. The target is to reach Jap Ox markets (580 kg liveweight or approximately 300 kg carcass weight by 42 months of age). Other turnoff includes heifers that are surplus to self-replacement requirements and a proportion of the breeders that are culled early for fertility, culled for age (10 years) or sold as a drought destocking requirement. There is an average stocking rate of an AE to about 8 ha, which gives a utilisation rate of 25-30%.

Calves are weaned at 8 months and females receive urea blocks during the dry season.

The pasture and herd simulations are based on the historical climate sequence of 1985-2010 for both the baseline and scenarios. The starting land condition is B condition as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003). The herd baseline mortality rate is 3% although this can increase when animals are in poor condition.

The model enterprise is assumed to have a $0 starting cash balance, no debt and no ongoing capital development costs to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.5.1.2 Scenario assumptions for the northern Queensland case study

The following brief notes cover the particular assumptions that underpin the seven scenarios that have been explored for the northern Queensland case study.

1. Improved pasture: legume + improved grass

- Most of the property is oversown to legumes and about one third of the property has sown grass.
- Seasonal decline in protein is much less because of legumes.
- Digestibility does not decline as quickly in response to legumes and improved grasses.
- Breeder numbers increased by about 200 in response to additional forage growth i.e. higher carrying capacity.
- Investment costs of $25/ha or $750,000. The capital costs of establishing the pasture are added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal but assumes $200/tonne cost landed on the property.

- Fed to all weaners at 0.3 kg, 0.4 kg for 1-2 year olds and 0.5 kg/head/day to all older animals between May and November.
- Some extra labour required for feeding out protein.

3. Irrigated forage sorghum

- 250 ha of irrigated forage sorghum receiving 80 kg N per hectare.
- All yearling and older steers go on to forage sorghum when it becomes available for grazing (usually in November after sowing in October).
- Because steers are finishing earlier breeder number are increased to keep AEs similar to the baseline.
- Capital costs of development and irrigation approximately $5000/ha or $1.25m and this a cost incurred to the overall balance sheet at the start of the simulation run and the debt paid off over time using profits.

4. Improved breeder genetics

- Weaning rate lifted by 5 percentage points over the baseline.
- Breeder number not actively increased but AEs increases slightly in response to higher weaning rates.
- No change to growth of animals.

5. Genetic growth efficiency increase

- Increase in growth efficiency of all animals (not an increase in frame size).
- Positively affects growth of steers, heifers and cows so both liveweight gain and weaning rate increases.
- No deliberate increase in breeder number but AEs increase slightly in response to improved weaning rate.

6. Rumen modifier

- Assumes normal seasonal decay in digestibility slows slightly and minimum digestibility increases by three percentage points (43 to 46% digestibility).
- This has a positive effect on growth of all animals improving weaning and liveweight gain. As a result herd numbers increase slightly but there is no deliberate increase in breeder numbers.

7. Combined scenarios

- Assumes no change in feed base (no improved pasture or forage crop) but it combines the breeder genetics, growth efficiency, rumen modifier and cheap protein scenarios
- No deliberate increase in breeder number but overall herd size (AEs) can increase in response to higher weaning rates and improved cow condition.

4.3.5.1.3 Summary of results for the North Queensland case study

Table 10 shows a summary of the main production, economic and resource management variables for the baseline and scenarios for North Queensland.

The baseline scenario produced a modest profit, in line with benchmark estimates for the region (e.g. McCosker *et al.* 2010). The target market for this case study was

heavy steers for export slaughter. Jap Ox specification is achieved by 42 months in good seasons only.

Average utilisation rates were 27% and this allowed land to remain in the starting A/B condition for the 25 year simulation run.

All improvement scenarios resulted in increased productivity and profitability over the baseline though there were significant differences amongst the scenarios.

Only the improved pasture scenario resulted in a significant change in animal numbers as the increased pasture productivity allowed an increase in carrying capacity. Profit for this scenario was relatively high as a result of increased animal numbers and a moderate increase in both weaning rate and liveweight gain. Animals reached a target liveweight of 580 kg in all but a few years and this was achieved by 36 months of age in about half of the years. The marginal return on the capital invested in oversowing with legumes and grasses was 23%, which is a good return on investment. This does assume reliable establishment within a few years, which isn't always the case with current technology.

The irrigated forage sorghum scenario allowed a significant re-structuring of the herd as all steers reached Jap Ox specifications by 2.5 years of age. Without an additional cohort of steers, breeder numbers could be increased and overall herd numbers increased by about 5% because of the high carrying capacity of the forage sorghum (2-3 AE/ha). However, capital costs were high ($1.25m) and the servicing of the debt associated with that combined with high operating costs resulted in a slight decrease in profit compared with the baseline. As a consequence marginal return on investment was -1%.

Increased weaning rates of 5 percentage points in the improved breeder genetics scenario led to modest increases in profit because the outcome was an increase in calf numbers rather than any impact on the growth of animals in the herd.

In contrast, the three scenarios that increased animal growth (genetic gains in growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) all had more significant effects on productivity and profitability because both weaning rate and growth rates were higher than in the baseline scenario. In particular, the cheap protein supplement resulted in a significant improvement in profit. Interestingly this was more on the back of much improved weaning rates than improved liveweight gains (24 kg/h/year). The protein supplement allowed cows to maintain a good body condition score and high re-conception rates. A combination of herd numbers increasing slightly and larger, more productive animals (AEs 9% higher than the baseline) meant that land condition was trending down to B condition by the end of the 25 year simulation run.

The combined scenarios of better breeder genetics, increased growth efficiency through genetic gain, a cheap protein source and improved digestibility via a rumen modifier resulted in much increased profit (116%) while maintaining herd size similar to the baseline scenario. This combination of scenarios resulted in a highly productive herd with weaning rates at 75% and annual liveweight gains at 180 kg/head. Interestingly, despite high profits there were actually more years (24%) where a loss was recorded. This was largely driven by large sale numbers in the year prior to a loss where two cohorts of animal reached sale weight.

Compared with the baseline total methane production increased by less than 10% for all scenarios with the exception of the improved pasture scenario which showed a

20% increase. Methane intensity was lower for all scenarios than in the baseline, with the reductions in the order of 10-15% for all scenarios except the combined scenario, which declined by 24%.

Table 10. Summary table of mean production, economic and resource management projections for the North Queensland (Charters Towers) case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated forage sorghum	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Adult equivalents (AE)	2901	3476	3170	3136	2980	3014	3122	3184
Gross margin/AE ($)	125	153	147	123	133	135	143	174
Gross margin/ha ($)	12.0	17.6	15.3	13.0	13.1	13.4	14.8	18.3
Profit ($)*	165,607	335,255	259,659	151,999	199,790	209,797	245,362	358,693
Percentage of years in which a loss occurred (%)	16	8	12	24	12	12	12	24
Marginal return on scenario capital investment (%)		23		-1				
Turnoff (head)	751	983	905	914	821	801	869	982
Beef turned off (kg)	331,091	452,459	413,481	436,717	354,421	361,482	388,432	466,981
Beef turned off per AE (kg)	114	130	132	139	119	120	124	147
Weaning rate (%)	58	69	69	62	63	61	64	76
Weaning weight (kg)	196	203	207	208	195	197	203	212
Liveweight gain (kg/hd/year)[+]	127	154	151	203	127	143	144	180
Utilisation (%)	27	24	28	26	28	28	29	28
Land condition	A/B	A	A/B	A	A/B	A/B	B	A/B
Methane (kg/ha/yr)	8.2	10.0	8.9	8.9	8.5	8.3	8.7	8.8
Methane intensity (g/kg)	748	668	652	625	723	696	677	570

*Profit before income tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.6 Southern, South-East and Central Queensland

4.3.6.1 Southern Queensland (Maranoa) case study

This case study was centred on the Maranoa region of southern Queensland. In areas dominated by woodlands and native pastures, local beef producing enterprises are generally oriented towards turning off store animals for finishing elsewhere. In areas with better soils, especially where there is significant scope for pasture development (e.g. buffel grass), the market orientation is more towards on-farm finishing of heavier steers for slaughter (Partridge *et al.* 1994). The Maranoa was one of the case study regions covered by the NGS project – however, following further consultation with local extension specialists a decision was taken to modify the baseline case study for this scoping study.

4.3.6.1.1 Assumptions for baseline

The case study enterprise is built on a 12,000 ha property of which 9,600 ha is presently accessible to grazing, the balance largely being remnant woodland with some further development potential. The grazing area is comprised of a mixture of undeveloped and partially developed native pastures and some developed buffel grass pastures. The baseline enterprise is presently carrying a self-replacing herd of approximately 1650 AEs producing feeder steers and heifers reaching ~400 kg/head at 18 months. Other turnoff includes heifers that are surplus to self-replacement requirements, aged cows, and a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement. The overall average carrying capacity of the property under its present state of development is approximately one AE to 5-6 ha.

The pasture and herd simulations are based on the historical climate sequence of 1985-2010 for both the baseline and scenarios. The starting land condition is A/B condition ('very good', 'good') as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003).The overall utilisation rate of pasture is predicted to be about 25-30% under the baseline grazing system. The herd baseline mortality rate is 2% although this can increase when animals are in poor condition.

The model enterprise is assumed to have no debt at the commencement of each scenario run, and also no on-going requirements for capital expenditure to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.6.1.2 Scenario assumptions for the Southern Queensland (Maranoa) case study

The following brief notes cover the particular assumptions that underpin the seven scenarios that have been explored for the Maranoa (Mitchell) case study.

1. Improved pasture: legume and grass mix

- The accessible grazing area is oversown to legumes and approximately 50% of the area has sown grass.
- Seasonal decline in available protein content of pastures is much less due to the legumes.
- Pasture digestibility does not decline as quickly as for native pastures in response to both the legumes and sown grasses.

- Carrying capacity is increased by 100 breeders due to the increased forage.
- A capital investment of $50/ha or $500,000 is required. The capital costs of establishing the pasture are added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal at a cost of $200/tonne landed on the property.
- The new protein product is fed to all weaners at 0.3 kg/head/day, at 0.4 kg/head/day for 1-2 year old animals and at 0.5 kg/head/day for all older animals between May and November.
- Additional labour is required to feed out the protein supplement.

3. Irrigated oats

- 150 ha of arable land is sown to oats in March and managed under irrigation.
- The crop receives additional N applied at the rate of 80 kg/ha.
- The crop is grazed by all weaner and older steers when it becomes available for grazing (usually around May following March sowing).
- The oat crop lasts until October/November and provides high quality feed during the winter-spring period that is usually characterised by relatively low animal growth.
- The steers are finished to Jap Ox weight rather than sold as trade steers in March-May.
- Breeder numbers were held constant in the anticipation that in some years there would be an extra cohort of males i.e. older than 2 years to reach Jap Ox target weight.
- The capital cost of establishing the pasture, plant and machinery and installing the irrigation infrastructure is $5,000/ha or $750,000 which is added to the overall balance sheet at the commencement of the simulation and the debt is serviced from available cash flows over time.

4. Improved breeder genetics

- Fertility enhancement is assumed to lead to an increase in weaning rates of 5% above the baseline.
- The breeding herd is not increased above the baseline although the total AEs carried increases slightly due to the increased weaning rate.
- It is assumed that the growth rate of animals is not changed over the baseline performance levels.

5. Genetic growth efficiency increase

- Genetic improvement leads to increased growth rate efficiency of all animals in the herd, but no change to frame size.
- The growth rate of steers, heifers and cows is positively affected and liveweight gain and weaning rate both increase over baseline performance levels.
- The breeding herd is not increased above the baseline although the total AEs carried increases slightly due to the increased weaning rate.

6. Rumen modifier

- The technology is assumed to slightly slow the normal seasonal decay in forage digestibility.
- The minimum digestibility is assumed to increase by 3 percentage points (increase from 45% to 48% digestibility).
- The technology has a positive effect on the growth of all animals leading to improvements in liveweight gain and weaning rates.
- As a result of the increased efficiency, the total herd numbers increase slightly over the baseline numbers although there is no deliberate increase in breeder numbers over the baseline herd.

7. Combined scenario

- This scenario combines the elements of the breeder fertility enhancing genetics, genetic growth efficiency, rumen modifier and cheap protein supplement scenarios (as above).
- It does not include the elements of the sown pastures and/or dryland or irrigated forage crops scenarios – therefore, there is no change in the underlying feed base.
- As a result of the increased efficiency, the total herd numbers increase slightly over the baseline numbers although there is no deliberate increase in breeder numbers over the baseline herd.

4.3.6.1.3 Summary of results for the Southern Queensland (Maranoa) case study

Table 11 shows a summary of the main production, economic and resource management variables for the baseline and scenarios for the Maranoa (Mitchell).

We initially had some difficulties in modelling animal production in this region. This was due to autumn and winter rainfall producing in some years significant amounts of pasture growth. This green growth in the middle of the year led to higher than expected levels of animal growth in autumn and winter in some years. Much of this was a result of using a generic GRASP model parameterisation across all regions of northern Australia which had a setting for the nitrogen % at which pasture growth stops that was too low for this region. This single parameter was set to a more appropriate level for this region and this corrected most of the issues. Another contributing factor is that any new pasture growth in winter in this region would be fairly quickly frosted off, reducing its quality to a greater degree than simulated in the animal production model.

In the baseline modelling, animal production on average was still higher in autumn and winter for most other regions but this is fairly realistic. The baseline scenario produced a modest profit, in line with benchmarking estimates for the region (e.g. McCosker *et al.* 2010). Average utilisation rates were 27% and this allowed land to remain in the starting A/B condition for the 25-year simulation run.

All improvement scenarios resulted in increased productivity and profitability over the baseline though there were significant differences amongst the scenarios.

Only the improved pasture scenario resulted in a significant change in animal numbers as the increased pasture productivity allowed an increase in carrying capacity. Profit for this scenario was relatively high largely due to the increased

carrying capacity, though modest increases in weaning rate and liveweight gain were also contributing factors. All animals reached their target weight of 400 kg by 18 months of age. This improved pasture scenario also included introduced grasses as well as legumes and capital costs associated with establishment were higher than for aerial oversowing of native pastures with a legume. The marginal return on the capital invested in oversowing with legumes and grasses was 21%, which like North Queensland is a good return on investment but it assumes reliable establishment, which is a constraint with current technologies and management approaches to pasture establishment.

The irrigated forage oats scenario allowed a significant re-structuring of the herd to produce Jap Ox steers generally by 2 years of age though in about 25% of years steers had to be held over until they were close to 30 months of age to reach the target liveweight. As a consequence, breeder numbers were held at a similar level to the baseline to allow for this additional cohort in some years. Overall AEs increased by about 10% though turnoff numbers remained similar to the baseline scenario but of course they were much heavier animals i.e. kg of beef sold was much higher for the same turnoff number. Profit increased modestly but at a low marginal return on capital invested.

For all the scenarios, the increase in productivity and profitability compared with the baseline was proportionally lower than for other regions, largely due to the fact that the baseline productivity for this region was already relatively high i.e. weaning rate of 72% and annual liveweight gain of 162 kg/head. Baseline nutrition was better through the autumn and winter and so improvements in protein or digestibility had less of a benefit.

Compared with the baseline total methane production increased by around 5% for all scenarios with the exception of the improved pasture scenario which showed a 20% increase. Methane intensity was similar to or slightly lower than the baseline for all scenarios. Compared with other regions the relative increase in productivity in the scenarios compared with the baseline was much lower and this flowed through to smaller efficiency gains in methane intensity.

Table 11. Summary table of mean production, economic and resource management projections for the Southern Queensland (Maranoa) case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated oats	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Adult equivalents (AE)	1659	1953	1739	1798	1687	1696	1718	1782
Gross margin/AE ($)	220	237	221	213	228	226	225	227
Gross margin/ha ($)	30	38	32	31	32	32	32	34
Profit ($)*	215,996	319,101	234,853	225,346	235,272	234,280	235,525	253,929
Percentage of years in which a loss occurred (%)	12	0	8	12	8	12	8	8
Marginal return on scenario capital investment (%)		21		1				
Turnoff (head)	678	791	701	669	716	699	696	722
Beef turned off (kg)	288,870	337,586	305,074	332,023	301,332	300,827	302,916	318,033
Beef turned off per AE (kg)	174	173	175	185	179	177	176	179
Weaning rate (%)	72	77	75	73	77	74	74	77
Weaning weight (kg)	226	225	221	227	225	224	225	227
Liveweight gain (kg/hd/year)[+]	162	172	175	256	161	178	175	198
Utilisation (%)	26.3	26.8	27.2	27.0	26.9	26.3	27.2	27.2
Land condition (ABCD)	B	B	B	B	B	B	B	B
Methane (kg/ha/yr)	12.1	14.3	12.7	12.9	12.3	12.1	12.4	12.6
Methane intensity (g/kg)	501	507	498	474	490	482	490	477

*Profit before tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.6.2 South-East Queensland (Burnett) case study

Although the Burnett region of south-eastern Queensland is recognised to comprise a significant number of specialist beef cattle enterprises, it was not actually included in the scope of the NGS project case studies (Table 1). To that end, a case study enterprise for this region has been constructed based around a breeding enterprise seeking to turn off heavier steers to north Asian markets - this being a typical production and marketing orientation for the region (MacLeod and McIntyre 1997), although it is recognised that many enterprises, particularly those centred on less productive land types (e.g. sandy granite 'forest' country), may be more likely to turn off light steers for finishing elsewhere.

4.3.6.2.1 Assumptions for baseline

The case study enterprise is built on a 7,000 ha property of which 6,300 ha are presently accessible for grazing – the balance being heavily timbered woodland supporting minimal pasture biomass. The accessible grazing land is comprised largely of native pasture with a small amount of pasture development on better soils (e.g. buffel grass on heavier clays and alluvial soils). The enterprise typically runs 850 breeding cows and seeks to turn off heavy steers within 42 months, giving a total baseline herd of 1600 AE. Other turnoff includes heifers that are surplus to self-replacement requirements, aged cows, and a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement.

The pasture and herd simulations are based on the historical climate sequence of 1985-2010 for both the baseline and scenarios. The starting land condition is B condition ('good') as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003). The overall utilisation rate of pasture is predicted to be about 30% under the baseline grazing system. The herd baseline mortality rate is 2% although this can increase when animals are in poor condition.

The model enterprise is assumed to have no debt at the commencement of each scenario run, and also no on-going requirements for capital expenditure to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.6.2.2 Scenario assumptions for the South-East Queensland (Burnett) case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the south-east Queensland (Burnett) case study.

1. Improved pasture: legume and grass mix

- All of the accessible grazing areas are oversown to legumes. Seasonal decline in available protein content is much less due to the legumes.
- Pasture digestibility does not decline as quickly as for native pastures in response to oversown legumes.
- Carrying capacity is increased by 100 breeders due to the increased forage productivity.
- The capital cost of oversowing legumes is $25/ha or $157,500. The capital costs of establishing the pasture are added to the overall balance sheet at the

start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal at a cost of $200/tonne landed on the property.
- The new protein product is fed to all weaners at 0.3 kg/head/day, at 0.4 kg/head/day for 1-2 year old animals and at 0.5 kg/head/day for all older animals between May and November.
- Additional labour is required to feed out the protein supplement.

3. Dryland oats

- 300 ha of arable land is sown to a dryland oat crop.
- The crop receives additional N supplied at the rate of 20 kg/ha.
- The area sown to crop remains fallow between crops.
- The crop is grazed by all weaner and older steers when it becomes available for grazing (usually around May following March sowing).
- Because steers are finishing earlier than under baseline conditions, the herd structure changes (one less male cohort) and breeder numbers are increased to 1050, although total AEs remain similar to the baseline.
- The oat crop lasts until October/November and provides high quality feed during the winter-spring period that is usually characterised by poor animal growth.
- The capital cost of establishing the pasture (non-irrigated), plant and machinery and supporting infrastructure is $1,000/ha or $300,000 which is added to the overall balance sheet at the commencement of the simulation and the debt is serviced from available cash flows over time.

4. Irrigated oats

- 200 ha of arable land is sown to oats in March and managed under irrigation.
- The crop receives additional N applied at the rate of 80 kg/ha.
- The crop is grazed by all weaner and older steers when it becomes available for grazing (usually around May following March sowing).
- The oat crop lasts until October/November and provides high quality feed during the winter-spring period that is usually characterised by poor animal growth.
- The steers return to the native pastures in November for the wet season or until they are finished.
- Steers are finished earlier (to 36 months old) thereby changing the age class structure of the steer herd and hence the structure of the whole herd. Along with the intensive use of the irrigated land freeing up some of the other pastures to grazing by other classes, and the loss of one steer cohort, the breeding herd is increased to 1050 animals although the total AEs are similar to the baseline.
- The capital cost of establishing the pasture, plant and machinery and installing the irrigation infrastructure is $5,000/ha or $1.0m which is added to the overall balance sheet at the commencement of the simulation and the debt is serviced from available cash flows over time.

5. Improved breeder genetics

- Fertility enhancement is assumed to lead to an increase in weaning rates of 5 percentage points above the baseline.
- The breeding herd is not increased above the baseline (~850 head) although the total AEs carried increases slightly due to the increased weaning rate.
- It is assumed that the growth rate of animals is not changed over the baseline performance levels.

6. Genetic growth efficiency increase

- Genetic improvement leads to increased growth rate efficiency of all animals in the herd, but no change to frame size.
- The growth rate of steers, heifers and cows is positively affected and liveweight gain and weaning rate both increase over baseline performance levels.
- The breeding herd is not increased above the baseline (~850 head) although the total AEs carried increases slightly due to the increased weaning rate.

7. Rumen modifier

- The technology is assumed to slightly slow the normal seasonal decay in forage digestibility.
- The minimum digestibility is assumed to increase by 3 percentage points (increase from 45% to 48% digestibility).
- The technology has a positive effect on the growth of all animals leading to improvements in liveweight gain and weaning rates.
- As a result of the increased efficiency, the total herd numbers increase slightly over the baseline numbers although there is no deliberate increase in breeder numbers over the baseline herd (850 breeders).

8. Combined scenarios

- This scenario combines the elements of the breeder fertility genetics, genetic growth efficiency, rumen modifier and cheap protein supplement scenarios (as above).
- It does not include the elements of the sown pastures and/or dryland or irrigated forage crops scenarios – therefore, there is no change in the underlying baseline feed base.
- As a result of the increased efficiency, the total herd numbers increase slightly over the baseline numbers although there is no deliberate increase in breeder numbers over the baseline herd (850 breeders).

4.3.6.2.3 Summary of results for the South-East Queensland case study

The projections of the main production, economic and resource indicator variables from the simulation runs for the baseline and scenarios are summarised in Table 12.

The baseline scenario for the case study enterprise produced a modest level of profit, which is consistent with other recent benchmarking estimates for this region (e.g. McCosker *et al.* 2010). The target market for this particular case study is heavy steers that have met the finish criteria for the Japan Ox market (approximately 580 kg liveweight to achieve a minimum carcase weight of ~300 kg). This target weight was achieved by 42 months in all but two years of the 25 year simulation, and in a few

years of the simulation the target weight was reached by one age cohort earlier at 36 months.

Average pasture utilisation rates were only a little over 30%, and this allowed the grazing land to remain in the starting B (good) condition for the whole 25 year simulation run.

Each of the improvement scenarios presents an increased average level of productivity and profitability relative to the baseline. Moreover, the proportion of years in which projected net income was negative was reduced in all cases relative to the baseline. Nevertheless, there were significant differences between the various scenarios.

Only the improved pasture scenario involved a significant change in animal numbers and herd composition as the increased pasture productivity directly facilitated an increase in herd numbers. The profit increase for this scenario was relatively high as a direct result of the increased animal numbers carried and turned off and also a moderate increase in both calf weaning rates and animal growth rates (LWG). The rate of return on investment was high (69%) and much greater than for all other regions other than central Queensland.

Both the dryland and irrigated oats forage improvement scenarios provided an opportunity for sale animals to reach the relevant target market weights at an earlier age of approximately 24 months. This occurs because weaner and young steers were able to maintain growth at 0.8 to 1.0 kg/head/day during the winter and spring months compared with growth rates that are typically at or just above maintenance on native grasses. The resulting absence of the need to carry an older cohort of steers in the herd permitted a change in the herd structure with approximately 200 more breeders being carried in comparison with the baseline scenario. However, because there are some significant capital and maintenance costs associated with introducing forage crops into the grazing system - especially those based on irrigation - the gain in profit was not as high as for the improved pasture scenario. The irrigated oats scenario required an initial capital investment of $1,000,000 ($5000/ha) which took some years to pay off (interest rate of 7% on debt).

Increasing calf weaning rates by 5 percentage points in the scenario centred on improved breeder fertility due to genetic gain led to relatively modest increases in profit. This is because the projected outcome was based on an increase in calf numbers rather than any impact on the average growth of animals in the herd.

In contrast, the three scenarios that increased animal growth (genetic gains in growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) all induced more significant and positive effects on herd productivity and profitability. This occurs because both the calf weaning rate and animal growth rates were higher than was projected for the baseline scenario. These three scenarios allowed target threshold sale weights of 580 kg to be achieved by about 36 months of age (range 28-42 months) in the majority of years – thereby also altering the herd structure to carry more breeding animals.

The combined scenario that encompassed a combination of enhanced fertility through improved breeder genetics, increased animal growth efficiency through genetic gain, access to a cheap protein source and improved digestibility of forages via a rumen modifier produced a much higher gain in enterprise profit while maintaining the overall herd size at around the same size as for the baseline scenario. An interesting aspect of the combined scenario is the largely additive

nature of the profitability of the individual component scenarios - $98,000 cumulative gain in profit from the combined scenarios compared with the baseline as opposed to $129,000 gain in profit compared with the baseline from adding the gains of the individual scenarios.

Across all scenarios the average pasture utilisation rate was fairly constant at around 30% allowing all scenarios to remain close to their starting land condition of B (good).

There was little variation in projected average methane production per hectare across the different scenarios despite their different animal outputs per hectare. This result arises because the scenarios that promoted enhanced growth rates of animals also resulted in less methane generation per unit of gain. For the combined and forage oats scenarios this represented about a 20% reduction in methane per unit of gain compared with that of the baseline scenario.

Table 12. Summary table of mean production, economic and resource management projections for the South-East Queensland (Burnett) case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Dryland oats	Irrigated oats	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Adult equivalents (AE)	1697	1859	1697	1723	1672	1725	1701	1734	1701
Gross margin/AE ($)	162	207	195	192	195	169	175	182	219
Gross margin/ha ($)	39	55	47.2	48	46	42	43	45	53
Profit ($)*	127,335	236,266	174,811	172,965	154,243	144,126	151,825	168,623	225,189
Percentage of years in which a loss occurred (%)	16	8	12	12	4	8	12	12	8
Marginal return on scenario capital investment (%)		69		15	3				
Turnoff (head)	512	585	550	622	638	542	532	548	575
Beef turned off (kg)	240,236	281,219	267,223	302,443	313,225	250,758	253,771	263,945	284,644
Beef turned off per AE (kg)	142	151	157	173	187	145	149	152	167
Weaning rate (%)	69	72	75	70	72	74	72	77	81
Weaning weight (kg)	212	214	222	216	218	211	215	232	230
Liveweight gain (kg/hd/year)[+]	140	168	173	216	248	140	156	158	197
Utilisation (%)	31	32	30	31	29	31	30	31	29
Land condition	B	B	B	B	B	B	B	B	B
Methane (kg/ha/yr)	21.3	23.8	21.4	22.3	21.1	21.8	20.9	21.5	20.7
Methane intensity (g/kg)	619	595	562	515	474	608	575	570	510

*Profit before tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.3.6.3 Central Queensland (Duaringa) case study

This case study was centred on the Duaringa region which lies roughly between Rockhampton on the coast and Emerald in the Central Highlands. Production conditions vary considerably within this region depending on the available land resources and pasture condition. In poorly endowed areas, especially with timber regrowth constraints, production is commonly geared to breeding herds turning off lighter steers for finishing on grass or grain elsewhere. In more favourably endowed areas (e.g. with extensive brigalow soils and sown pasture potential) production is frequently based on breeding and sale of heavy slaughter steers for export.

4.3.6.3.1 Assumptions for baseline

The case study enterprise is built on a 12,000 ha property of which 11,000 ha are presently accessible for grazing – the balance being more inaccessible or heavily timbered remnant woodland. There is a mixture of cleared country with some eucalypt (box, narrow leaf ironbark) woodland with largely native pastures on moderate productivity soils. The enterprise runs 2300 AE consisting of breeding cows and growing steers which are turned off for the trade market at 450 kg and approximately 30 months old. Other turnoff includes heifers that are surplus to self-replacement requirements, aged cows, and a proportion of the breeders that are culled earlier for fertility or as a drought destocking requirement. Calves are weaned at 6-7 months and females receive urea during the dry season. Baseline mortality is 3% but increases if animals are in poor condition.

Carrying capacity is an AE to 4.5 ha to achieve a sustainable utilisation rate of around 25%.

The pasture and herd simulations are based on the historical climate sequence of 1965-1990 for both the baseline and scenarios. The starting land condition is A/B condition as rated against a four-category 'ABCD' land condition rating system that is commonly employed by State land management agencies in northern Australia (e.g. Chilcott *et al.* 2003). The overall utilisation rate of pasture is predicted to be about 27% under the baseline grazing system. The herd baseline mortality rate is 2% although this can increase when animals are in poor condition.

The model enterprise is assumed to have no debt at the commencement of each scenario run, and also no on-going requirements for capital expenditure to maintain the baseline management regime. Any debt that is incurred under any particular scenario carries a 7% interest rate.

4.3.6.3.2 Scenario assumptions for the Central Queensland (Duaringa) case study

The following brief notes cover the particular assumptions that underpin the scenarios that have been explored for the central Queensland case study.

1. Improved pasture: legume + improved grass

- All of the accessible grazing area is oversown to legumes.
- Seasonal decline in protein is much less because of legumes.
- Digestibility does not decline as quickly in response to legumes.
- Breeder numbers increased by about 100 in response to additional forage growth i.e. higher carrying capacity.

- The capital cost of oversowing legumes is $25/ha or $275,000. The capital costs of establishing the pasture are added to the overall balance sheet at the start of the simulation and the debt is serviced from available cash flows over time.

2. Cheap protein

- A source of protein is provided of the same quality as cottonseed meal but assumes $200/tonne cost.
- Fed to all weaners at 0.3 kg, 0.4 kg for 1-2 year olds and 0.5 kg/head/day to all older animals between May and November.
- Some extra labour required for feeding out protein.

3. Irrigated forage sorghum

- 150 ha of irrigated forage sorghum receiving 80 kg N per hectare
- All weaner and yearling steers go on to forage sorghum when it becomes available for grazing (usually in November after sowing in October)
- Because steers are finishing earlier breeder number are increased to keep AEs similar to the baseline.
- Capital costs of development and irrigation approximately $5000/ha or $750,000 and this is a cost incurred to the overall balance sheet at the start of the simulation run and the debt paid off over time using profits.

4. Improved breeder genetics

- Weaning rate lifted by 5% over baseline
- Breeder number not actively increased but AEs increases slightly in response to higher weaning rates
- No change to growth of animals

5. Genetic growth efficiency increase

- Increase in growth efficiency of all animals (not an increase in frame size)
- Positively affects growth of steers, heifers and cows so both liveweight gain and weaning rate increases
- No deliberate increase in breeder number but AEs increase slightly in response to improved weaning rate.

6. Rumen modifier

- Assumes normal seasonal decay in digestibility slows slightly and minimum digestibility increases by three percentage points (43 to 46% digestibility)
- This has a positive effect on growth of all animals improving weaning and liveweight gain. As a result herd numbers increase slightly but there is no deliberate increase in breeder numbers.

7. Combined scenarios

- Assumes no change in feed base (no improved pasture or forage crop) but it combines the breeder genetics, growth efficiency, rumen modifier and cheap protein scenarios
- No deliberate increase in breeder number but numbers can increase in response to improved productivity.

4.3.6.3.3 Summary of results for the Central Queensland (Duaringa) case study

Table 13 shows a summary of the main production, economic and resource management variables for the baseline and scenarios for central Queensland.

The baseline scenario produced a modest profit, in line with benchmarking estimates for the region (e.g. McCosker *et al.* 2010). The target market for this case study was trade steers with a target weight of 450 kg by 30 months of age. This was achieved in about half of the years; in poorer years animals reached weights of about 400 kg at desired time of sale.

Average utilisation rates were 27% and this allowed land to remain in the starting B condition for the 25 year simulation run.

All improvement scenarios resulted in increased productivity and profitability over the baseline though there were significant differences amongst the scenarios.

The improved pasture scenario resulted in a significant change in animal numbers as the increased pasture productivity allowed an increase in carrying capacity. Profitability for this scenario was relatively high as a result of increased animal numbers and a moderate increase in both weaning rate and liveweight gain. Animals reached the target liveweight of 450 kg by 30 months in all years and on average by 27 months. The marginal return on the capital invested in oversowing with legumes and grasses was 55%, which would be considered a reasonable return.

The irrigated forage sorghum scenario allowed a significant re-structuring of the herd as all steers reached their target weight of 450 kg by 18-20 months of age. Without an additional cohort of steers, breeder numbers were able to be increased and overall herd size went up in response to the high carrying capacity of the forage sorghum. However, capital costs were relatively high ($0.75m) and although revenue increased by over $200,000, profitability increased by $47,000 over the baseline due to the relatively high operating costs of irrigated forage crops. As a consequence marginal return on investment was 6%.

Increasing weaning rates by 5 percentage points in the improved breeder genetics scenario led to modest increases in profitability because the outcome was simply an increase in calf numbers rather than any impact on the growth of animals in the herd.

In contrast, the three scenarios that increased animal growth (genetic gains in growth efficiency, a cheap protein source and a rumen modifier that improved digestibility) all had more significant effects on productivity and profitability because both weaning rate and growth rates were higher than in the baseline scenario.

In particular, the cheap protein supplement resulted in a significant improvement in profitability. Interestingly this was more on the back of much improved weaning rates than improved liveweight gains (24 kg/head/year). A combination of herd numbers increasing slightly and larger more productive animals meant that land condition was trending down slightly to B condition by the end of the 25 year simulation run.

The combined scenarios of better breeder genetics, increased growth efficiency through genetic gain, a cheap protein source and improved digestibility via a rumen modifier resulted in much increased profitability (129%). This was due to both a highly productive herd with weaning rates at 79% and annual liveweight gains at 188 kg/head. Some of the additional profit was also due to a slight increase in AEs (8%) though this had only a small flow on impact in terms of utilisation (from 27% in

baseline to 29% in this scenario) and no impact on land condition. Compared with the other scenarios there was a slight increase in the percentage of years in which a loss occurred.

There was up to a 10% increase in total methane production across the different scenarios with the improved pasture scenario showing the greatest increase. Methane intensity was lower in all scenarios with this reduction in intensity near 20% for the irrigated forage sorghum and combined scenarios.

Table 13. Summary table of mean production, economic and resource management projections for the central Queensland (Duaringa) case study baseline and scenarios.

Mean result for simulation run	Baseline	Improved pasture	Cheap protein	Irrigated forage sorghum	Improved reproduction	Improved growth efficiency	Rumen modification	Combined scenarios
Adult equivalents (AE)	2295	2569	2473	2543	2329	2369	2440	2482
Gross margin/AE ($)	128	167	169	138	137	142	148	181
Gross margin/ha ($)	27	39	38	32	29	31	33	41
Profit ($)*	121,293	259,162	243,050	168,347	146,507	161,944	184,724	278,458
Percentage of years in which a loss occurred (%)	8	0	0	0	4	8	0	12
Marginal return on scenario capital investment (%)		56		6				
Turnoff (head)	748	884	905	963	814	803	835	944
Beef turned off (kg)	296,008	355,186	351,085	397,898	312,767	321,190	339,673	387,726
Beef turned off per AE (kg)	129	138	142	156	134	136	139	156
Weaning rate (%)	62	68	70	64	67	66	68	79
Weaning weight (kg)	180	185	189	190	180	182	189	203
Liveweight gain (kg/hd/year)[+]	132	161	160	203	132	148	154	188
Utilisation (%)	27	28	28	28	27	28	28	29
Land condition (ABCD)	B	B	B	B	B	A/B	B	B
Methane (kg/ha/yr)	18.7	21.3	20.2	20.7	19.1	18.8	19.6	19.4
Methane intensity (g/kg)	693	658	633	581	671	644	636	551

*Profit before income tax and assumes no capital costs apart from development scenarios

[+]Liveweight gain of yearling animals (steers and heifers)

4.4   Synthesis across scenarios and regions

4.4.1   Overall confidence in modelling approach and baseline scenarios

This scoping study represents the first significant effort at conceptually developing and constructing an enterprise level model for northern Australia that can simulate herd dynamics and productivity based on fundamental inputs of protein and energy and their role in growth, body condition, reproduction and mortality. There are in place good approaches to simulating herd dynamics and enterprise economics, e.g. Holmes 2002, MacLeod *et al.* 2004, but these earlier approaches have relied on either assumptions of main herd production characteristics or on simple empirical relationships between pasture growth characteristics and liveweight gain and between liveweight gain and weaning and mortality rates. The modelling approach adopted in this study provides more flexibility to explore a wide range of enterprise types and development options, particularly when these impact directly on animal reproduction, nutrition and growth.

In order to explore the implications of different management and development options on the wider production and pasture system, in addition to animal productivity and enterprise returns, the model can simulate the feedback effects of resource use on land condition, soil erosion and methane emissions. These environmental aspects can be integrated to provide an index of environmental impacts. In this scoping study we sought to explore baseline and development options that are sustainable in the long-term rather than merely to test options that might promote short-term profitability but long-term declines in land condition. As such, stock numbers were set to achieve average utilisation rates that maintained or improved land from its starting condition, which for the different regions was A/B, B or C condition, based on the commonly employed 'ABCD' framework (Chilcott *et al.* 2003).

The modelling of baseline enterprises produced results that are realistic in terms of the main production, profit, and resource condition outcomes for beef enterprises in different regions across northern Australia (Table 14). We are a little less confident in the baseline model results for two of the case study regions (Southern Queensland and the Pilbara) when compared with the other regions. The GRASP model that provides the underpinning forage production estimates has not been as well calibrated for the Pilbara region as it has for other regions. When combined with the arid, low productivity and highly variable environment that characterises the Pilbara, this limit on calibration has provided more challenges than for other regions. Nevertheless, the model was able to produce results in animal productivity that are consistent with benchmarking surveys (Stockdale *et al.* 2012, McCosker *et al.* 2010). For Southern Queensland, the greater proportion of years with autumn and winter rainfall compared with other regions meant that pasture growth and animal production in this region was higher through the middle of the year, leading to overall higher weaning rates and annual liveweight gains than for other regions. Although this result is broadly consistent with available survey results and industry data, productivity levels for the baseline case may be on the high side. Consistent with current industry trends, the baseline scenarios produced profit levels that were relatively low, representing 1-3% Return on Assets (RoA). These results assume no outstanding debt (i.e. 100% equity) at the commencement of each simulation and did not include any ongoing capital investment. In the more extensive regions of northern Australia that rely on the live export industry, the average debt held across the region is approximately $1.4m (Gleeson et al. 2012), while for other parts of the northern industry average enterprise debt exceeds $800,000. Servicing these debts would in a number of regions, such as the Kimberley, produce overall negative cash flows. ABARES has recently reported that approximately 35% of properties in the northern

live export region are suffering negative cash flows (Gleeson *et al.* 2012). The modelling results for the baseline properties are, therefore, consistent with this analysis.

However, sensitivity analysis of the baseline modelling also shows that modest improvements towards adopting current best practice management in husbandry, land management and financial management can greatly improve enterprise profitability. In various discussions with landholders in Queensland, this picture of achieving reasonable profits under good management was widely supported, though that view may not hold true for other regions.

We are not making any conclusions about one region versus another in terms of profitability of the baseline scenarios because profit is dependent on the assumptions used in the model within each case study region, the enterprise set-up, and the historical years used in the simulation periods. However, it is appropriate to compare across regions the relative benefits of the different intervention scenarios compared with the baseline and that is addressed in the next section.

Table 14. Summary of the main production, profit, and resource condition outcomes for baseline enterprises in each of the study regions across northern Australia.

	SE Qld	Southern Qld	Central Qld	North Qld	Western Qld	Barkly-NW Qld	Katherine-VRD	Central Australia	Kimberley	Pilbara
Profit ($)	127,335	215,996	121,293	165,607	148,319	1,786,189	912,766	235,374	101,620	127,996
Gross margin/AE ($)	162	219.8	128	125	166.8	113.8	101.3	151.0	64.9	100.3
Return on assets (ROA %)	4.5	2.8	1.0	2.3	1.9	2.5	1.5	2.7	1.1	2.6
Weaning (%)	69	72	62	58	64	56	51	55	47	53
Beef turnoff/AE (kg)	142	174	129	114	143	118	100	118	83	108
Liveweight gain (kg/hd/yr)[+]	140	162	132	127	143	123	125	141	105	120
Utilisation rate (%)	31	26.3	27	27	27.3	12.0	8.8	16.3	12.5	25
Methane (kg/ha/yr)	21.3	12.1	18.7	8.2	9.0	5.0	3.0	0.9	3.6	2.2
Methane intensity (g/kg)	619	501	693	748	630	759	877	748	1,074	824

[+]Liveweight gain of yearling animals (steers and heifers)

4.4.2 Scenario modelling

A summary of the benefits of the different scenarios across regions is shown in Table 15. The benefits, costs, opportunities and constraints of the different scenarios based on this summary across regions are discussed below. In considering the scenarios across regions it is also important to look at possible interactions between scenario and region of implementation. Figs. 17a-g show the interaction between scenarios and regions for three key variables – gross margin per AE, beef turned off and methane production (per ha and per kg of beef produced). Given the inherent differences in productivity and profitability between the regions the results have been normalised by comparing the net gain relative to the baseline for each of the scenarios.

 (a) Improved pasture

For this scenario, it was assumed that a legume could be oversown across the property at low cost by aerial sowing of seed by helicopter or light aircraft. Current costs for this establishment technique for stylo can be around $20-$25/ha (Roger Landsberg, pers comm.), and so costs used for the scenarios were assumed to be in the order of $25/ha. It was also assumed that establishment was successful the first time. However, it is known that establishment can be poor if weather conditions are unfavourable and that it can take two to eight years for the legume to successfully establish, depending not just on weather and climate but also competition from existing grass in the treated pastures (Miller and Stockwell 1991).

It was also assumed for this scenario that a suitable legume is actually available for all environments. There are legumes presently available (e.g. Stylosanthes) for non-clay soils in the tropics, but historically there have been challenges in achieving legume persistence on heavier clay soils (Clem and Hall 1994) and for the inland sub-tropical environments. However, a more recent examination of longer term trial sites suggests that good legume persistence can occur across a range of environments (Peck *et al.* 2012) and that there may be opportunities to more effectively align various legume species to specific environments.

For these scenarios, we have not included tree legumes such as leucaena because it is presently not possible to reliably simulate forage yields and quality with the existing suite of crop or pasture models, which is a requirement for the animal model.

The improved pasture scenario produced significant gains in both animal productivity and enterprise profitability across most of the regions. Central Australia was the main exception, where the highly variable production environment resulted in production benefits that could not produce returns that are sufficiently high to service the initial capital outlay. This led to sustained negative cash flows and long-term debt.

In Queensland, the gains in productivity (kg beef turned off) were in the order of 30% and profit increases were approximately 100%. These productivity and profit gains were a result of improved production per animal but more so the increased carrying capacity (approximately 15%) facilitated by higher levels of pasture production. The projected returns on capital investment were consistently high (>20%) suggesting that this might be a good investment option. The animal production per head increases of approximately 20-30 kg/annum are consistent with experimental data (Partridge and Wright 1992, Coates *et al.* 1997), although the increase in carrying capacity used in these scenarios is lower than many of the experimental results obtained from small scale grazing trials. An important aspect of the improved productivity in this scenario is the improvement in weaning rates of 5-10 percentage

points, as all animals had access to the legume-augmented pastures. Nearly all experimental data on legume improvement has focussed on steer growth and this result suggests that the benefits can be just as, if not more, important in terms of enhanced reproductive performance of the breeding herd.

Table 15. Summary of productivity, profitability, utilisation and methane production for each scenario averaged across all regions.

	Baseline	Improved pasture	Cheap protein	Irrigated forage[1]	Improved reproduction	Improved growth efficiency	Rumen modifier	Combined scenarios
Profit ($)	394,247	628,203	576,472	356,286	470,510	534,520	717,371	983,815
GM/AE ($)	133	162	147	135	141	144	153	174
Animal equivalents	7,938	9,186	8,797	9,237	8,156	8,304	9,086	9,894
Weaning (%)	59	66	66	61	64	62	66	74
Liveweight (kg/hd/yr)[+]	132	158	151	195	132	148	154	184
Beef turned off (kg)	874,877	1,143,905	1,093,872	1,158,082	933,529	978,034	1,120,983	1,391,574
Beef turned off per AE (kg)	123	134	135	146	128	129	134	151
Utilisation rate (%)	21	22	21	23	22	21	22	22
Methane (kg/ha/yr)	8	10	9	10	9	8	9	9
Methane intensity (g/kg)	748	677	671	648	723	693	668	578

[1]Irrigated forage scenario was not implemented for Central Australia, so comparisons with other scenarios are more appropriately represented in Figure 17.

[+]Liveweight gain of yearling animals (steers and heifers)
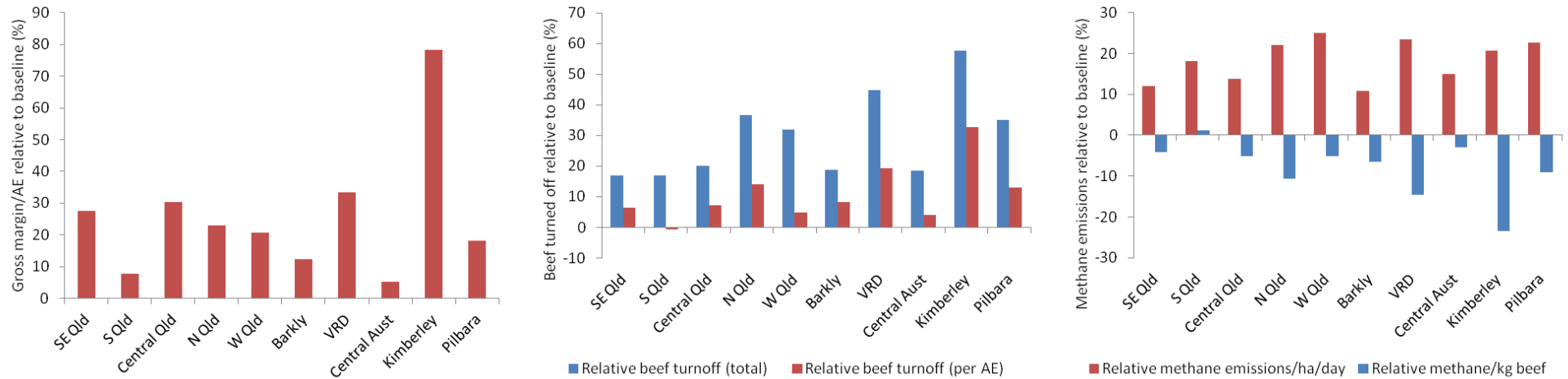
Fig. 17a. Relative gain (% against baseline) for the improved pasture scenario across regions for gross margin per AE, beef turnoff and methane production.
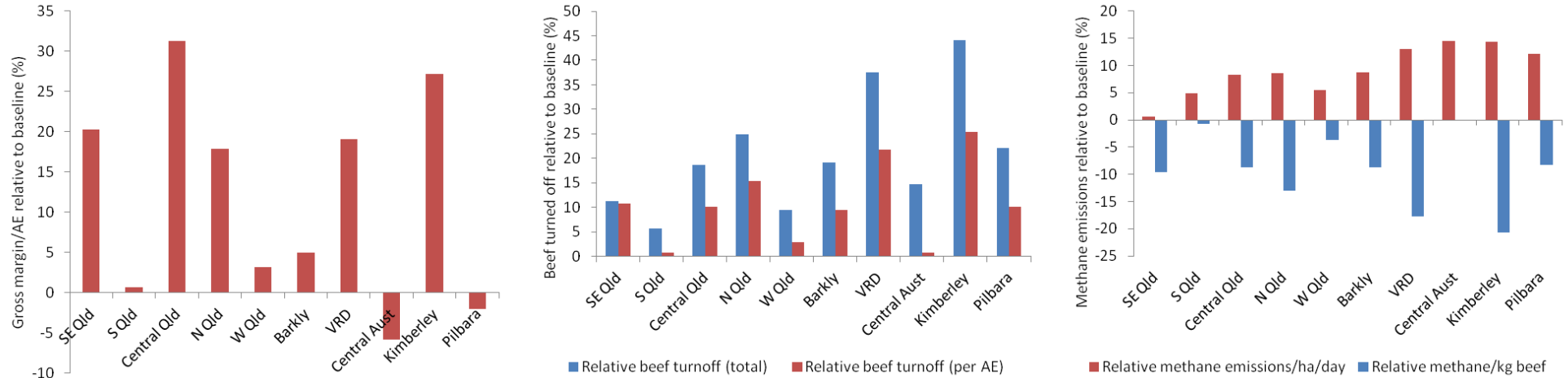

Fig. 17b. Relative gain (% against baseline) for the cheap protein scenario across regions for gross margin per AE, beef turnoff and methane production.
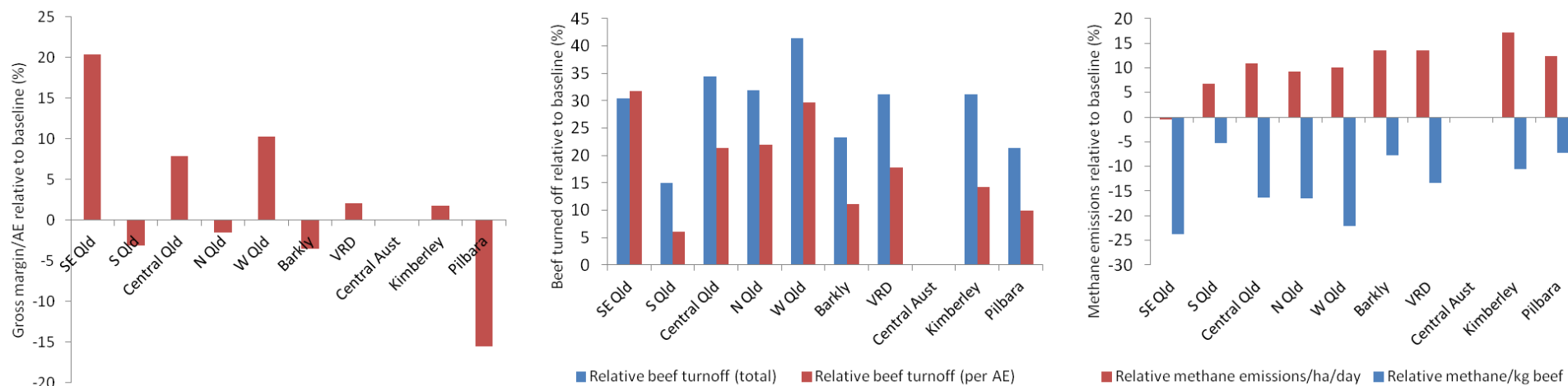
Fig. 17c. Relative gain (% against baseline) for the irrigated forage scenario across regions for gross margin per AE, beef turnoff and methane production. Note: No irrigation strategy was assessed for central Australia.
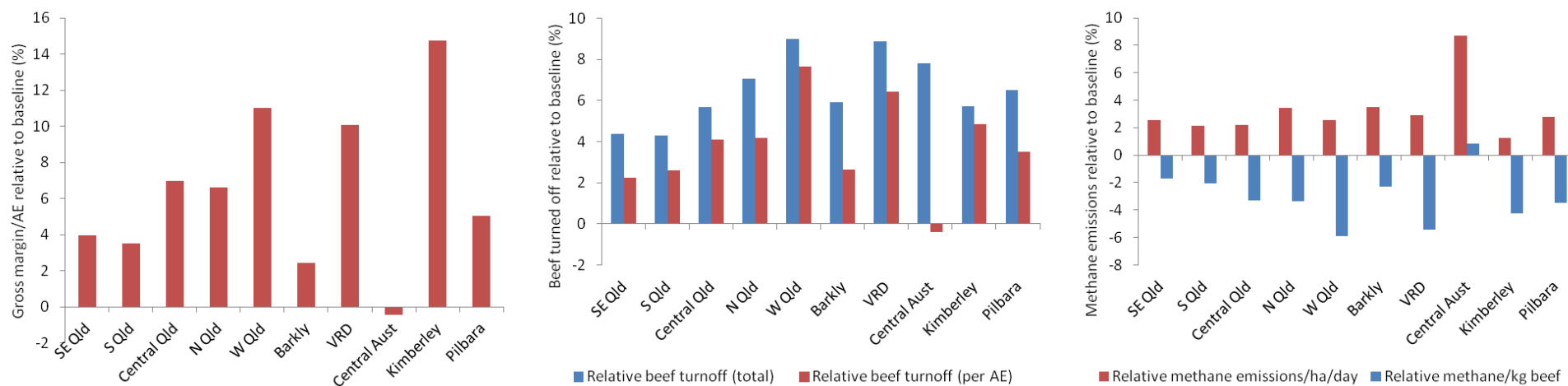
Fig. 17d. Relative gain (% against baseline) for the improved reproductive efficiency scenario across regions for gross margin per AE, beef turnoff and methane production.
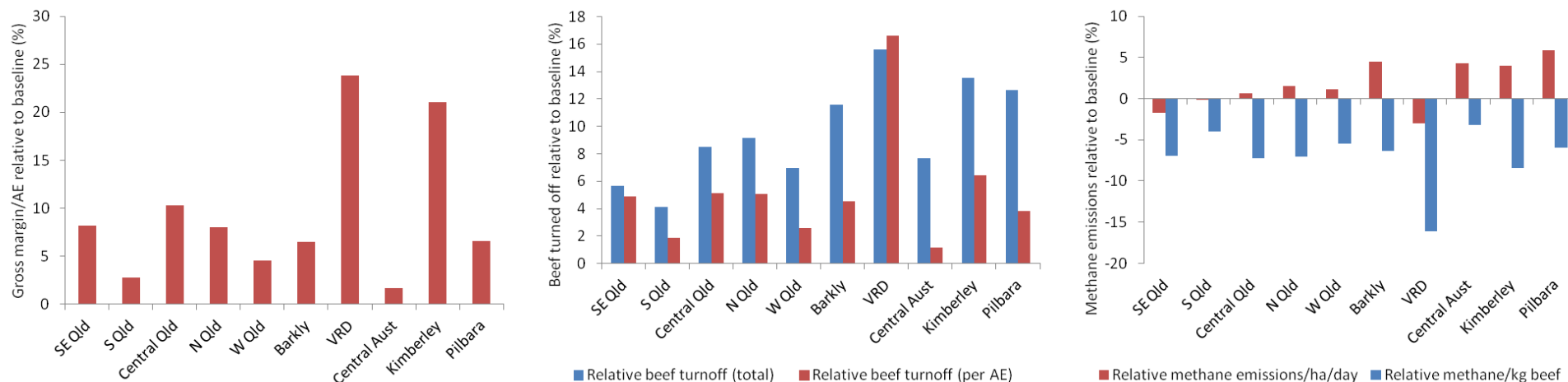
Fig. 17e. Relative gain (% against baseline) for the improved growth efficiency scenario across regions for gross margin per AE, beef turnoff and methane production.
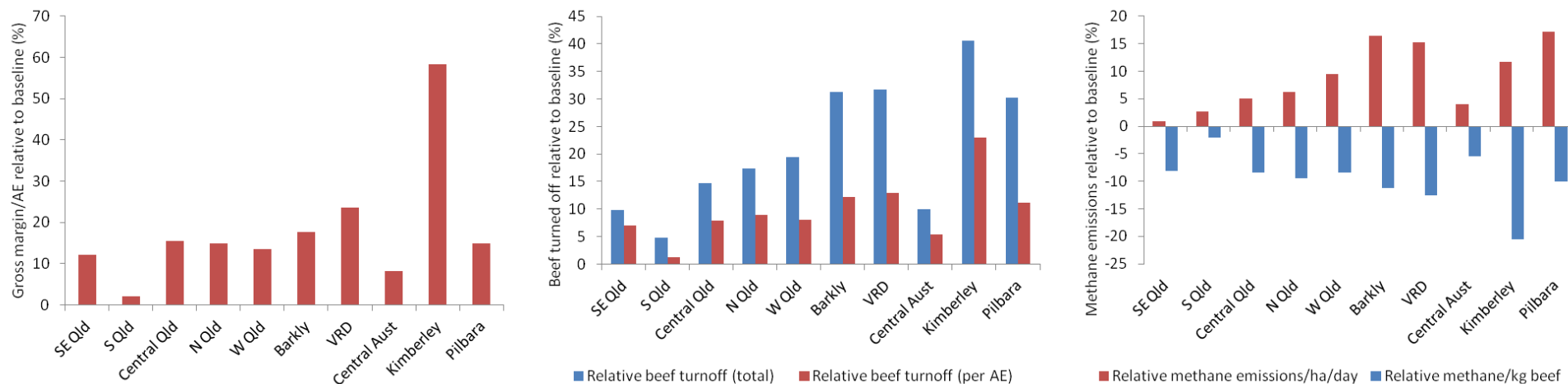
Fig. 17f. Relative gain (% against baseline) for the rumen modified scenario across regions for gross margin per AE, beef turnoff and methane production.
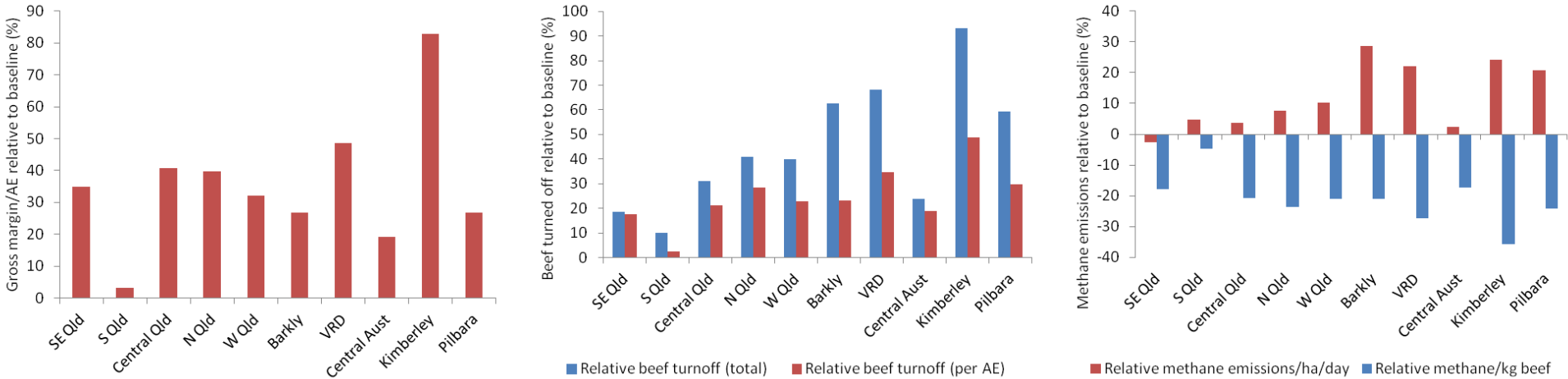
Fig. 17g. Relative gain (% against baseline) for the combined scenarios across regions for gross margin per AE, beef turnoff and methane production.

For the Barkly region, projected productivity gains in terms of liveweight gain and weaning rate were similar to Queensland. However, for the Victoria River Downs, Kimberley and Pilbara case studies, the productivity gains were approximately 50% higher than the baseline for kilograms of beef turned off. While the increase in carrying capacity from sowing improved legumes was similar across regions, the increases in liveweight gain per animal (30-40 kg/annum) and weaning rate (10-12% percentage point increase) were greater than for Queensland. However, apart from the Kimberley, where baseline profitability was very low, relative increases in profit were similar to or lower (Barkly) than in Queensland. This reflects the larger capital expense involved in oversowing pasture per AE carried compared with Queensland where stocking rates are higher. Indeed, the return on capital invested was considerably lower (2-12%) than for Queensland and, given the risks that are involved, such an investment would appear at best to be marginal. In these scenarios, the target market was altered from live export to young trade steers and heifers (420 kg). It may be worth testing other production-marketing options, such as producing heavier export steers, given the improvements in liveweight gains, or targeting smaller specialised areas to be sown.

At least for Queensland, more widespread use of legumes, assuming good persistence in areas where that is not yet proven, would offer significant opportunities in terms of productivity and profitability. Legume persistence remains an issue for many regions, particularly on heavier clay soils, and more effort may be warranted in targeting legume species for specific environments. Another approach is to consider using more than one legume in a particular environment on the basis that different species have different attributes that together provide a more reliable supply of high quality pasture.

Given the large positive impact of this legume scenario on productivity and profit it raises the question as to why legumes are not more widely used in areas where suitable species are currently available. It would appear that concerns about successful establishment are a major consideration and there is a lack of confidence in achieving a return on investment. Considerable research effort has been expended in the past to address issues of establishment but this aspect remains an important challenge. This is not surprising given the fundamental constraint of a surface sown seed trying to establish in competition with an existing grass sward, often with variable conditions for germination. Nevertheless, continued effort in addressing these challenges would seem warranted, perhaps drawing on some new areas of science e.g. materials science and novel polymer coatings.

In considering possible expansion of oversown legumes, attention must also be given to the potential environmental consequences. For example, stylo, the most successful pasture legume used in northern Australia, is not without potential negative consequences. These largely relate to legume dominance, which can result in soil acidification, reduced cover levels and increased erosion risk, and biodiversity impacts (Noble *et al.* 2000). Nevertheless, these risks can be managed in part through strategic use of fire, grazing management and fertiliser use.

As a result of higher carrying capacity and significantly higher herd numbers, methane production per hectare increased by 25% compared with the baseline, while the intensity of methane production actually declined by 10%. This improvement in intensity of methane production maybe understated and overall methane production overstated because the equations used in the model assume the same methane production per unit of intake for grasses and legumes. Recent work of Kennedy and Charmley (2012) suggests that tropical legumes produce less methane per unit of

digestible organic matter intake. If that could be incorporated into our modelled methane calculations it would likely show a smaller increase in total methane production and a more significant improvement in methane intensity.

Most of the tropical legumes currently in use in the northern regions are not particularly high in digestibility, although leucaena is an obvious exception. Efforts in plant breeding to improve legume digestibility would not only reduce the amount of methane produced, it would increase animal productivity.

(b) Cheap protein

For this scenario, all animals were assumed to have access to a cheap and high quality protein source (i.e. similar in quality to cottonseed meal) that could be fed at $200/tonne in situ. This is less than half the price that protein supplements of that quality can presently be fed to animals in the paddock. It is unlikely that such a protein source will become available simply due to a price drop in existing protein meals. It will more likely require access to novel forms of protein meal such as algal biodiesel residue (Bryant *et al.* 2012), on farm algal protein production or synthetic protein meals that are not yet commercially developed.

Providing such a protein source in the scenarios showed some modest to significant increases in productivity and profitability. The largest gains were achieved in the monsoonal tropical regions that are characterised by short summer growing seasons, long dry seasons and lower fertility soils where protein is deficient. In these areas, productivity gains were in the order of 20-30% with consequent profit increases projected to be around 50-100%. The source of the productivity gains was a combination of being able to support a small increase in carrying capacity (less than 10% over baseline), improved liveweight gains (20-30 kg/head/annum) and significant improvements in weaning rate (5-10% percentage points). These liveweight gains are broadly consistent with experimental data for similar quality protein meals (e.g. Addison *et al.* 1984) although the gains achieved are somewhat lower than might be predicted by relationships between the amount of protein supplied and the liveweight gain response (McLennan *et al.* 1995). For the simulations cottonseed meal was fed at approximately 1 g/kg liveweight/day which should produce liveweight gain responses in the order of 300 g/day, but we were simulating on average 150-200 g/day The lesser response in the simulations compared with the expected response (McLennan *et al.* 1995) may have been, in part, due to years in the simulation where green pasture was available through the dry season as a result of autumn or winter rainfall. McLennan *et al.* (1995) showed that the response to protein supplement on medium quality forage was much less than for low quality forage. An important effect of protein supplementation is to stimulate consumption of low quality roughages, thereby increasing digestible energy intake. It may be possible that intake depression simulated in the model as a result of protein deficiency was under-estimated, resulting in a dampened response to protein supplementation and this is being investigated.

In other areas where the seasonal decline in protein is not as significant (e.g. southern Qld, western Qld, Barkly) the projected gains in animal productivity and profit were approximately half those of lower quality pastures on lower fertility soils in the tropics.

This scenario requires ongoing feeding of supplements over the dry season (May-October) to all classes of animals. While an allowance for additional labour was incorporated within the scenarios for supplementary feeding, it does not consider

other capital costs e.g. one potential cheap protein source is on-farm production of algal protein which would require ponds, harvesting and drying equipment.

Total methane production was projected to increase by about 10% in this scenario compared with the baseline although the intensity of methane production was estimated to be 10% lower. Given that a supplement is being fed on a daily basis to animals it might be cost effective to include feed additives such as monensin to further reduce methane production.

(c) Irrigated forage crops

There is now considerable interest being shown in the development of mosaic agriculture in northern Australia, and opportunities for the northern beef industry to benefit from irrigated pastures (CSIRO 2009). Therefore, it was considered important to assess the potential for irrigated pastures to provide alternative market opportunities for the northern beef industry, and particularly for the part of the industry that relies solely on the live export market.

This scenario tested how grazed irrigated forage crops – forage sorghum for tropical areas and oats for southern and western Queensland – might lift enterprise profit and provide additional market opportunities. Many of the enterprises in the study region are largely reliant on access to live export markets, and although there are presently no large scale commercial abattoirs sited in the region this supply chain constraint was not considered for this scenario. That is, the scenario is based on the assumption that regional processing facilities are available in order to assess the full on-property potential of the irrigation option.

In general, the scenario assumes that enough land would be developed for forage crops to support the grower animals, with a strong emphasis on meeting early and middle of the dry season forage needs. Depending on case study region this varied from 150 ha to 1500 ha. For southern Queensland a dryland oats scenario was also considered given the amount of autumn and winter rainfall that occurs in that region. There are very significant capital costs associated with forage crop development e.g. $5000/ha to develop relatively open country with little or no timber. These costs include land preparation and costs of irrigation equipment such as centre pivots. Also there are significant ongoing variable costs associated with planting, fertiliser, herbicides, pumping water, and irrigation with the assumption that water charges will be applied, though they are presently modest. We didn't attempt to identify the potential water resources for irrigation in each region but these span extraction directly from rivers or new surface storages through to groundwater, either extracted directly for irrigation or made available from mining activities.

An important caveat on the results from this scenario is the relatively small amount of irrigated forage crop data available for northern Australia, especially relating to forage quality. This makes it difficult to validate model output so this needs to be taken into consideration when interpreting these results, particularly as forage quality drives animal growth in the model. Consequently, there are higher levels of uncertainty about the animal production results from the model for the forage crop scenarios. Because of these limitations we only explored oats and forage sorghum. With further effort there would be scope to simulate a wider range of forage crops for these environments. In addition, the timing of the forage crops is an important consideration. In some parts of the northern tropics where winter temperatures are not a constraint to tropical crops such as forage sorghum, there is an opportunity to grow crops right through the dry season to take advantage of the main feed quality gap i.e. planting in the late wet season rather than in September/October, with forage

available from March/April until December. Further work needs to be undertaken to assess the potential of forage crops over this dry season growing period.

Using irrigated forage crops on the whole significantly increased productivity through being able to turn off growing animals at a much younger age. Liveweight gains of growing animals increased from their base levels to an average of around 180-200 kg/head per annum. Liveweight performance was particularly sensitive to the amount of forage available per animal. Where not enough forage was available for the cohort of animals, liveweight performance was markedly reduced. This played a significant role in the more modest liveweight gains of animals in the Barkly, Katherine-VRD, Kimberley and Pilbara case studies where it was more difficult to achieve enough scale in the irrigation to match the forage demands of all the growing steers. Another contributing factor in these tropical environments was the more rapid growth and senescence of forage sorghum, even with the addition of nitrogen fertiliser.

Overall carrying capacity also increased by approximately 10% in response to some native pasture land being freed up for additional animals because of the high stocking rates that could be carried on the irrigated forage crops (3-5 animals/ha). Productivity gains, in terms of total beef produced, were on average about 30% higher than the baseline. However, with the large costs involved in capital development and ongoing variable costs, profits were highly variable with North Queensland, Kimberley and Pilbara regions showing reduced profitability compared with the baseline. In the Pilbara, returns from the investment in irrigated forage could not cover the costs of production and the interest on debt thereby resulting in a significant loss. The biggest increase in profit was 20%, which occurred in the central Qld region, and in general the Qld regions performed somewhat better in this scenario.

Given the relatively small increases in profit relative to the large capital investment, the marginal return on investment was low, averaging around 1-2%, although in central Queensland it did reach 6%.

Based on these figures and the underlying assumptions that underpin the scenario widespread use of targeted irrigation for grazed forage crops would carry significant risk in terms of financial returns. However, in areas where irrigation cropping might provide an opportunity to exploit alternative markets (e.g. fattening steers instead of live export) further investigation of its potential is warranted because opportunities such as market diversification may be more important than a single financial indicator such as marginal return on investment. Also, as mentioned above, we only examined two forage crops (oats and sorghum) and there is opportunity to explore other crops e.g. Bambatsi panic and to assess using the crops at different times of the year e.g. growing summer crops during the middle part of the year in the northern tropics. An option not considered in these scenarios was growing irrigated forage crops for hay. The hay could be used on-farm and fed to early weaned calves, thus allowing cows to re-conceive more easily, lifting overall herd productivity. Excess hay production would likely have a market within the region.

Another option that warrants further exploration is putting breeding animals, especially first and second calf heifers, on to irrigated forage crops instead of growing animals. In environments where weaning rates are low, this may have more benefits than using the forage for growing animals. The northern beef systems model will be modified slightly to allow a wider range of animal classes to be allocated to irrigated forage crops so that this option can be evaluated.

In considering the longer term viability of the northern beef industry, it would also be worth testing the return from using the irrigated land for cash crop production rather than as pastures for animals. This scenario was not within the scope of this study, but it should be considered as it may provide a means of increased returns via diversification rather than intensifying the beef enterprise. Puig *et al.* (2011) using a simulation modelling approach found that diversification into crops or horticulture in the Northern Territory resulted in profitable enterprises, with levels of profit being regionally variable but overall similar to a business-as-usual cattle enterprise scenario.

Total methane production increased by about 10% compared with the baseline scenario as a result of higher herd numbers though there was a marked improvement in intensity of methane production of 15%. This was due to the growing herd achieving high liveweight gains.

(d) Improved reproduction

Herd fertility is a well-recognised significant profit driver for northern beef enterprises. Accordingly, considerable effort has gone into improving the reproduction efficiency of the northern beef herd over the last several decades. An economic assessment of the value of infusing *Bos indicus* into the northern beef herd showed a Net Present Value of $8.1b (Farquharson *et al.* 2003) so the gains have been significant and potential remains to achieve even further gains in this area.

This scenario assumed an improvement in weaning rate of the existing *Bos indicus* dominant herds through further genetic gain of 5 percentage points, recognising that there are still significant gains to be made through improved management. Based on workshop discussions, this level of genetic gain was thought to be achievable over the next decade. This quantum of gain may in fact be too conservative with Barwick et al. (2013) recently suggesting that increases in weaning rate of 10-15% are possible within the next decade.

Implementing this scenario was achieved by altering the shape of the cow liveweight, body condition and conception rate relationships within the model so that for the same bodyweight a 5% point gain in weaning rate was achieved. There were no changes made to the relationships that determine the growth of animals, so this scenario simply represented putting more calves on the ground.

The results of this scenario show modest gains in productivity with increases in the total kilograms of beef produced in the order of 5-10% and profit increases of 10-20%, although the relative profit improvement was considerably higher for the Kimberley and Pilbara where the baseline weaning rates are very low and baseline profitability was also low. These results highlight the need to pursue improvements in genetic gain in combination with approaches that address nutritional constraints to realise full production potential from genetic gain.

The projected improvements in herd productivity and profitability were not as high as those projected for the improved pasture or cheap protein scenarios because in those cases the increases in whole herd productivity were achieved through enhanced liveweight gain and weaning rates.

The increase in gross margin over the baseline outcome was approximately $10 per AE. This sort of gain is comparable with economic modelling results obtained by Schatz (2011) who found that when overall herd reproductive efficiency was increased by about 5 percentage points through lifting reconception rates of lactating

first calf heifers by 30 percentage points, gross margins increased by $6-$8 per AE. Greater economic gains than this have been demonstrated where more significant improvements in reproductive efficiency are achieved. For example, Burrow *et al.* (2003) found that by shifting breeds from *Bos indicus* to tropical composites, weaning rates could be increased by 17 percentage points which led to a $17/AE gain, and when this was coupled with a $7/AE increase due to genetic gain in growth efficiency, a total gain of $24/AE was achieved. We simulated this tropical composite scenario by increasing weaning rates by 17% and increasing growth efficiency, assuming half of the gain represented in the growth efficiency scenario in (e) below. The simulated tropical composite increased Gross Margin per AE by $32, which is higher but not dissimilar to the value obtained by Burrow *et al.* (2003). Weaning rate was 79% (vs 62% in the baseline scenario of a Brahman herd) and higher growth efficiency in the composites increased annual liveweight gain of steers by 12 kg/animal.

In this scenario we focussed on improving conception and weaning rates. Gains in overall reproductive efficiency can be achieved through: earlier puberty (Fordyce *et al.* 1994, Fortes *et al.* 2012); reducing pre-, peri- and post-natal mortality rates, which are currently high (and simulated accordingly in this modelling study) but the causes are not well understood (Burns *et al.* 2010); and reducing disease.

 (e) Improved growth efficiency through genetic gain

This scenario explored how genetic gain leading to enhanced growth efficiency may affect herd productivity and profitability. This was achieved by altering slightly the parameters in the model that affect the conversion of energy into animal growth. This resulted in a consistent increase of 15-18 kg/head/year in liveweight gain across the regions, which also had some minor flow-on benefits for cow condition and weaning rates, which increased on average by 3% units.

This resulted in an increase in beef turned off of approximately 12% and profit increases of approximately 30%, although there was considerable variation between regions, with profits doubling in the Pilbara and increasing by about 200% in the Kimberley. However, these gains have to be seen against the very low baseline profits in the Kimberley and the Pilbara relative to the size of the operations, and small increases in productivity translate to large percentage gains in profit.

The gains simulated here are within the scope of what can be achieved over 20 years by selecting bulls with high Estimated Breeding Values (EBVs) for 600 day weight (Burrow and Rudder 1991). In that study, gross margins increased by 10% by the end of the 20 year breeding program and in the simulations in this study, gross margins averaged across all study regions increased by a similar amount.

Growth rates are moderately heritable (Burrow 2001, 2012) indicating there is good opportunity to achieve reasonable gains through genetic improvement. However, heritability relating to weight is higher than that relating to gain, especially post-weaning (Davis 1993). There is a risk that selecting for weight simply results in an increase in the mature body size rather than in growth efficiency, with commensurate increases in feed requirements. Nevertheless, Burrow (2012) suggests that it should be possible to select for improved growth rates without simultaneously increasing mature body sizes. Genetic improvement in growth efficiency is most likely through feed conversion efficiency although available experimental results are variable (e.g. Burrow *et al.* 1981).

Although adult equivalents were 5% higher in this scenario than the baseline, total methane production did not increase as it was offset by a 7% decline in the intensity of methane production.

While not included as a scenario in the project, it is worth considering the combined benefits from genetic gains in both reproduction and growth efficiency. This was touched on above in comparing tropical composites with *Bos indicus*. Table 16 shows the combined benefits of genetic gains in growth efficiency and an increase in weaning rate of 5 percentage points for North and South-East Queensland. In terms of gross margin per AE and profit the combined effect of growth efficiency and reproductive efficiency is nearly additive, with gross margin increasing by about 15% and profit by over 30%. These are significant impacts for achievable genetic gains.

Table 16. Effect of combining genetic gains in growth efficiency and reproductive efficiency for the SE Queensland and North Queensland regions.

		AE	Beef turnoff (kg/AE)	Gross margin ($/AE)	Profit ($)
Nth Qld	Baseline	2901	114	125	165,607
	Reproduction	2980	119	133	199,790
	Growth efficiency	3014	120	135	209,797
	Combined	3059	125	143	236,830
SE Qld	Baseline	1697	142	162	127,335
	Reproduction	1725	145	169	144,126
	Growth efficiency	1701	149	175	151,825
	Combined	1725	152	180	164,699

(f) Rumen modification

Considerable research effort has been expended on understanding rumen ecology in order to develop technologies to improve the digestive efficiency of ruminants. This has included research on feed additives such as ionophores (e.g. monensin) to reduce methane (Guan *et al.* 2006) and improve animal performance on grain diets (Goodrich *et al.* 1984), although the benefits for cattle consuming low quality tropical pasture may be negligible (McLennan *et al.* 1995). In addition, research has focussed on altering the rumen ecology in an effort to improve digestion, although fundamental understanding of rumen processes still limits any significant practical breakthroughs (Klieve 2009). Despite these current practical limitations, we examined a scenario whereby it was assumed that a rumen modifier (either feed additive or alteration in rumen ecology) could slow the seasonal decline in forage digestibility and increase base digestibility in the dry season by three units of digestibility e.g. 43% to 46% digestibility.

The benefits from this scenario were initially surprising, as the modest improvements in digestibility led to significantly increased productivity and profitability in most regions. Only in the South-East Queensland and Southern Queensland case studies were the increases in productivity (kilograms of beef turned off) less than 10%. In western, central and northern Queensland the increases in productivity were between 15 and 25% with profitability increasing by 50%, while in the NT and WA the

productivity increases were greater than 30% and profit levels were significantly higher again.

The greater response in the NT and WA compared with Qld was due to both higher levels of production per head and relatively higher increases in stock numbers. In Queensland, increases in production per head were approximately 15 kg/head in annual liveweight gain and around 5% units in weaning rate. In the more extensive tropical pasture zones in the NT and WA, increases in annual liveweight gain were 25 kg/head and weaning rates increased by 8-10 percentage points. This may reflect the shorter growing season in the NT and WA with rapid maturation and senescence of pastures resulting in a longer period of low digestibility compared with Queensland. As a consequence, rumen modification provides relatively greater scope for benefit in the more energy constrained environments.

The greater gains in productivity in the larger, more extensive properties in NT and WA were also due to the greater stocking rate increases with the rumen modification scenario compared with Queensland where the baseline scenarios are already closer to maximum sustainable utilisation levels. In Queensland, AEs could only be allowed to increase by about 10% before utilisation rates started to reach a level where land condition declined. It is worth noting that this increase in AEs was not driven by a deliberate increase in breeder numbers but occurred as a result of higher growth rates and weaning rates. In the larger and more extensive properties of the NT and WA, overall levels of utilisation are generally much lower so relatively larger numbers of AEs could be carried with the rumen modification scenario without affecting land condition. It is important to note that while total AEs increase, actual cattle numbers usually do not increase much and may even decrease. This is because the breeding herd is on average heavier (contributing to higher AEs), but fewer breeders are needed to achieve the productivity gains.

While the productivity gains achieved in this scenario appear to be very significant for what is a relatively small change in digestibility, it is important to note the very strong relationship that exists between digestibility and intake in grazing ruminants (Minson 1990). The liveweight gain results projected from the model certainly fit within what might be expected based on experimental results. For example, Chapman *et al*. (1972) used two different varieties of Bermuda grass (*Cynodon dactylon*) that differed in digestibility by around 6% units with the higher digestibility hybrid achieving 50% higher liveweight gains (0.72 kg/day vs 0.48 kg/day). In a similar study, but conducted over four years of grazing, Utley *et al.* (1974) showed a 40% higher liveweight gain in the hybrid Bermuda grass compared with the unimproved coastal variety.

Most efforts in overcoming nutritional constraints in northern Australia have focussed on addressing protein and other mineral and trace element deficiencies because these have been more tractable problems to address. However, the low level of digestible energy in tropical pastures is a major constraint to productivity, both directly and indirectly, through its effect on decreasing protein use efficiency (Poppi and McLennan 1995). Research to improve energy in the diet has concentrated on high energy supplements, which have not been widely adopted, largely due to cost.

This has led to subsequent efforts on improving energy efficiency directed to rumen modification via additives or through manipulation of rumen ecology. It seems that any significant breakthroughs in successfully manipulating the rumen for animals at pasture in extensive operations of northern Australia are still many years away, if at all achievable.

Another possibility is to revisit efforts aimed at improving the digestibility of sown grasses through plant breeding, but using modern genetic and genomic techniques. In the early years of tropical pasture development this need to improve the digestibility of tropical grasses was recognised (Stobbs 1971). Wilson *et al.* (1989) showed that amongst 12 buffel grass genotypes there was a difference of 12 percentage points in digestibility of both leaf and stem. The commonly used commercial varieties, Biloela and Gayndah, were 4-6% digestibility units lower than the best genotype. The study concluded that there was a possibility to improve digestibility by 3-6 percentage points through plant breeding.

However, research efforts in increasing pasture digestibility have not been pursued. Renewed effort in this area of plant breeding would be applicable to the large areas of northern Australia that are sown to tropical grasses. In addition, the digestibility of the commonly sown *Stylosanthes* species is also limiting so future breeding effort should not be constrained only to grasses. In suggesting this line of research, it is worth keeping in mind the advice offered from Stobbs (1971) over forty years ago in the context of tropical pasture systems, 'Insufficient intake of digestible energy is the feed factor primarily responsible for limiting production under practical farming conditions.'

Rumen modification produced a 10% decline in the intensity of methane production compared with the baseline scenario, but this could not offset an overall increase in total methane production resulting from total adult equivalents increasing by 12% and intakes of animals increasing in response to higher digestibility. The improvements in intensity of methane production were much higher in regions where the digestibility of pastures is inherently low i.e. VRD, Kimberley, Pilbara, Barkly.

(g) Combined scenarios

It is unlikely in practice that any single development scenario would be deployed in isolation from others, and so it was important to investigate whether there were any additive or substitution effects from combining different scenarios. For this study we decided to combine four of the individual scenarios that provided benefits to different aspects of animal productivity i.e. genetic gain in reproductive efficiency, genetic gain in growth efficiency, a cheap protein source and a rumen modifier to improve energy available to the animal. We chose not to use the scenarios that fundamentally alter the feed base.

The combined scenarios produced some very significant increases in enterprise productivity and profitability compared with the baseline scenarios. These gains were relatively much higher in the NT and WA than in Queensland. Within Queensland the southern Queensland (Maranoa) case study produced the least benefit, in part because of its already high baseline productivity. For the other Queensland case studies, weaning rates were 15% units higher on average and annual liveweight gains more than 50 kg/head greater than the baseline scenarios. As a result, overall productivity as measured in kilograms of beef turned off, was some 30% higher, with profit close to doubling in comparison with the baseline scenarios.

In the NT and WA, weaning rates were 17% units higher and liveweight gains 50 kg/head/year greater than the baseline scenario. With the higher stock numbers that could be carried for little change in overall utilisation because of the more rapid rate of turnoff, increases in productivity (kg beef turned off) were over 60% higher than the baseline.

For all of the regions, the main productivity and profitability indicators for the combined scenarios were higher than for any of the individual scenarios that made up the combination. However, the projected benefits were not simply additive. For example, the benefits of the combined scenario for animal productivity (kg beef turned off) were only 72% of the cumulative benefits from the individual scenarios that made up the combination. This level of additive gain is still quite high and demonstrates that substitution effects between the components were relatively modest.

The magnitude of the gains suggests that for some regions the herd structure and operation could be changed to finishing steers rather than selling trade animals for finishing. For example, in the Barkly and VRD, we shifted the operation from live export animals to light trade steers. An alternative strategy could have been to assess the merits of finishing heavier steers and this warrants further testing.

These results illustrate the benefits of combining a range of different production technologies and practices rather than focussing too much effort in one particular area. It is also important to target these technologies to different aspects of animal productivity to achieve the greatest gains.

Another feature of this combined scenario is the very significant improvement in intensity of methane production of 23% in comparison with the baseline scenario. Adult equivalents increased by 20% in this scenario over the baseline numbers leading to an increase in overall methane production of about 10%. Maintaining the numbers of AEs at baseline levels would see some significant reductions in methane production if this were to be scaled up across significant areas.

4.4.3 Profit-environment trade-offs

In the scenario modelling we adopted an approach of trying to increase productivity and profitability whilst maintaining or improving land condition. This was achieved by constraining animal numbers so that utilisation rates did not increase enough to trigger a loss of perennial grasses. However, as shown above under nearly all productivity improvement scenarios methane per ha increased even though methane produced per kilogram of beef decreased.

To obtain a better understanding of the trade-offs between profit and environmental outcomes we examined the effect of reducing stock numbers for the Combined scenario in North Queensland and the VRD. The trade-offs examined included: reducing herd numbers so that methane output per ha was the same as the Baseline scenario; reducing herd numbers so that the profit was the same as the Baseline scenario; and reducing herd numbers so that the profit increase of the Combined scenario was reduced to 50% compared with the Baseline scenario.

The results for North Queensland and the VRD are shown in Table 17.

Reducing herd numbers so that methane output per ha is no higher than the baseline still results in a significant profit increase compared with the baseline (approximately 100% increase). Reducing herd numbers in the combined scenario so that the potential profit gain is halved compared with the baseline reduces Adult Equivalents, methane output per ha, and utilisation rate all by about 15%. This would represent a significant environmental benefit yet still allow a substantial profit gain.

Further reducing stock numbers so that profit levels are the same for the combined scenario as in the baseline resulted in a reduction in methane output per hectare and

utilisation rate of over 30%. While it is highly unlikely that producers would forego an opportunity to lift profitability from the benefits that the combination of production technologies provides, it does highlight the significant environmental benefits that can be accrued if profit is not optimised. In the context of methane, the significant reduction in total methane produced by holding profit constant and reducing stock numbers may become financially important should the price of carbon increase in the years ahead.

Table 17. Profit-environment trade-offs for the Combined scenario in North Queensland and the VRD regions. The first column is the Baseline scenario and the second column is the Combined scenario as per the results in Tables 4 and 10. The next three columns are modifications of the Combined scenario to test profit-environment trade-offs.

		Baseline	Combined	Methane = Baseline	Profit = 50%	Profit = Baseline
Nth Qld	AE	2901	3184	2962	2535	2011
	Gross margin/AE ($)	125	174	175	179	177
	Gross margin/ha ($)	12.0	18.3	17.1	15.0	11.8
	Profit ($/yr)	165607	358693	326833	261998	165473
	Methane (kg/ha/yr)	8.2	8.8	8.2	7.0	5.6
	Methane (g/kg beef)	748	570	566	553	547
	Utilisation (%)	26.8	28.4	27.1	23.5	18.7
VRD	AE	18721	23341	19281	17931	12851
	Gross margin/AE ($)	101	151	151	151	148
	Gross margin/ha ($)	3.4	6.4	5.3	4.9	3.5
	Profit ($/yr)	912766	2518827	1915676	1714127	912234
	Methane (kg/ha/yr)	3.0	3.6	3.0	2.8	2.0
	Methane (g/kg beef)	877	638	636	636	631
	Utilisation (%)	8.8	10.8	8.8	8.2	6.0

4.4.4 Relative attractiveness and feasibility of different scenarios

The scenarios used in this study vary in their stage of development and readiness for application, their potential benefit and their risk. For example, increasing weaning rates by 5 percentage points over the next decade is very achievable given the R&D in progress. In contrast, development and practical implementation of a rumen modifier to improve forage digestibility is a long way off but the benefits if successful are likely to be very significant. There are also other risk factors to be considered such as the large capital costs associated with irrigation infrastructure that makes investment in this scenario challenging even though productivity increases can be impressive. To illustrate these trade-offs Figure 18 shows a feasibility-attractiveness matrix that subjectively compares the different scenarios based on the results of this

scoping study. It provides a framework for examining future investment in R&D i.e. whether to invest in lower risk, higher certainty gains versus higher risk, higher return technologies or whether to take a balanced portfolio approach.
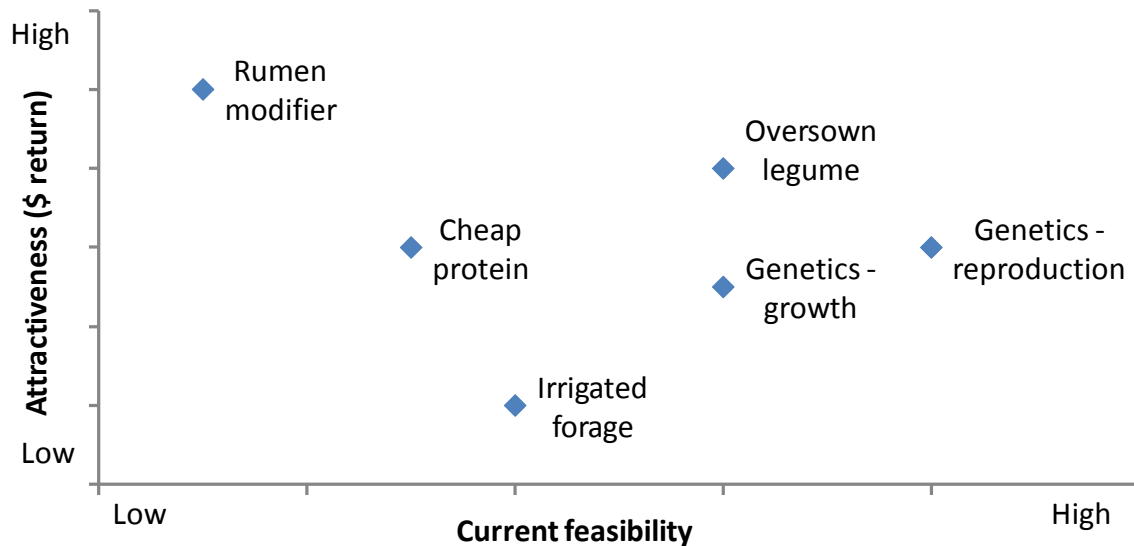

Fig. 18. Relative attractiveness ($ return) versus feasibility of technology (present day).

5 Success in achieving objectives

This project was designed, initiated and completed against the background of a set of challenging objectives – consistent with the challenges of maintaining a healthy beef production and marketing sector for the vast areas encompassed within northern Australia.

Objective 1. Identify alternative development pathways for the northern beef industry on a regional basis and assess their likely contribution to:
- *achieving total factor productivity growth of at least 2% p.a. over the next 20 years;*
- *maintaining or improving land condition;*
- *reducing the intensity of greenhouse gas emissions;*
- *being readily adopted by industry.*

First and foremost through a process of consultation, intelligent application of simulation modelling and common sense, it sought out viable pathways for the sector, across all of its constituent production regions, through which the productivity-profitability impasse that has beset it for a decade might be broken. There is scope, as shown by the modelling outcomes in preceding sections of the report, for the sector to apply both new and extant practices and regain productivity advances in excess of the present 'terms of trade' impost (~2% per annum cumulative). This will necessarily involve combinations of practices rather a single practice or technological application alone.

At the same time, these productivity gains need not necessarily be reaped at the expense of important environmental values, in particular land condition. Ongoing

stewardship and resource monitoring must necessarily go hand in hand with the uptake of these practices, especially those that naturally drive up animal numbers through increased weaning rates.

Improvements in animal productivity can be accomplished through access to and the application of improved management and technologies and this will have a positive impact on reducing the intensity of greenhouse gas emissions per kilogram of beef produced. The net effect on total greenhouse gas emissions from the sector will naturally depend on how aggregate animal numbers are deployed across the regions.

Change cannot occur without adoption and the challenge will be for the R, D & E sector to produce some of the technologies and practices that underpin the modelling scenarios employed in this project. Two obvious examples are rumen modifiers and novel sources of cheap protein. Nevertheless, our judgment is that the nature of the genre of technologies and practices that have been screened for review and investigation is such as to make them reasonably tractable for promotion within the context of contemporary commercial beef production enterprises in the northern regions. That is, the technologies and practices that offer the most promise will not necessarily require a major structural change in the sector before adoption can be accommodated.

Objective 2. Quantify the likely impacts of alternative futures through bio-economic modelling of a range of development scenarios to capture the production and resource consequences of applicable land management decisions.

Through the various modelling scenarios that have been described within the body of the report, the project has clearly succeeded in quantifying the scope and nature of the likely impacts of application of a range of improved practices and technologies on production, financial and environmental performance indicators for typical enterprises sited across the northern beef industry. One of the possible changes in the industry in the future is a significant restructure or even loss of the live export cattle market. There is also considerable interest and current activity in developing new abattoirs for northern Australia. In the scenarios we explored these potential changes by testing whether it was possible to turn off finished steers in areas that currently only sell into the live export market.

Objective 3. Collate and summarise the production and environmental consequences of benchmark and selected scenarios for each study region and the reaction of stakeholders to the scenarios.

The formal requirement to collate and summarise the production and environmental consequences of benchmark and selected scenarios for each study region and the reaction of stakeholders to the scenarios has been accomplished. The results of the bio-economic simulation modelling task for both benchmark and development scenarios are presented by regions under Results and Discussion (Section 4.3, sub-sections 4.3.1 to 4.3.6) of the report. A synthesis of these regional results across the whole sector is presented in sub-section 4.4. The modelling of the representative regional enterprises has produced a set of benchmark and scenario results that appear to be realistic in terms of the main production, profit, and resource condition outcomes projected for the different regions. Critically, the sensitivity testing that was carried out for the benchmark studies suggested that even modest improvements towards adoption of current best practice management in husbandry, land management and financial management can greatly improve existing enterprise profitability. Adoption of the technologies and practices screened for the scenario

testing would further broaden the scope of this potential improvement for the sector into the future.

As stated in the Methodology section (Section 3.0), the project was undertaken with a significant level of interaction between the project team, research and extension community and other sectoral stakeholders. The project put in place a Steering Committee of MLA representatives, the Chair of NABRC, and key senior managers from State agencies. This Steering Committee met on a number of occasions throughout the course of the project. In the case of seeking out opinions, data and reactions from beef producers, this largely was accomplished through consultations with the Regional Beef Research Committees, including scoping workshops on the candidate technologies and practices, as well as a sectoral overview through liaison and formal presentations to the project steering committee.

Objective 4. Identify knowledge gaps and specify uncertainties in the scenario analyses so that R&D options for the future can be assessed with all the information and caveats well understood.

Throughout the report we have been clear to state the assumptions in both how the model has been developed and in the way we set up baseline and development scenarios. We have also stated where have a lack of confidence in results and put caveats on some areas of the development scenarios e.g. lack of empirical information on irrigated forage crops in the northern tropics to inform/validate model output.

Objective 5. The primary deliverable from this particular research investment is to present the project findings in a final report that will include the following:
   a. An assessment of the productivity potential of current and alternative herd and land management options at the paddock to property scales for the range of agro-ecological regions of the northern beef industry.
   b. An assessment of the effects on land resource condition and the consequent greenhouse gas (GHG) footprint for each scenario option.
   c. An assessment of systems analysis capability for the northern beef industry developed in the project and associated knowledge gaps.
   d. The reactions of industry stakeholders to the development scenarios.
   e. Identified research opportunities with both short and long-term horizons and possible approaches.

The present report is the embodiment of the achievement of this overarching objective.

6 Impact on meat and livestock industry – Now and in five years time

It would be clearly unrealistic to expect an R, D & E investment of the nature of the present project to have generated an immediately observable impact on industry practice, and through that a tangible impact on industry outputs. Rather, the project has a central pathfinding focus that is seeking to scope where and in what way targeted R, D & E might provide a means for the northern beef industry to once more reap the magnitudes of productivity gains that it did in the past (e.g. the 1970s) with considerable success. For the present, the project has reviewed the types of practices and technologies on offer for adoption, or for which technical solutions are yet to be found but do offer realistic scope for economic application.

Looking to the future, even on a relatively short time frame of five years, there is scope for profitable implementation of some of the technologies and practices that are embodied in the regional scenarios. For example, the sensitivity analysis that has been conducted as part of the benchmark modelling has revealed that even modest improvements consistent with alignment to current best practice management in husbandry, land management and financial management can greatly improve enterprise profitability. Moreover, in discussions with various stakeholders, and especially producers, this picture of achieving reasonable profitability under good management was widely supported. Taking up extant 'best practice' opportunities is by and large an extension issue rather than a key role for future R, D & E investment planning.

The challenge for reaping near to longer-term impact is to apply R, D & E focus on some critical areas including the search for low cost legumes suited to a wider range of environments than presently available, and overcoming the critical constraint of reliable establishment. This technology can improve the feed base for enhanced herd nutritional management and/or finishing opportunities for turnoff animals into more profitable markets. However, this does incur significant upfront costs if used over large areas and this acts as a constraint to investment. The other scenario that was explored to improve the feedbase was the use of forage crops. The analysis showed that animals could be successfully grown to reach a wider range of markets than those presently available but the large capital and operating costs makes this scenario largely unattractive. There may be more opportunities in field crops as a diversified enterprise mix and this warrants further exploration.

Genetic improvements also offer continuing scope to improve productivity and profit gains, particularly when these can target both animal growth rates and enhanced fertility. These are proven innovations and ways of accelerating these gains should be a priority. Technologies other than legumes that address protein deficits, including novel sources of cheap protein have considerable scope for supporting further productivity gains. Energy deficits are a primary constraint on herd performance and, while often shadowed by the search for protein, are still a promising target for future R, D & E efforts - rumen modification and genetic improvement of plant digestibility are two candidate areas. However, and as noted before, while individual technology innovations and improved practices offer genuine scope for productivity gains, the largest gain lies in their effective integration within grazing and property management systems. This suggests the need for and opportunity to exploit systems based approaches to both R, D & E practice and the intelligent application of the fruits of that effort.

A key innovation that is directly attributable to the project is the development of a beef systems simulation model for northern Australia and its application to addressing future R, D & E opportunities. A key component of this project was the articulation and testing of an array of promising technologies and practices for productivity improvement while concurrently remediating any environmental downsides including the emission of greenhouse gases. The simulation model that was specifically developed for this purpose fulfilled its intended role. However, this model also offers considerable scope for future application across a much wider set of problem settings. The modelling approach that incorporates the model provides more flexibility than previously available to explore a wide range of development options relating to nutrition, reproduction and forage supply while concurrently examining feedback effects on resource condition (land condition, soil cover) and other environmental metrics (especially methane production). This capacity will likely prove to be a major legacy of this project.

7 Conclusions and recommendations

7.1 Overall modelling approach

The central aim of this project was to explore some potential options for sustainable improvement in the productivity and profitability of the northern beef industry based on the application of technological innovation to address ongoing concerns about stagnating productivity, rising costs and declining profitability.

These options were explored at the enterprise scale by developing and testing a new bio-economic modelling approach that captured production, economic and resource consequences of a range of development scenarios. The central innovation of this modelling approach is that for the first time we have the capacity to simulate herd dynamics and whole of enterprise productivity in northern Australian beef enterprises that is based on fundamental inputs of protein and energy and their role in growth, body condition, reproduction and mortality. This new modelling approach provides considerable flexibility for exploring a wide range of development options relating to nutrition, reproduction and forage supply and, at the same time, examining the feedback effects on resource condition (pasture condition, soil cover, methane production).

The new capacity developed in the modelling approach presents a legacy for research and extension applications that will endure well beyond the scope of this present scoping study. The integrated model relies on output from other simulation models, such as the GRASP pasture production model and the APSIM crop yield model, but is itself coded within Microsoft Excel® and therefore readily amenable to further modification. However, the better longer term option would be to have the model software engineered with a stand-alone source code.

A number of aspects of the model could be further enhanced with modest effort to improve its present functionality. For example, we could not adequately test tree legumes such as leucaena in the forage improvement scenarios because there is presently no ability to confidently simulate tree legume fodder production from year to year. We have used a limited range of forage crop scenarios because production data on irrigated forage crops for the tropics of Australia is relatively sparse. Also given the relatively short-term nature of this project, the modelling approach could significantly benefit from some increased effort in improving its interface and output modules appropriate for a more general user rather than just the present project team.

Climate change impacts were not specifically considered in this study as the potential impacts of climate change were not incorporated into the databases that were embedded within the present model. The scenario timeframes in this study were two decades and so it is unlikely that the impacts of climate change would affect the results greatly over that timeframe. Nevertheless, it is possible to include climate change factors in future development of the model through forage inputs in GRASP and APSIM and through the animal model via heat loads. This, in effect, was the procedure that was adopted for the MLA funded Northern Grazing Systems project the last stage of which considered the opportunity for applying 'best-practice' management options under various regional projections of future climates across northern Australia (MLA B.NBP 0616 – Developing improved grazing management practices to assist beef production enterprises across northern Australia to adapt to changing and more variable climate).

Also, the interactions that inevitably will exist between specific animal diseases, animal productivity and herd mortality were not specifically addressed in this scoping study. These may be important issues for many enterprises and the capacity to incorporate existing and likely significant diseases and pests should be considered for the future.

It is recommended that the modelling approach developed in this project be communicated more widely and, if sufficient interest is expressed by State agencies or other groups, that some more formal training or extension of the model takes place.

Finally. as a caveat to the key conclusions from development scenarios below, it needs to be re-iterated that this is the first use of this prototype model. There are bound to be issues that need to be addressed to improve its functionality or to better represent individual components of the overall livestock system.

7.2   Development scenarios

a) The results of this study suggest that improvements in future technology and practices have the potential to substantially lift productivity and profitability of enterprises across each of the regions. The scope exists to lift productivity by the desired target of over 2% p.a. over a 20-year time frame i.e. 40-50% gain in productivity over the next two decades.

b) No single technology or practice will necessarily provide the required productivity and profitability benefits, but combinations applied in a systematic and systemic fashion do offer such scope.

c) Of the individual scenarios that were reviewed, access to low cost legumes that are adapted to a wider range of environments than are currently available provided significant benefits in productivity in nearly all of the case study regions. Although profitability also increased, the significant outlays required for pasture establishment on the large, extensive properties in the NT and WA resulted in unfavourable marginal returns on the capital investment. There were generally good returns on capital investment in pasture augmentation in Queensland, assuming successful establishment of the legume. Environmental concerns associated with more widespread legume use will need to be considered in further exploring this scenario. For a number of regions, legumes are already available and have been widely sown over the last two decades. It would be worthwhile to review the extent of these efforts and to assess the benefits as there may be some significant additional gains to be achieved in the industry using the existing technologies by focussing research on their effective implementation.

d) The other scenario that was examined with major implications for the property feed base was irrigated forage crops, of particular relevance with a growing interest in the application of mosaic agriculture in northern Australia. Crop modelling using APSIM suggested that where sufficient water is accessible forages could be reliably grown in sufficient quantities and quality to finish large numbers of growing animals, opening up new market opportunities in lower productivity environments. However, increases in profit were very modest and in some regions profit levels were lower than the baseline. Given, the large capital investment required in irrigation infrastructure, the marginal returns on investment were, on average, very low (1-2%) and based on the assumptions used in this project, not economically attractive. However, growing irrigated

forage crops offers alternative market options for finished steers that may make this option more attractive should existing live export markets suffer further setbacks.

An important caveat on the modelling work with forage crops is that within this study we did not explore a wide range of forage crops or growing them out of season and this warrants further effort. In addition, for the APSIM model output to be confidently used to simulate animal production, more work is required on validating forage quality, given its central role in driving animal growth in the NABSA model.

While not within scope of this study, the modelling approach can be extended to explore the use of irrigated land for alternative field crops. This may offer options for diversification in revenue options and higher returns on investment than from irrigated forage crops for beef. This warrants further exploration.

e) Scenarios that improved nutrition of all animals in the herd or genetically improved the growth efficiency of specific classes of animals typically provided larger productivity benefits than those that only lifted weaning rates. This was because improved nutrition or genetic gains in growth efficiency lifted both growth rates and weaning rates, especially in regions where cow weights and body condition routinely limit conception rates.

f) Genetic gains in productivity are best achieved by pursuing both gains in growth and reproductive efficiency because the benefits are largely additive, and when combined, very significant. Increasing weaning rates alone resulted in more calves being put on the ground and while this had clear benefits in profitability there was no additional effect on other aspects of herd productivity. However, the scenario used in this study of improving reproductive performance by increasing weaning rates by 5 percentage points may have been too conservative based on current expectations for herd improvement.

g) Significant effort in addressing nutritional constraints in northern Australia has been on overcoming protein limitations and both the legume and cheap protein scenarios highlighted the productivity and profitability benefits of addressing this constraint. Some future work on examining novel protein supplement sources, e.g. algal protein, as an alternative to legume-based pastures is warranted.

h) This study has highlighted how available energy is a primary limitation for enhanced animal productivity, and relatively small changes in minimum digestibility of available herbage can have very significant impacts on productivity across the herd. The low energy value of tropical pastures has been recognised for many decades as a constraint to raising productivity, but there has been limited practical success in addressing this limitation for extensive enterprises. Consequently, a greater focus has been put on overcoming protein limitations, and the need to overcome digestible energy constraints has faded as a research priority. However, because large productivity benefits can be reaped from relatively small improvements in energy efficiency, increased R&D effort in this area is clearly warranted. Rumen modification is one possibility and while the benefits could be very large from this approach, the chances of success are highly uncertain. Another area for R&D application that warrants additional emphasis, and which may have a greater chance of success, is genetic improvement of sown grasses to increase digestibility. In previous decades active research was applied to exploiting the genetic variability of tropical grasses in order to select high digestibility lines. Modern genetic and genomic

techniques provide an opportunity to re-explore this area as there could potentially be significant gains given the number of cattle in Queensland supported by sown grass.

i) The most significant potential gains in herd productivity and profitability come from exploiting synergies from combining several production technologies and practices that individually have benefits for different aspects of animal productivity. The combined scenarios that were explored in this study resulted in productivity and profitability increases that met the desired target. Most importantly, the combined scenario suggests that R&D needs to be better integrated. It is not good enough to compartmentalise R&D into reproductive technologies or nutritional strategies in isolation from each other – a more systems based approach is required.

j) In assessing the various development scenarios it is important to seriously consider the environmental implications because a number of the scenarios provided the opportunity to raise stock numbers in response to increased weaning rates and improved growth. However, feedback effects were incorporated within the model to allow for the impact of increased pasture utilisation on land condition. In all modelled scenarios the grazing pressure was set at levels at which land condition would not decline, which meant that pasture utilisation rates stayed fairly constant or increased only modestly over a simulation run. For a number of scenarios this meant that adult equivalent numbers increased, and in some cases not insignificantly, even though herd numbers may not have increased greatly. In the case of the legume-augmented pastures, total stock numbers increased more significantly because of greater forage production and increased carrying capacity, but utilisation rates still remained within safe levels.

Methane production per unit area increased in response to scenarios where there was higher productivity and more beef turned off. This was especially the case for the legume-augmented pasture scenario because stock numbers were considerably higher than for the baseline scenario and the improvements in digestive efficiency did not offset the increased livestock number. However, for many of the development scenarios while there was a small to modest increase in overall methane production per hectare, there were significant improvements in intensity of methane production per head. In the case of the combined scenarios this improvement in methane efficiency was approximately 20%.

We did not comprehensively explore development scenarios where overall methane production was kept to baseline conditions and profitability assessed. However, we did examine for the combined scenario in two regions the effect of reducing stock numbers to reduce methane output. Maintaining methane at the same levels as the baseline still produced large profit increases and if stock numbers were reduced to the point where the combined scenario produced the same profit as the baseline, methane was reduced by 30-40%. So there is considerable flexibility in the trade-offs between profit and methane can should be further explored.

k) In summary, the project has developed a useful tool for assessing future development options for the northern beef industry. The results point to several areas of worthwhile opportunities to lift future productivity and profitability of beef enterprises through research and development investment. Importantly, this needs to be accomplished in an integrated way in order to maximise benefits to the industry.

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9 Appendices

Appendix 1 – Reports from Expert Technical Workshops

Notes from Nutrition workshop, Northern Beef Scoping Project

27th July 2011

Participants: Dennis Poppi, Stu McLennan, Rob Dixon, Michael Freer, Lindsay Bell, Nigel Tomkins, Mark Morrison, Ian Watson (also facilitator), Leigh Hunt

1. Unimproved pastures

Obstacles

Stocking rate and spatial and temporal heterogeneity of pasture availability and utilisation; matching stocking rate to availability
Stocking rate is at upper limit for sustainability
Seasonal differences in digestibility, protein, P and minerals
Optimise utilisation rate in relation to sustainability
Seasonality – lack of protein in dry season
       Lack of minerals all year round
       Low quality throughout the year
       Nutritionally constrained in the wet (digestibility, protein, N, P and minerals)
Long wet season making access and management difficult (length of wet season and dry season more generally
Difficulty in unlocking energy from the pasture because high lignification
Not always certain what the rate limiting step is (i.e. protein or energy) since they interact
Poor understanding of effect of nutrition on reproduction – two options

- Get animal up to suitable body condition or
- Get the animal pregnant at poorer condition with condition gain during pregnancy (considered high risk of greater mortality by this approach)

Challenge in the north is to increase body condition at the right time of year so that they calve at the right time of year, but this is difficult to do both in the north.

Opportunities

Much better estimates of quantitative nutrition and diagnosis of nutrient intake
Strong relationships between body condition and reproduction
Personalised medicine for animals determined by the genotype of each animal – target each animal to get appropriate response (matching management to genotype and environment)
Germplasm is available in other breeds across the world that has not been exploited (look for SNP variations) – current work is limited to a limited number of commercial breeds. Could benefit growth, reproduction and cost reduction.
Better understanding of physiology and body condition (and benefit from spike feeding)
Nutrition X genotype interactions e.g. improved feed conversion efficiency (already made some gains in this area over last 20 years)
Walk-over-weighing may allow exploitation of different genotypes
Climate change may increase rain in NW but reduce elsewhere with effects on pasture production
Extension of the growing season with supplements etc

Better use of Bos taurus genes (e.g. for growth rate) – could increase prices received
Improved management of animal through new remote technologies so calving etc at right time, rather than using expensive nutrition supplements
Get a higher proportion of the herd performing at optimum (Sarah Streeter has data on performance spread within herds)
Remote technology and data management
Adopting best management practice

Building into scenarios
Effect of climate change on biomass and feedbase
Parameterise using B. taurus attributes

What would be nature and scale of impact?
Analogy with Texas and Arizona where there are B. indicus but doesn't seem to have much effect on meat demand and prices.
Spike feeding could increase weaning rate by 10% (shown by Geoff Fordyce)
B Taurus genes could improve weaning rate by 10%
Rob Dixon suggests that an improvement of one body condition score is equivalent to a 10 kg increase in liveweight and a 5% increase in reproductive units.

2. Improved pastures

Obstacles
Same as above but also:
- Anti-nutritional factors
- Any increase in intake might increase methane emissions
- Pasture run-down
- Weed invasion
- Increasing dry matter production
- Legislative, political and institutional issues

Opportunities
Ones on unimproved list above plus the following:
- Legumes in grass-based pastures (although a little bit goes a long way)
- Special purpose pastures/mosaic irrigation (and management systems to use forage)
- Improved species with higher digestibility as spin-off from bio-fuel production
- Improved digestibility of C_4 species or improved adaptive range of C_3 species (higher digestibility) to grow in the tropics
- Modify plant or management system to increase DM production or make more tolerant of low rainfall – so more suited to dry regions (including improving water use efficiency in plants)
- Silage/hay for north
- Overcome anti-nutritional factors using bacteria in rumen
- Role of endophytic micro-organisms on plants in the rumen
- Use of algae as feed resource (grown on property)
- Getting the right mix in improved pastures
- Marginal dryland cropping areas to pastoral areas

What would be nature and scale of impact?
- Improvement of digestibility to up to 80% (equivalent to temperate pastures), may double livestock production (if starting at 50 unlikely to get it that high but current average is about 60%). If at 70% now might only manage to increase to 75%. Increase above 80% is unlikely.

- Improved nutrient supply with fewer feed gaps
- Benefits might include increased stocking rates, lower age at turnoff

Building into scenarios
- Change feedbase
- Increasing digestibility
- Other income streams (biofuels, crops)
- More effective use of water
- Others from whiteboard notes

3. Supplements

Obstacles
Knowing what the deficiencies are
Urea/ammonia toxicity
Delivery mechanisms
Understanding substitution rates
Increasing growth rates

Opportunities
Where/when you use supplements – relationship to growth path
Water medication (to lower costs)
Urease inhibitors to reduce ammonia from urea
Novel protein sources (algae) produced on property – lower costs. Spin-off from biofuel technology could lead to livestock value adding to other industries (algal)
Improved animal management to reduce P needs (improve efficiency of use of existing P and remobilisation from bone)
Compensatory growth (is it possible?)
High energy crops (e.g. cassava) - need re-visiting for contemporary situation

What would be nature and scale of impact?
Why use supplements?
To optimise the use of existing feed
To maintain body weight and body condition
Increase growth rates
In many cases gains would be relatively small

See email from Dennis about algae (ponds of 2.5 ha over 12 months can produce enough supplement for 1000 weaners for the dry season. Algae grows at 250 kg/ha/yr)
Rob Dixon has done estimates of benefit of P supplement (se NBRUC paper and others?) – increase in LWG of 40-60 kg per year, and increase weaning rate by 10-15% (P increases intake, increase growth and therefore improves reproduction)

Building into scenarios
Increased P in diet can increase intake by 20-40%
Reduction of mortality (through botulism, although could also vaccinate for this)
Increase in mature cow body weight (i.e. reference weight in model) if using P supplement
Stu has response curves for effect of energy and P supplements
Time and cost of supplement use is important

4. Rumen modification, animal physiology and genetics

Obstacles
Maintaining the modification in herds (need to maintain the selection pressure) – how effectively and for how long can you do this?
Don't understand compensatory growth
Understanding and use of HGPs
Socially acceptable solutions (related to HGPs and rumen modification); can we mimic HGPs?

Opportunities
Identifying bioactives that have a large effect in small amounts and are persistent (e.g. slow release boluses) and methods for delivery
Genetic manipulation (effects on growth and meat quality such as marbling)
Interfering with rumen biology to stop uptake of trace nutrients (e.g. selenium) by bacteria so they remain available to the animal
Identification of other cellulose digesting organisms that can be switched on or off depending on N supplements – may provide better use of forage
Vaccination of animals to redirect rumen populations
Plant breeding to improve pasture quality (peptide delivery)
Biochemical adjustment to animal physiology
Three rumen mechanisms that can be modified:??
- Reduce methane production
- Increase (fibre) digestion
- Protein production by microbes (for use by animal)

Understanding biology (and physio-chemical mechanisms) of methane production and then interfere with it
Understanding threshold considerations in the micro-biology
Plant breeding for reduced secondary compounds
Vaccine technology
Improving skeletal growth (hormonal and nutrient related phenomena)
Ability to cope with low protein diets and role of N recycling
Parasite and nutrition interactions (part satiety and part partitioning of nutrients)
Improving growth rates
Understanding mechanism of satiety – e.g. role of ghrelin hormone (subst effects)

Three key options are related to:
- animal phenotype(characterise microbiology of animals that show variation, and holistically change rumen ecology)
- host genotype
- Identifying ideal/optimal rumen population and ensure most animals have this

Parasite/nutrition interactions (part satiety, part partitioning of nutrients)
Mechanism for satiety and hormone substitution effects

What would be nature and scale of impact?
Only small gains are likely (5-10%)
Improvement in fibre digestion by 10% is realistic starting point and is a key advance as reduced methane and increased protein availability would flow from this
Might be possible to increase microbial protein production by 30-40%
20% reduction in methane production is an aspirational target
Physiological effects would be similar to genetic gains (say about 5%)
Changes to satiety and rumen fill might be potentially up to 30% (because this is the sort of difference found amongst animals)

Improved skeletal growth by up to 30%

Building into scenarios
Change factors that drive feed conversion rate in model/animal
Many factors are intertwined so will need to tweak several parameters in the model (see Ian Lean's report)
Should have scenario 'altered rumen biology' (already have one on rumen modification)
Improved skeletal growth should affect meat yield and also possibly quality (follow this up with Stu)

5. Nutrition and methane emissions

Obstacles
As before
Scale issue in north and difficulty of doing anything about methane production
Animals might already be naturally selected for relatively low methane production (because methane is of no value to the animal)

Opportunities
Quantify methane from different feeds and livestock classes
Feed additives
More efficient production systems
Rumen manipulation
Reduce methane per unit intake (e.g. wallabies produce 1/5 of the volume of methane per unit of digestible energy that sheep do; methane is 1-2% of DE in macropods cf 8% in sheep)
May be related to gut shape (which affects microbe population) and types of microbes present
Capture half the energy lost as C in methane (from 12% loss down to 6% loss) by modifying composition of microbes in the rumen
Approaches to reducing methane are centred around changing fermentation, by changing microflora of rumen (working with existing microflora), selecting animals (methane production has heritability of 0.2?) which might be related to gut shape as there is a host genotype role in methane production

What would be nature and scale of impact?
10-25% reduction in methane production (by using food additives)

Building into scenarios
Tweak feed conversion ratio
Change in methane emission rate per kg feed intake by using feed additives
Reduce the proportion of animals in the herd with higher methane production

6. Blue sky

Cellulosic enzymes from the bio-fuels industry
- Aerobic and anaerobic enzymes could increase feed digestibility from 50 to 80% by allowing existing gut flora to better attack cellulose following pre-treatment of the feed with the enzymes.
- Need to know more about rumen biology to know what are the best enzymes to use
- Could speed up digestion process (reduce from 36 to 24 hours)

- Should result in higher intake so easy to incorporate in the model
- Additional present limitation is producing enough enzyme at a reasonable price

Individual livestock monitoring and management

Integration of precision agriculture technologies including telemetry, walk-over-weighing, smart tags

Use to select animals with higher growth rates and reproductive performance

Individualise management based on the genotype of the animal and its particular growth path or reproductive characteristics, and selecting the animal for the environment (can animals be tailored to individual regions?)

General comments

Nutrition and meat quality (and market appeal such as having grass-fed flavour or omega-3 fats)

Need for a bio-chemical model of individual animal

Summary of key opportunities

- Technology from the bio-fuel industry:
  - enzymes to pre-treat forage to increase digestibility (30% improvement?) - higher digestibility results in higher intake
  - novel protein sources - grow algae on property as high quality feed supplement
- Capacity to select and breed animals on rumen fill (30% increase in intake, greater production)
- 10-25% reduction in methane production per kg feed intake may be possible (using animal selection and feed additives)
- Aspirational goal of halving energy lost from rumen as C (from 12% to 6%)
- Modification of rumen ecology more likely than genetic manipulation of rumen flora
- Increased P supplementation can increase intake by 20-40%, which equates to:
  - 40-60 kg increase in annual LWG
  - 10-15% increase in weaning percentage

Northern beef systems scoping study reproduction and genetics technical workshop notes 18 August 2011
Participants: Andrew Ash, Lee Fitzpatrick, Geoffry Fordyce, Sigrid Lehnert, Tim Schatz, Mike McGowan. Facilitator: Felicity McIntosh

Session 1: Benchmarking data for breeder herds

Available benchmarking data	Known constraints	Source
Beef CRC	Lack of on-farm data. Reproduction is a two year measure. No clear breeder herd productivity indices.	
Range of age at puberty – 10 years worth of phenotypic data.	Quantitative genetics from Johnston's work good for making comparisons.	Geoffry Fordyce and David Johnston
Beef CRC regional templates	These are best guess not based on fact.	Bill Holmes *et al* http://www.dpi.qld.gov.au/16_6886.htm
Cash Cow	Not randomly selected properties – 'better' producers were targeted. Although cattle mortalities known to be high this is not reflected in these data sets. Need to be aware of the difference between data that is 'precise' versus 'accurate'.	
Cash Cow – exposing northern breeder herd productivity	Only one reproductive cycle at this stage.	NBRUC 2011 conference proceedings pp 19-23
Net beef production data available from March 2012		
RCS P/L		Terry McCosker and Braithwaite
Herd performance, pasture and cash flow data		
Northern Territory		
Heifers		Tim Schatz
Live weight gain (growth) post weaning available from mid 2012		Tim Schatz
Breeders – Mt Samford and Pigeon Hole		Tim Schatz
Other		
Beef cattle performance in Northern Australia	Somewhat dated – more recent studies,	Peter Hasker pdf available from Felicity McIntosh

– a summary of recent research (2000)	e.g. Producer Demonstration Sites (PDS) data.	
High input systems for northern breeding herds – Final Report NBP.334 (2007)	Biological and economic focus.	Fordyce *et al* pdf available from MLA
Phil Holme's data from Northern Territory, etc showing rates of up to 11-12% breeder mortality	Need to check datasets, e.g. Alice Springs.	
O'Rourke and Sullivan's work in Hasker (see above)		Hasker (2000)
Neithe's work regarding cow mortality, unpublished		Geoff Neithe
Swans Lagoon annual reports, unpublished		Geoffry Fordyce

Issues and comments
- Difficulty in defining reproductive and genetic potential.
- The need to have clearly defined productivity indicators/parameters, for example:
    - Number of cows retained per year versus the weight of weaners produced
    - Net beef production = kilograms of beef produced per animal equivalent
- The need to develop a benchmarking framework for the northern beef industry.
- Reproductive benchmarking parameters:
    - Weaning rate versus weaner weight
    - Growth rates of steers and heifers – replacement heifers
- Selecting for growth in heifers can result in problems – need to look at putting heifers on better country versus putting just the steers there. (That is, assuming the steer growth rates are the same as the heifers.)
- Heifer best management practice, i.e. high pregnancy rates over a short term, can set up a business.
- Cows in condition score 4 (590 kg at slaughter therefore carcase weight of approx. 300 kg)
- Mortality rates: majority of losses occur within a week of birth (neonatal) deaths
    - Need to include cull cows in weaner 'rate'
    - Very little idea of cow mortalities.

Session 2: Improving productivity – best management practice

Current best management practice in reproduction and genetics	Potential gains by 2030
Heifer segregation and targeted management, including: nutrition; joining weights in maiden heifers; pre-calving rates in first calf cows.	Pregnancy rates in maiden heifers 60-75% and first calf cows from 15% to 45%.
Best practice weaner/weaning management (BPM), the keys being: feed, water, strategic weaner management (e.g. vaccination, castration and dehorning techniques).	Could reduce cost per calf by $10/head. If it wasn't necessary to brand, castrate or dehorn calves could get a 7% decrease in mortality. Similarly best practice of these procedures also helps to significantly decrease mortalities.
Foetal aging	
Using BREEDPLAN bulls with genetic merit for daughter and bull fertility: - selecting for growth rate is OK but has reached its limits, need a balance – nutrition is the limiting factor - feed conversion efficiency.	Approximately 0.5% per year, i.e. 10% in 20 years.
Selection for pollness.	
Selection of bulls using BBSE and reducing the percentage of bulls used, i.e. reducing cost per calf. This is closely linked weaning BPM.	
Reducing percentage of bulls used.	
Increased adoption of 'controlled mating' (Holmes & Sackett), i.e. using mating management with suitable nutrition to minimise dry season lactation. This includes using best practice weaning and mating management. That is, good cow condition and heifer growth which relies on having the right genetics with best practice feed and water management (incl. distance to water).	
Crossbreeding versus pure Brahmans (composites), i.e. using selection pressure with breeds.	This may increase, or widen, marketing opportunities.
Good weaning management is: pregnancy testing (foetal age)	Consistently achieve pregnancy rates, e.g. 75-85% which would/could result in a weaning rate of 70% which is 20% greater than the median.

- reducing calving interval to every 12 months by getting weaners off at right time - Monitoring heifer growth, in terms of condition and skeletal development. Monitoring cows condition score, not necessarily their weight. - Monitoring tools include: NIRS, remote sensing, etc. - Vaccinating for botulism, pestivirus and vibriosis (in that order).	Vaccination would reduce mortality rates significantly.

Targets
1. Weaner rate
2. Growth rate
3. Mortality

Issues
- Understanding production limits – need to identify these and keep in focus.
- Heifer (young cattle) growth – liveweight versus skeletal growth.

Session 3: Improving productivity – future gains

Future reproduction and genetic technologies	Potential gains
Development of a framework/program for ongoing performance benchmarking.	
Improved AI technologies, including: semen production; adoption; cost effective large scale AI programs for northern herds.	
Marker selection would increase female fertility/genetic gain: - these innovations/technologies will increase adoption and push female fertility to desired limit - identifying greater numbers of bulls and decreasing risks associated with reduced gene pools - industry wide selection fertility supplemented by markers… <NB Not sure what this was leading to/about>	A 0.5% increase per year for 10 years and would also decrease production costs.
Not marking calves will significantly decrease mortalities, decrease	For example, greater returns (in the order of 7%) for carcases from

costs, increase animal welfare, and increase growth. And in turn increase potential market premiums.	animals with increased feed conversion efficiency.
Semen sexing – available now in/for dairy cattle, not commercially viable for beef cattle yet.	
Genomics to identify parasite resistance.	
Remote sensing technologies, e.g. automatic drafting for steer paddock	
Changing the way we think about production, i.e. in terms of kilograms of beef per hectare or animal equivalent.	
Refining bull joining percentage, which (a) increases genetic progress and (b) reduces calf cost.	
Improved supplementation technologies, or managing without supplements, due to potential negative aspects, e.g. availability, cost and environmental impacts.	Potential loss/cost if production lost.
Decreased neonatal deaths will have a significant impact.	
There is still a lot of genetic variability to exploit.	
Selection for 'adaptation' between and within breeds, e.g. thermoregulation – one in five Brahmans has poor semen quality…. <NB Rest of sentence missing from pdf>	

Productive potential
- 75% weaner rate as a 'rolling' average.
- 85% weaner rate is possible.
- Female genetic gain is currently -0.5%.

General comments
- Vital to remember/include the people aspect in any modelling, e.g. succession planning.
- Similarly the impact of land values
- Barkly and north west Queensland are quite different.
- Adoption rates and research.
- Different groups of producers have different requirements and possible targets (in terms of reproduction and genetics).
- Managing nutrition/energy flow through the system.

Appendix 2 – Report on the performance and development of extensive beef industries in other countries

Beef Industry Productivity and Development In Some Major Beef-Producing Nations: A Review

Leigh Hunt, CSIRO Darwin

Introduction

In exploring the potential for increasing the productivity of Australia's northern beef industry it is prudent to reflect on international trends in productivity and technological developments in beef production. Innovations in beef production systems in other countries may inform potential development opportunities and associated risks in Australia's beef industry. The collation of productivity data for the beef industry in other countries also provides a benchmark against which the current and potential performance of Australia's northern beef industry can be evaluated. A review of the international literature was therefore conducted to identify innovation and productivity improvements that might be included in the scenario analysis of potential development options in the northern beef industry.

The review involved the searching of on-line databases of scientific literature (e.g. Web of Knowledge), the review of relevant journals and where necessary discussions with relevant authors/scientists to obtain additional information. Web searches for relevant grey literature (not published in the formal literature) were also conducted.

The review concentrated on areas of the world with relatively advanced commercial beef industries and agro-ecological characteristics similar to northern Australia. The countries identified as satisfying these conditions were the Argentina, Brazil and the United States.

Several issues arose in obtaining relevant information for conducting this review. Firstly, while some countries publish regular reports and reviews on the performance of their agricultural industries, many countries do not. Where such reports were not available for review, an assessment of the industry for a given country was made based on available data.

Secondly, the nature and detail of reporting on the performance of agricultural production varies considerably amongst countries. In many cases only very general statistics on livestock industry performance are reported, and the data are often not reported on the basis of geographic or agro-ecological regions, so it is difficult to separate production data in rangeland or savanna settings from overall data.

Thirdly, the variables used to report production performance (or the definition of performance variables) also frequently differ amongst countries. Finally, another limitation was that scientific developments reported in the literature usually do not include details of the effect or potential benefit of a development on the performance of the industry. Furthermore, the implementation of technological developments that contribute to a more productive industry are not necessarily reported in the scientific literature.

This report first reviews the recent performance of the cattle industries in major beef producing countries and explores the reasons for trends in this performance. The

report then briefly discusses a number recent technological developments that may have relevance to improving productivity in Australia's northern beef industry.

World trend in cattle production

The Food and Agriculture Organisation (FAO) reported that improvements in cattle production over the last twenty years have lagged behind that for monogastric animals, especially in developing countries. A trend towards 'industrialised' production systems based on concentrate feeds has benefited monogastric production to a greater extent than ruminant production. The main drivers of growth in livestock production in general have been cheap inputs (low grain prices and to some extent fuel) and efficiencies of scale (fewer larger properties with associated technological improvements) which have led to increased livestock numbers. Gains in production due to higher yields (i.e. production per animal) have been relatively small (1-2% annually) in both the monogastric and ruminant sectors. The greatest increases in yield for cattle production have been in the Near East and north Africa, with an average annual yield growth of 2% (FAO 2009).

Beef production systems and trends in major beef producing countries

Argentina
Overview
The state of Argentina's beef industry was recently reviewed by Feldkamp (2011). Between 2003 and 2010 Argentina's national herd averaged 55 m head, with about 28 m cattle (i.e. ~58% of the national herd) in the rangelands. Breeding operations tend to dominate in the rangelands.

Importantly, there has been a recent shift in the nature of the Argentine beef industry, including a decline in the area of land available for cattle (Feldkamp 2011). This reduction in cattle grazing land has been driven in part by an increase in cropping (especially soybean production) on lands traditionally used for cattle production (e.g. the Pampas) due to improvements in low tillage crop production technology. As a result cattle production has moved out of the more fertile regions. Breeding operations have become less intensive and are now largely confined to the less productive areas (in the north and west of the country) and rangelands, with associated reductions in production efficiency (Steiger 2006). The development of cattle operations has occurred in some new regions and this has often involved clearing and sowing of improved pastures (including *Panicum* and *Cenchrus* spp.). Meanwhile, cattle (steers) for fattening are now sent to areas that were once used for breeding.

The loss of land for cattle grazing was not followed by an immediate decline in cattle numbers. In the rangelands stocking rates therefore tended to be above carrying capacity, so overgrazing and degradation was common. A major drought and overstocking in 2008-09 resulted in land degradation, and this was followed by a marked decline in cattle numbers and production. Feldkamp (2011) suggested these effects might last until 2016.

Meanwhile, the production of feeder cattle has become more intensive and has involved the use of higher energy feeds. A shift from grazing lucerne pastures to feeding corn in the early to mid 2000s was an important development in increasing the productivity of the Argentine beef industry (Steiger 2006). Feldkamp (2011) also reported a general improvement in cattle and veterinary care and increased use of supplements in recent years.

The Argentine beef industry has historically had lower costs of production compared with other beef producing nations (Steiger 2006). Over the last 20 years the use of cheap local grain (especially corn) and corn silage has resulted in a marked increase in the feedlotting of cattle for the last 90-100 days of the fattening period. In the early 1990s feedlots were of little importance but by 2009 they supplied 40% of the finished cattle. However, the shortage of land for growing cattle meant they were being sent to feedlots at a lighter weight, with subsequent lower slaughter weights (280-350 kg). The Argentine Government subsequently banned slaughter at less than 300 kg (165 kg carcass weight?), which was expected to increase average carcass weight.

Productivity and industry development
It was not possible to locate performance data for Argentina's beef industry separated according to agro-ecological regions such as the rangelands or tropical savannas. The productivity of Argentina's beef industry overall (i.e. including mesic agricultural regions and the lower productivity rangelands) appears to be below that of Australia's northern beef industry. Key performance indices for the Argentine industry for the period 2003-2010 are:
- Average weaning rates of 60-65%.
- Carcass weights of between 207 and 226 kg (IPCVA 2011).
- Beef yield per animal of about 53 kg.
- Extraction rates (turnoff) of approximately 25%.

In comparison, turn-off in Queensland has been about 32-35% over the last 10 years, carcass weight has been about 250-280 kg, and beef yield per animal has been around 80-90 kg (Ash 2010).

There has been little improvement in carcass weight in Argentina over the last 50 years (mean increase of 0.17% per year) (Fig. 1), although this has improved slightly since 1990 (0.24% increase per year). This increase may reflect the imposition of the minimum slaughter weight by the Argentine Government rather than a genuine increase in performance. Low carcass weights are attributed to short growing and fattening periods (the latter related to seasonal uncertainty), and a lack of access to export markets that take heavier animals (Feldkamp 2011). Rangeland scientists in Argentina have recognised the need for improvements in production systems to increase weaning rates, carcass weight and turn-off (Feldkamp 2011).
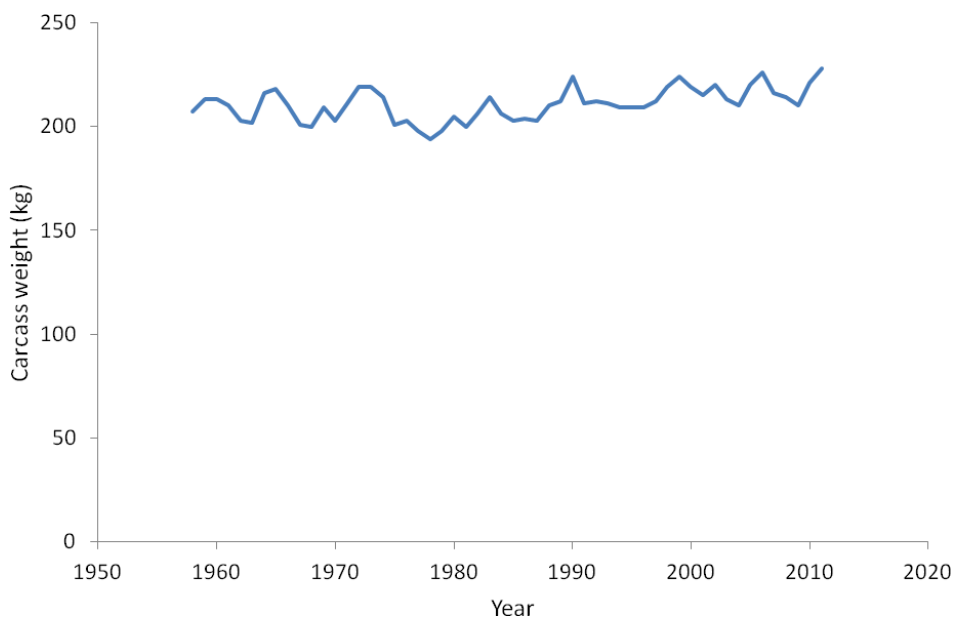
Figure 1. Mean annual carcass weight for the Argentine beef industry since 1958 (data from IPCVA 2011).

Annual turn-off and annual production per head for the Argentine beef industry since 1958 are presented in Figs 2 and 3. The strong relationship between turn-off rate and production per head is apparent in these figures (which are both related to the numbers slaughtered). These data suggest there has been no consistent improvement in production per head for several decades. However, the effect of producers retaining animals to build-up the herd and periods of herd reduction (driven to some extent by seasons and market conditions) influence turn-off and production per head. When turnoff is above about 25% herd size declines, suggesting insufficient replacements are being produced to sustain greater turnoff.
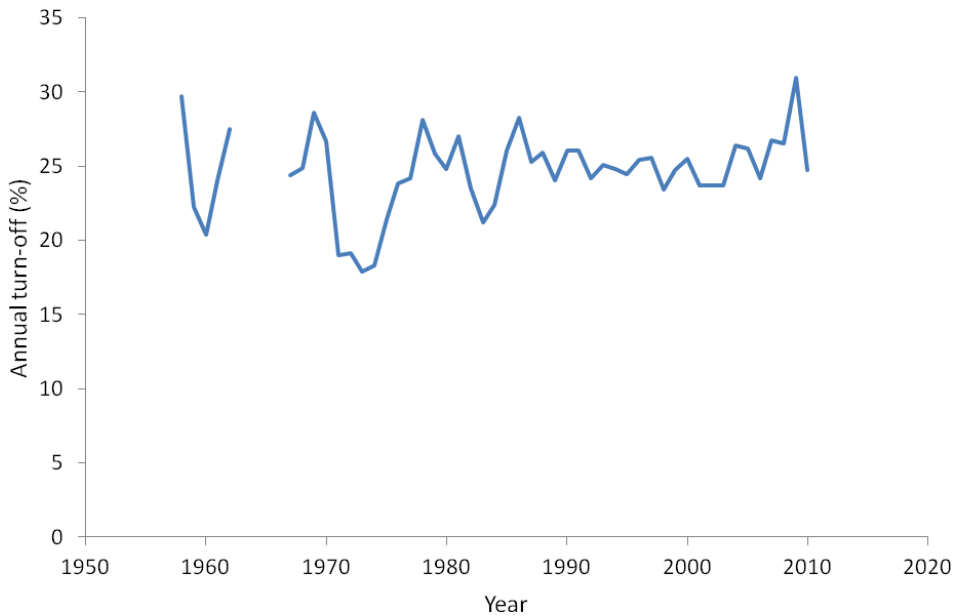
Figure 2. Annual turn-off (percent) for the Argentine beef industry since 1958 (data from IPCVA 2011).
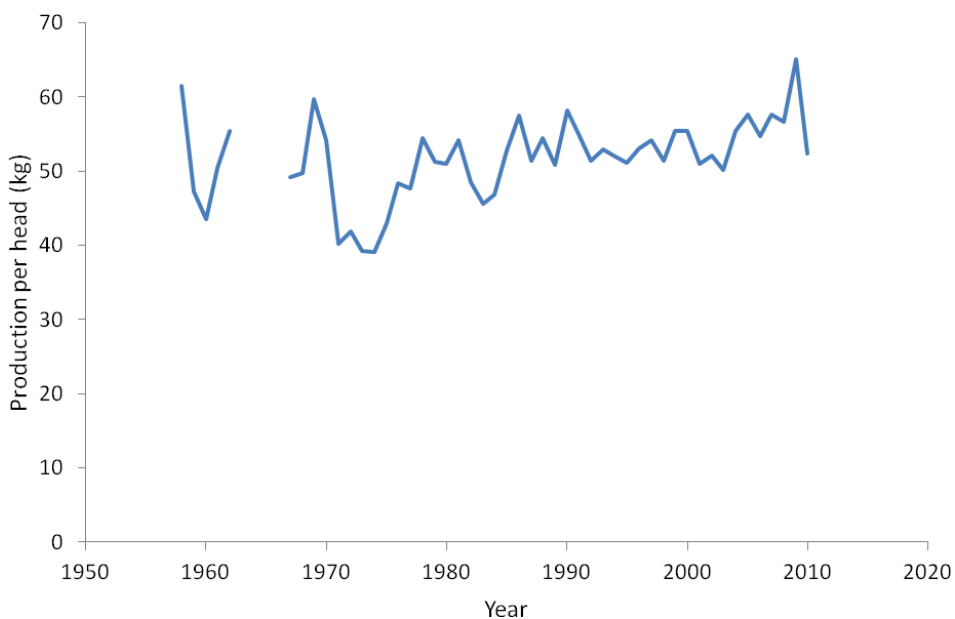
Figure 3. Mean annual production per head for the Argentine beef industry since 1958 (calculated from data published by IPCVA 2011).

Management issues

In some of the more arid rangeland areas of Argentina the production system is essentially one of harvesting virtually wild cattle. Feldman (2011) suggests that a major problem in these areas (such as parts of the Chaco region) is uncontrolled livestock distribution and patch grazing due to the large paddocks and sparse distribution of water points. These problems lead to poor livestock performance and land degradation. On more developed properties seasonal shortages of forage reduce livestock production, but some producers have sown buffel grass to help alleviate this problem. The use of salt and phosphorus supplements has helped to improve calving rates and liveweight gain in some regions (Feldman 2011).

Summary and future developments

The data suggests development of the Argentine beef industry has been flat in recent years. There have been no notable technological developments that have benefited the industry. Rather, the industry has suffered as a result of improvements in cropping technology. However, observers of the industry expect that there will be further intensification of beef production over the next decade (Feldkamp 2011). For example, large meatworks have recently begun establishing large-scale feedlots.

Improvement of rangeland pastures by introducing non-native species is considered to have potential to increase livestock carrying capacity, but this is expected to have adverse environmental consequences including the loss of biodiversity. Also, vegetation clearing is now banned, which will limit future development of more productive pastures where unimproved pastures are the norm.

Future challenges for the industry include maintaining stability in the face of climate variability and the tendency for overstocking to occur as beef prices rise (as is occurring presently).

Brazil

Overview

The beef industry in Brazil has undergone greater development than that of Argentina. However, few data on trends in productivity in the Brazilian beef industry were located so this assessment is based on various reports by other authors. Reports generally refer to the entire Brazilian beef industry, rather than specific regions such as the rangelands.

Brazil has shown strong growth in beef production in recent years, with production increasing 36% in the ten years to 2009 (cattle site web site). This growth is due to both an expanding herd and productivity improvements arising from government investment in research and development. The national beef herd in Brazil grew by 24% in the period 1994-2006 (Steiger 2006) and was approximately 143 m head in 2005 (Carvalho 2006). This growth has been driven by increasing beef exports and a sizeable domestic market, while the availability of (newly cleared) land for the expansion of grazing, the provision of credit subsidies to support expansion (through investment in improved genetics, pastures, machinery and cold storage facilities) and favourable trading conditions (relaxed trade barriers and good exchange rates) have been important in allowing this growth.

These developments have allowed the benefits of economies of scale, which have contributed to the growth in overall production. Large modern specialised beef operations are achieving higher efficiencies and cost economies than the traditional production systems (Somwaru and Valdes 2004). Traditional production systems have very low productivity but still dominant the more remote (and 'frontier') regions. Overall efficiency in the industry has been low but the most integrated operations (i.e.

those rearing cattle from calving to slaughter) are the most efficient and benefit from economies of scale (Somwaru and Valdes 2004).

In 2004, Brazil's beef production enterprises were dominated by grass-fed systems, with less than 3% in feedlots. The grass-based systems tend to be smaller enterprises whereas larger enterprises (>4000 head) are usually a mix of grain and grass fed systems (Somwaru and Valdes 2004).

Savannas account for 55% of Brazil's extensive beef enterprises. Some of this area has improved pastures, but the productivity of these areas is generally low due to low soil fertility, overgrazing and the use of animals with poor genetic potential (Carvalho 2006).

As in Argentina, an increase in soybean cropping in the Centre-West region (the traditional region for beef cattle in Brazil) and the associated increase in land values has forced cattle production into new areas. In particular, there has been a northward shift where land is cheaper. However this reduction in land cost has contributed to an improvement in profitability of about 10%.

The beef industry in Brazil has benefitted from historically lower costs of production by world standards (Steiger 2006), giving Brazil's beef producers a competitive advantage in international markets. Production costs have been 60% and 50% lower than in Australia and the US, respectively (Somwaru and Valdes 2004). However, in recent years, rising input costs and land prices have slowed beef production in Brazil (Voss 2011).

Productivity and industry development
There have been productivity improvements in certain aspects of Brazil's beef production system over the last decade or so. The average slaughter rate to 2004 was 21% and average slaughter age was 4 years (compared with 37% and 2 years for the US, respectively; Dyck and Nelson 2003), but four years later the average age at slaughter was 36-40 months (Euclides *et al.* 2008, Carvalho 2006). However, increased demand for Brazilian beef had helped to reduce average slaughter age (Steiger (2006). Beef yield per animal increased by about 20% between the 1980s and 2000s (Somwaru and Valdes 2004). [yield data?] However the birth rate is only 60% and inter-calving interval is 21 months (Carvalho 2006).

Improvements in the productivity of the Brazilian beef industry have been attributed in part to improved livestock genetics (related to live weight gain) through the use of cross-breeding and artificial insemination (with imported semen from Red Angus, Angus, Simmental and Limousin). Steiger (2006) considered there was still scope for production growth in Brazil through cross-breeding and reducing the content of traditional breed genetics in the herd (which tend to produce lower value, slow growing and less well muscled beef from pastures).

Government subsidised land conservation programs, improved pastures and better pasture utilisation have also been credited with some of the productivity improvements. Pasture improvements have included the use of legumes and pasture irrigation (with associated improvement in irrigation infrastructure). There has been some irrigated production of tropical forages in recent years to boost carrying capacity, although this is not profitable in all areas. Improved management of stocking rate has involved the use of specific pasture utilisation targets (Carvalho 2006).

Supplements are used at certain times of the year, in particular protein during the dry season to increase the intake of low quality standing forage (Carvalho 2006). Euclides *et al.* (2008) reported research that investigated feed supplementation of cattle grazing pasture during the dry season to help overcome seasonal shortages. As the level of supplementation increased (up to 6% of liveweight) average daily gain increased and time to target weight declined (although the best economic performer was not the highest level of supplementation). In these studies, grazing of the pasture was deferred for a few months before being used.

Management issues
Government policies that specify minimum stocking rates as justification for retaining ownership of land and the importance ranchers place on retaining cattle as a form of financial security and liquidity have contributed to considerable overgrazing on cattle ranches in many areas such as the Brazilian Pampa Biome (Carvalho *et al.* 2011). Meeting the legislative requirement of a minimum stocking rate is considered to be the dominant factor influencing management of the properties, and is reflected in generally poor livestock production. Apparently authorities believe that setting minimum stocking rates contributes to generating greater livestock production, but the high stocking rates and the negative effect on individual animal production mean that overall production is relatively low.

The dominant management practice of continuous year-round grazing is also considered to contribute to land degradation because of the considerable intra-year variation in forage availability. Research has suggested that better matching of stocking rates to pasture production can double livestock production (Maraschin 2001) on native pastures, with moderate stocking rates proving most productive. Liveweight gain could exceed 200 kg/ha/year. Carvalho *et al.* (2011) suggested strategic intensification of pasture production on more favourable restricted areas (through the application of N and P) to reduce the effect of poor production during periods of low growth, and also to reduce grazing pressure on other less productive areas. An outcome of this proposed strategy was to improve the sustainability of the grazing system.

Invasive weeds and wildfire are also contributing to declines in beef production.

Summary and future developments
In summary, recent expansion of Brazil's beef industry has resulted from a combination of opening up new grazing lands and productivity improvements resulting from better cattle genetics and pastures. Future expansion of the industry (in particular the emergence of larger, more commercial operations) may be impeded due to pressure to reduce the clearing of vegetation to create new grazing land. Nonetheless, Steiger (2006) suggested that the industry's current status as a low cost-low value industry that is poorly coordinated and variable in nature, means there is scope for improvements in the entire production chain. Steiger (2006) also argued the industry should become more sophisticated and target niche markets and higher value opportunities whilst remaining a low cost supplier. In recent years the abundance of large feedlots has been increasing (McAlpine *et al.* 2009).

Efforts to reduce the average age at slaughter to below 40 months are considered important to improve production efficiency in the industry (and there is evidence of some progress in this). Efforts include using concentrate supplements to overcome dry season pasture shortages (Euclides *et al.* 2008). However government policies such as the provision of subsidies to small farms are likely to continue and may limit the growth and development of the beef industry.

United States

Overview

The US cattle industry is characterised by a 9-14 year cycle in herd size (driven by price and the biophysical constraints that limit the ability of producers to quickly respond to prices), but there is a long-term trend of a shrinking US cattle herd. The contraction in the industry in recent years has been due to low profitability, which reflects weaker demand and increasing input costs (www.thebeefsite.com). Environmental pressures (e.g. riparian management, biodiversity) and the high cost of land are also contributing to the shrinking national cattle herd (G. Shewmaker, pers. comm.).

It was not possible to locate data specifically related to extensive cattle operations in rangelands, so this discussion and associated data refers to the entire US beef industry. The industry has seen a consolidation of cattle operations in recent years, with a greater proportion of the herd being produced by fewer, larger properties. Both the total number of cattle operations and the number of beef cow operations declined by 1% in the year to 2009, continuing a trend over the last 20 years. The typical beef enterprise in the US in 2007 had 40 head, but those that carry in excess of 100 head produced the majority of beef in the US (Economic Research Service 2009). The industry is characterised by a large proportion of the herd being grain-fed prior to slaughter. The considerable use of corn for growing and finishing cattle in the US differentiates the US industry from that of other major beef producing countries (Peck 2009). This practice has also had a strong influence on beef genetics and production systems in the US to maximise the benefit of feeding corn.

The number of cattle in feedlots declined in the three years to 2009, partly because of an increase in the price of corn which has reduced the profitability of feedlot operations. However, in 2010 there was a 4% increase in the number of cattle in feedlots.

Productivity and industry development

Despite cattle numbers having declined by 15% since 1979 beef production has increased by about 22% (Fig. 4). This increased production is attributed to an increase in average dressed weight of about 23% over this period (Fig. 5). This reflects a long-term trend toward producing heavier animals (Mintert *et al*. undated).
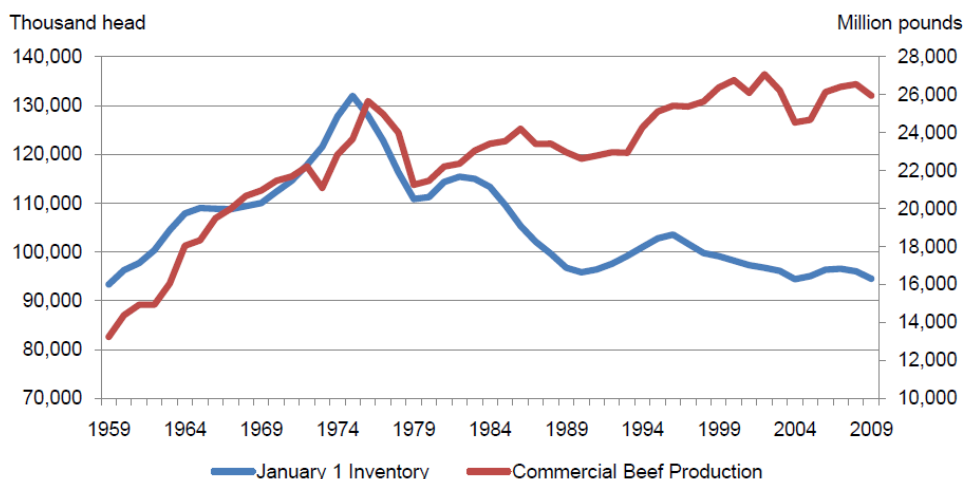
Figure 4. The size of the beef herd and total commercial beef production in the US in the 50 years to 2009 (USDA 2010).
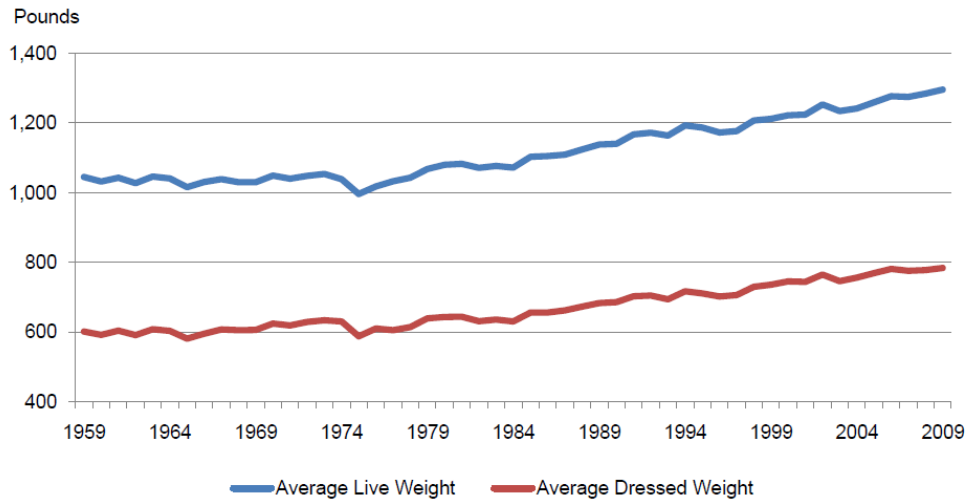
Figure 5. The average live and dressed weight for cattle in the US in the 50 years to 2009 (USDA 2010).

Over the period from the mid 1960s to 2005 beef production per cow increased from 400 pounds (182 kg) to 585 pounds (266 kg). However, the trend in beef production per cow appears to have flattened out over the last decade, notwithstanding some annual variation (Fig. 6).
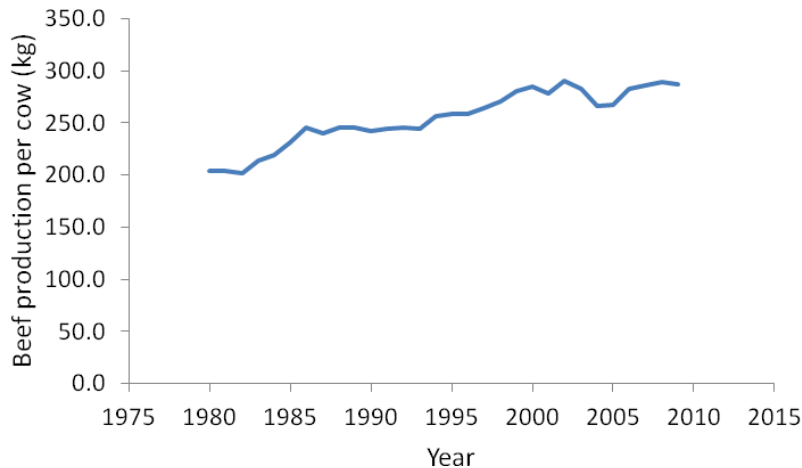
Figure 6. Mean annual beef production per cow (kg) for the US beef industry over the past 30 years. (Calculated from data from USDA 2010).

Mintert *et al*. (undated) attributed the increase in beef production per cow to slaughter at heavier weights, and a reduction in the slaughter of calves (especially in the dairy industry) which effectively increases production per cow. The degree to which selection for larger framed animals has contributed to heavier weights is not clear.

Management issues
Much of the research on productivity improvements in the US beef industry focuses on improved finishing of cattle and the effect of different forages or management practices on animal performance and carcass characteristics during finishing, or on improving reproductive performance through the adoption of reproductive technologies. In particular, there are efforts to increase the use of artificial insemination (AI) and associated reproductive technologies to accelerate genetic improvement of the national beef herd (Johnson *et al*. 2011). Given the relatively small size of many beef enterprises in the US the feasibility of using these

technologies is greater than for many of the more extensive properties in northern Australia.

Summary and future developments
The US beef industry appears to have experienced only incremental improvements in productivity in recent decades, and a long-term trend of increasing carcass weights reflects to some extent a change in marketing (i.e. delayed sale of animals) rather than genuine productivity gains. While there has also been a trend of increasing production per cow during the 1980s and 1990s, in the last decade this increase appears to have flattened off, as it has also done in the northern Australian beef herd.

The direction of future development in the US beef industry appears to be related to the improvement of finishing practices and the adoption of advanced reproductive technologies. A theoretical economic modelling exercise has suggested that intensification of beef production (using improved forages and irrigation) in the more mesic parts of Utah would generally be profitable and sustainable, but the authors suggested this needed testing with empirical research (Coppock *et al.* 2009). The United States Department of Agriculture (USDA 2010) considered it unlikely that the national cattle herd will grow in the near future. It is not clear what this may mean for advances in productivity in the industry.

With low profit margins in the rangeland beef industry there is an increasing trend of cattle ranches being sold for other uses including urban development. However, many ranchers have a strong motivation to stay on the land despite poor profitability and more than half have been reported to support their ranch with outside funds (Brunson and Huntsinger 2008, and references therein). Many ranchers also generate revenue by developing hunting and tourism activities on their ranch. These developments suggest limited opportunities to improve the productivity and profitability of beef enterprises.

Conclusions from review of international beef industries
The reports reviewed suggest that in general productivity growth in the beef industry in major beef producing countries has been low in recent years. There appear to have been no major technological developments that have led to substantial improvements in the performance of beef production in any country. The opening up of new land for cattle grazing has contributed to increased beef production in some countries, but this has not been associated with improvements in total factor productivity. Conventional developments such as improvements in pasture productivity and the genetic stock have contributed to increases in productivity in some countries, but these have generally started from a relatively low productivity base.

The literature search uncovered few new technologies with the potential to transform the northern beef industry and generate substantial increases in production. In the following section a number of more general issues and prospective technologies for improving productivity that have been discussed in the literature are presented.

While it is difficult to make direct comparisons with other countries (due to the unavailability of suitable data) the productivity of Australia's northern beef industry appears to compare favourably with the countries considered here. The limited data suggests that at least in some regions of Australia (e.g. Queensland) productivity per head is greater or at least similar to that other of nations. However other regions of northern Australia such as the NT may not compare as favourably.

Potential technological options for productivity improvements in the northern beef industry

A number of emerging technologies or ideas may have potential for improving productivity in the northern beef industry. It is likely these will produce incremental rather than substantial gains in productivity. The challenge in exploiting these technologies will be in incorporating them into what are generally extensive, low input operations.

A recent publication suggested there was an opportunity to improve feed conversion efficiency in cattle. Reynolds *et al.* (2011) noted that because of the low digestibility of forages consumed cattle have a lower residual feed intake (RFI, an indicator of feed conversion efficiency) than poultry and pigs. However, since there is a genetic contribution to variability in feed conversion efficiency among animals it is possible that RFI in herds could be improved through animal selection (Reynolds *et al.* 2011, Herd and Arthur 2009). The benefits of improving feed conversion efficiency could include reduced intake and less effect on natural resources, as well as reduced methane production. A prerequisite for selection of animals on the basis of feed conversion efficiency is the identification of biomarkers for RFI, since it is difficult and time-consuming to measure (Reynolds *et al.* 2011). Considerable progress has been made in identifying DNA markers for feed efficiency in Brahman cattle (Australian Brahman Breeders Association 2007). Digestibility of feed contributes to RFI as well, and there has been interest in improving digestibility (in dairy cattle) by using feed additives such as ionophores (antibiotics that improve feed efficiency), yeasts, enzymes and microbials (Casper 2008, cited by Reynolds *et al.* 2011).

Other emerging technologies such as altering livestock behaviour (through selection and training) (see Provenza *et al.* 2003, and generating research interest in countries such as Argentina; N. MacLeod pers. comm.) may offer some benefits in increased production and lower environmental effects, but the improvements are likely to be incremental rather than transformational. Advanced reproductive technologies may also offer benefits such as accelerating genetic gains in the herd or allowing sex selection in offspring (for example to increase the number of female calves in a breeding operation). However, implementing many such technologies on the extensive beef enterprises typical of northern Australia will present a considerable challenge. The cost-effectiveness of such technologies is also uncertain at this stage.

There is speculation that nanotechnologies and transgenic techniques may have a role to play in increasing livestock production in the future (Thornton 2010). Nanotechnology may be used to deliver medications to animals or enhance the uptake of nutrients from forage (Thornton 2010). New strains of livestock with higher growth rates, improved feed conversion efficiency, better carcass composition and improved reproductive performance could be developed using transgenic techniques (Wheeler 2007, cited in Thornton 2010).

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Appendix 3 – Improved forages review

Meta-analysis of beef production on improved forages in northern beef industry

December 2011

Prepared by Lindsay Bell, CSIRO, Toowoomba

1. Introduction

The North Qld beef industry is facing some major challenges associated with profit drivers but there are also some significant opportunities to ensure a prosperous industry into the future. While profitability is driven by prices, costs of production and productivity of the herd, producers really only have influence over two of these drivers in costs of production and productivity. The MLA-CSIRO 'Research opportunities for sustainable productivity improvement for the northern beef industry' project is examining a range of future interventions and the implications this could have on productivity and sustainability of the northern Beef industry.

One area where improvements in productivity might be possible is through the use of improved or more intensive forage production systems where increased beef turn-off and possibly enhanced marketing opportunities are possible. In particular, one opportunity being proposed is the potential to intensify forage production on small areas of large cattle properties, where cultivation might be used to grow rain-fed or irrigated forage crops or improved pastures. A large amount of previous work has investigated various improved forage technologies that could be used to improve beef production via either improved animal nutrition and/or increased grazing yield. It seems pertinent to analyse this large body of past research to validate the scale of changes in productivity that could be expected via the use of sown pastures and forages and to assess the types of forage systems that are feasible in different regions in northern Australia.

2. Purpose

The purpose of this review is three-fold. Firstly, to provide a basis for sensibility testing of simulation modelling and predicted production levels for beef production systems being conducted in the whole-enterprise simulation modelling analyses. Secondly, to identify where there are gaps in data for the animal production potential on various forage sources in a range of regions across northern Australia. Thirdly, to provide some guidance on the relative productivity of beef cattle grazing various forage sources available in northern Australia. This meta-analysis was not designed to make direct comparisons between different forage sources, but to examine the range of production levels that might be expected in different regions. Few studies compared a diverse range of forage sources under the same growing conditions, but there were sufficient studies where grass-based pastures with and without legumes were compared to examine the effect of legume introduction more widely.

3. Scope and details of literature used

We examined over 60 published articles where beef production in northern Australia had been reported, and have collated data for 1170 measured treatment.years. This spanned articles examining the interactions of pasture composition and stocking rate, comparisons of the production from various forage types, as well as the impacts of supplementation and pasture fertilisation on beef production. Studies where breeding herds were used were not included because of the difficulty in comparing the overall

beef production across different enterprises, hence, data were collated using annual live-weight gain of yearling to 3 year-old animals. Appendix 1 provides a summary of the articles arranged by the various forage types and geographic region where data were sourced.

In Table 2, it can be seen that the vast majority of grazing studies have been conducted in North, Central, the Wide-Bay Burnett and south-east Queensland. Not surprisingly these are associated with beef research stations in each of these regions (i.e. Lansdown Research Station (188), Brigalow Research Station (75), Brian Pastures (85) & Narayen (249) Research Stations, and Samford (112) and Beerwah (117) Research Stations. Studies that reported beef production from native pasture or sown grass pastures with or without sown legumes were the most common. There was far less data from the Northern Territory and northern Western Australia. The proportion of studies in central, southern and south-eastern regions of Queensland is disproportionate to the proportion of the northern beef herd (41.4%) (Table 2). The representativeness of the range of studies examined here against the northern beef herd Some surprising gaps in the data were 1) the lack of reported data from the southern inland regions of Queensland (e.g. Darling Downs); 2) the lack of published comparative data on animal production with and without leucaena, most of which were focused in south-east Queensland at Samford Research Station.

Table 1. Number of annual beef production measurements across a range on different forage sources reported in different regions of northern Australia.

Forage source	Total	NT/ Kimberley	North Qld Qld	Central Qld	Wide-bay/ Burnett	Southern Qld	SE Qld/ Moreton
Native pasture	167	14	55	34	59	5	5
Native pasture + legume	288	12	100	125	51		
Native pasture + leucaena	6				6		
Sown grass	247		33	13	79	14	122
Sown grass + legume	278	5	60	6	101	8	106
Sown grass + leucaena	33			1	8		24
Forage sorghum	63	3		32	14	2	14
Summer legume	38	9		7	22		
Winter cereal	43	6		11	15	2	11
Other annual forage	6			6			
Total	1169	49	248	235	355	31	251

Table 2. Estimated adult equivalents in each region and the contribution this makes to the northern beef herd.

Region	Estimated AE	% of herd	Areas included [†]
Katherine/Kimberley	841	7.6	511, 713, 714
Pilbara/Central Aust.	538	4.9	512, 711
Barkly/NW Qld	1146	10.4	311b, 313d,712
Western Qld	1633	14.8	312, 314
North Qld	2303	20.9	311a,313a-c, 313e, 332
Central, southern & south-east Qld	4556	41.4	321,322,331

[†] refer to BreedCow data.

Figure 1 also shows that the majority of data were collected during the period 1966 to 1985. In the past 20 years the frequency of reported grazing experiments that

measure animal production has declined. It is not clear if this is just due to a decline in the number of studies where animal production is being measured or due to lag times in publishing data. For example, in the published studies, it was common for there to be 10-25 year time lag between the last measured year of an experiment and when it was published in the literature (e.g. ('t Mannetje and Jones 1990; Burrows *et al.* 2010; French *et al.* 1988a; Gardener *et al.* 1993; Jones 2003; Tothill *et al.* 2008)
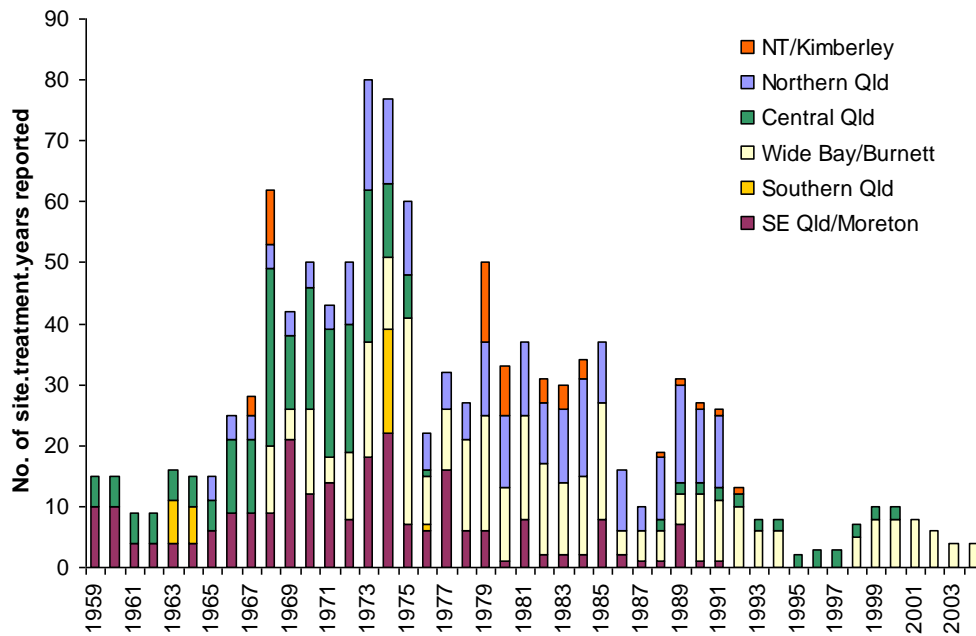
Figure 1. Distribution over time of measured beef production across regions of northern Australia.

4. Beef production on various forage sources in Northern Australia.

Beef production for each annual period reported was calculated in two ways; 1) in terms of average daily live-weight gain (kg/head/day) over the grazing period, and 2) in terms of total beef production per hectare per year (kg/ha/yr) which was a function of the stocking rate, grazing period and daily live-weight gain over that period. The later approach was taken to enable direct comparisons between experiments, years and forage sources once differences in stocking rate and grazing periods were removed.

4.1 Live-weight gain per beast

Figure 2 compares the variation in daily liveweight gains measured for beef cattle grazing different forage sources in northern Australia. Firstly, this shows significant seasonal and site differences in animal growth rates across the full range of reported studies. Though, interestingly the inter-quartile ranges in animal growth rates were similar across most forage sources, between 0.17 and 0.2 kg LW/hd/d. Secondly, this analysis shows that the native pastures generally achieve the poorest animal growth rates. Cattle grazing sown grass pastures generally had improved performance and the introduction of a legume increased animal growth rates on native pastures but this same improvement in growth rates was not as evident when legumes were introduced with sown grasses. Animal performance was higher where leucaena was part of the pasture, to a level similar to sown forage crops like forage sorghum and summer growing legume forages (e.g. lablab, butterfly pea, burgundy bean). Overall, animal growth rates on winter cereals were the highest, but still only ~15% of studies record growth rates greater than 1.0 kg/head/day.
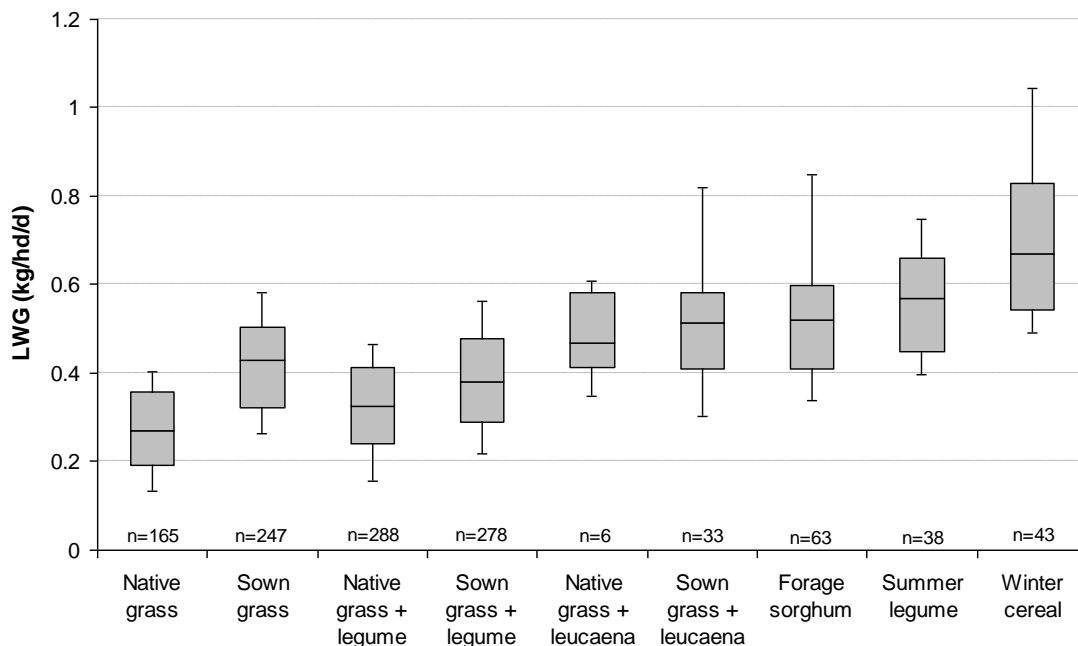
Figure 2. Box-plots depicting the range of experimentally measured live-weight gain of beef cattle over the grazing period on various forage sources. Bars depict the median, upper and lower quartile and whiskers the 90th and 10th percentile of all reported observations. *n* is the number of recorded observations for each forage source.

4.2 Beef production from native and improved pastures

Figure 3 shows the variation in beef production per hectare of all studies where cattle grazed permanent grass-based pastures (sown or native) with and without introduced legumes across regions of northern Australia. In most regions the animal production per hectare from unimproved native pasture compared to improved sown grasses (Fig. 3). The lowest but least variable production recorded was on native pastures in the Northern Territory, in studies centred in the Katherine district. Based on only a few treatment.years in this region, substantially higher production (> 400% increase) was observed via the use of sown grass-legume pastures (Fig. 3a). In north Queensland there their was a large range in annual beef production and similar levels of production were observed under native, native with introduced legumes, and sown grass-only pastures. A similar range of production levels were observed in southern inland and central Queensland, with pasture improvement generally resulting in higher production levels. The highest production levels were observed in south-east Queensland (500-850 kg LW/ha/yr) with higher stocking rates on introduced grass pastures. The higher production from grass-only pastures in this region was due to many studies in the region included nitrogen fertilised pastures, which were able to be stocked more intensively than unfertilised grass-legume pastures.
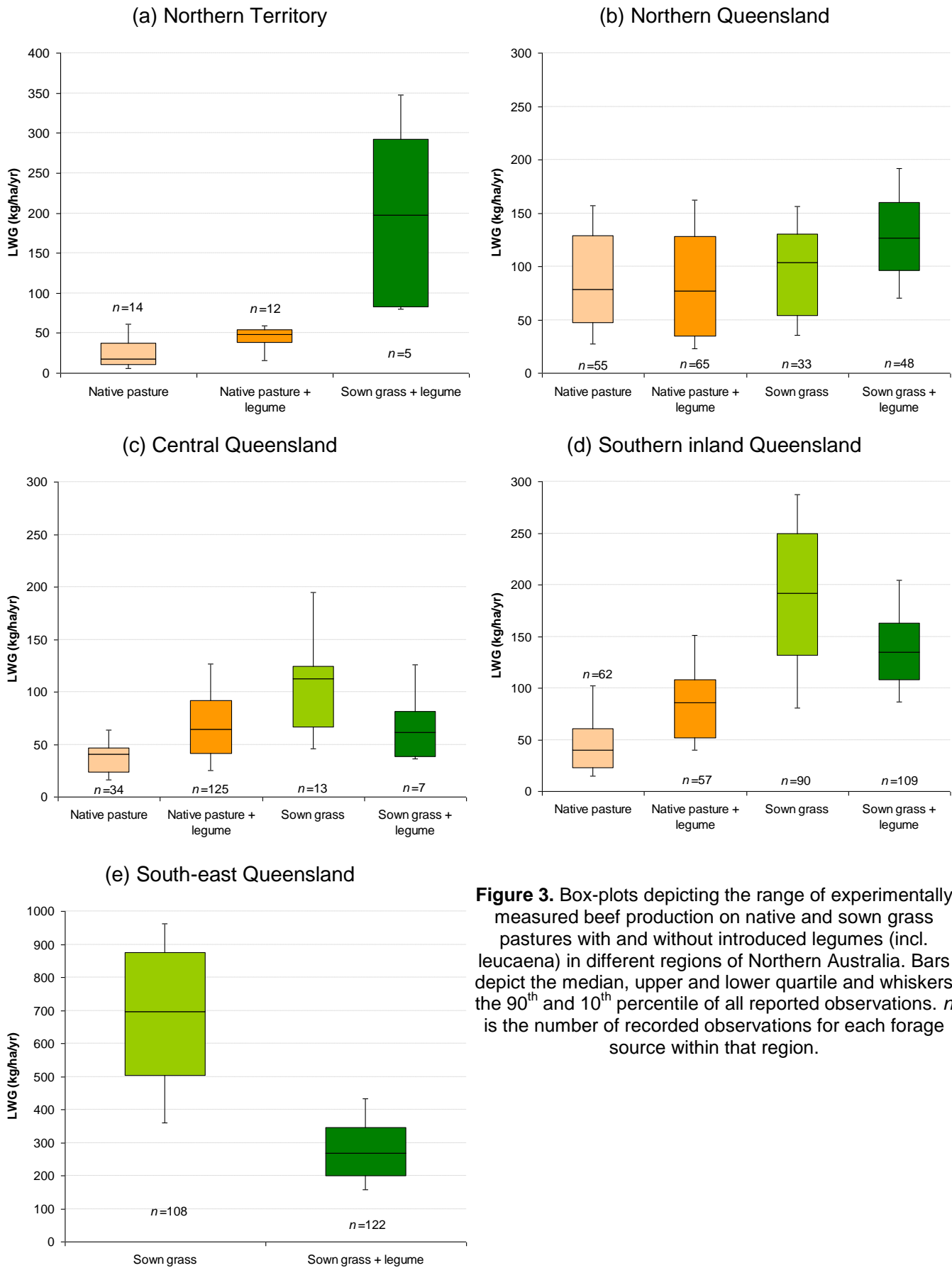
Figure 3. Box-plots depicting the range of experimentally measured beef production on native and sown grass pastures with and without introduced legumes (incl. leucaena) in different regions of Northern Australia. Bars depict the median, upper and lower quartile and whiskers the 90th and 10th percentile of all reported observations. n is the number of recorded observations for each forage source within that region.

Because the studies in Figure 3 include all measured animal production with a range of treatment effects care should be taken in interpreting the effect of legume introduction because all studies don't necessarily compare the same growing conditions. To more accurately examine the effect of legume introduction we examined only those studies where a sown grass or native pasture was compared against the same pasture with a forage legume introduced (Fig 4.). This analysis showed that on average the livestock production per hectare was increased by 30 kg/ha/yr through the introduction of a legume. There was a wide range of responses across different studies, but in 90% of treatment.years legumes had a positive influence on beef production with most responses between 10 and 60 kg/ha/yr. Interestingly when a grass-legume pasture was compared with a grass-only pasture fertilised with nitrogen there was no difference in beef productivity on average (these are not included in Fig 3).
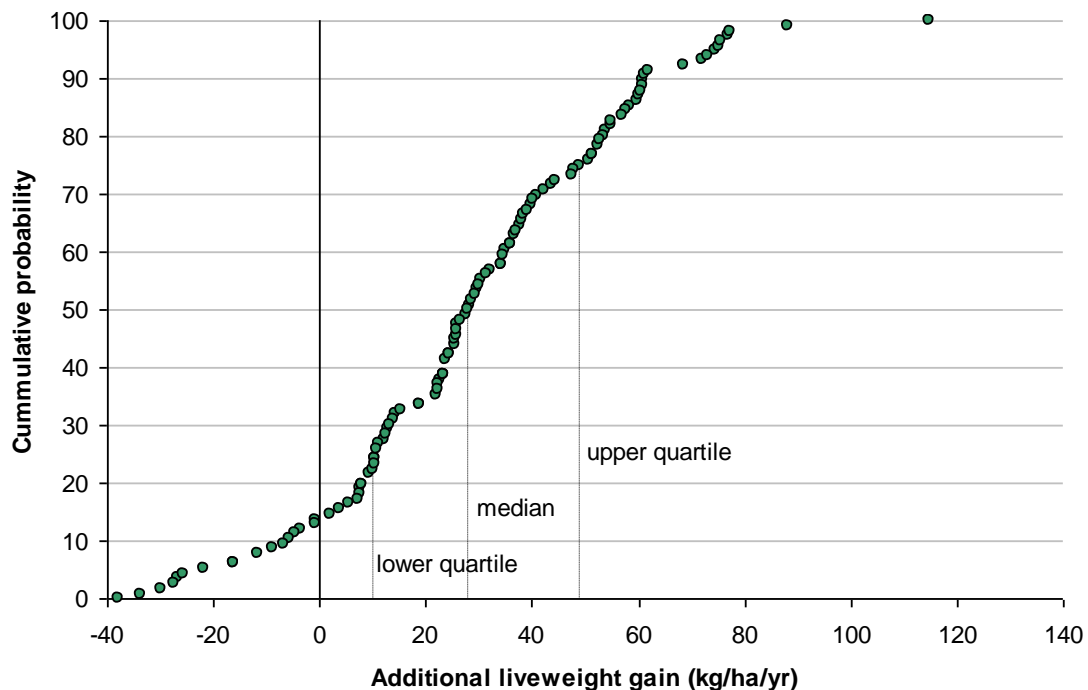
Figure 4. Frequency distribution of additional beef production per hectare per year due to the introduction of a legume into the pasture across a range of studies in northern Australia. Studies included are those where direct comparisons between sown grass or native pasture only and the same pasture with a forage legume introduced (*n* = 117). Data only include nitrogen unfertilised pasture controls and where the same or similar stocking rates were used (cases where higher stocking rates were implemented on the grass-legume pastures were omitted).

4.3 Beef production from sown short-term forages

Figure 4 shows the range of annual beef production per hectare obtained from various short-lived forage options grown in pure swards (i.e. not permanent pastures). Forages were categorised into forage sorghum (includes both annual and perennial sorghums such as Silk etc), summer legumes (includes options such as lablab, butterfly pea, burgundy bean, centro), and winter cereals (includes forage oats, barley and wheat). Most of these studies were rain-fed conducted in the mixed farming regions in southern-inland and central Queensland, but there are several studies involving rain-fed tropical legumes at Katherine (McCown *et al.* 1985), and irrigated forage sorghum and winter cereals in the Kimberley (Blunt and Fischer 1973; 1976).

Across all measured experimental years (note this does not include direct comparisons), the median beef live-weight production was 80 kg/ha/yr for summer legumes, 127 kg/ha/yr for forage sorghum and 168 kg/ha/yr for winter cereals, though there was clearly significant variation associated with growing conditions. Irrigated forage sorghum and oats in the Kimberley showed potential to be very productive, producing 300-500 kg LW/ha/year in the reported studies.
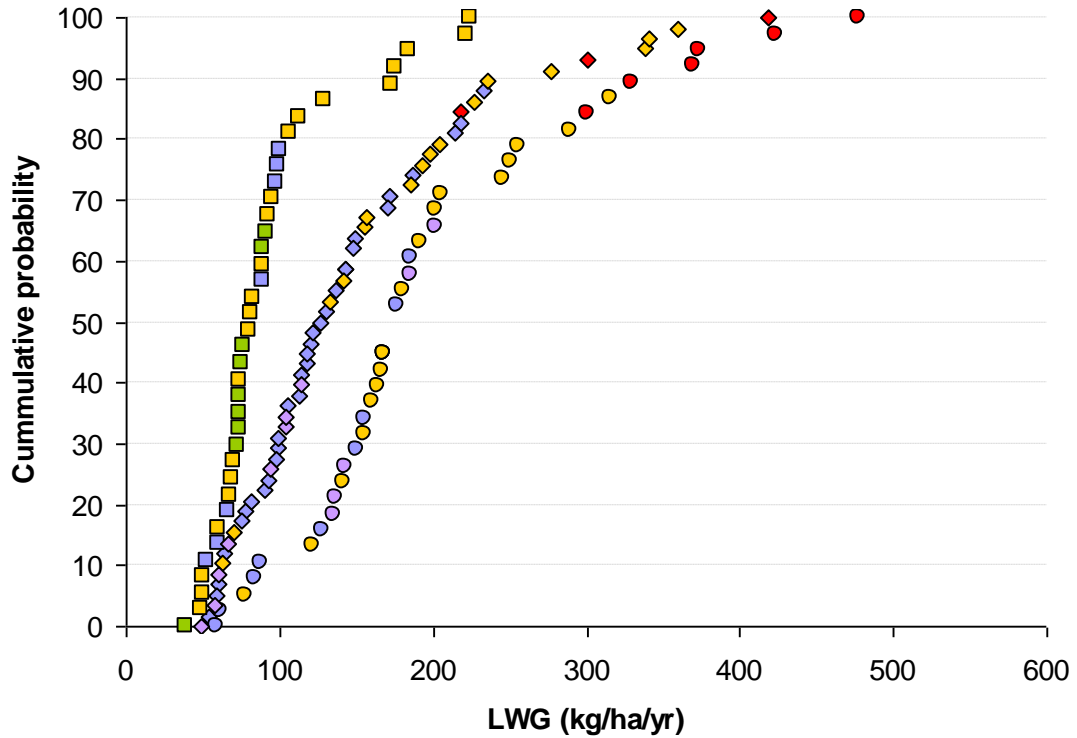
Figure 4. Frequency distribution of beef production per hectare per year on sown forage crops - forage sorghum (diamonds, *n* = 59), summer-growing legumes (squares, *n* = 38), and winter cereals (circles, *n* = 42) – in experimental studies in northern Australia. Colours denote the experimental region and conditions – south-east Qld (purple), southern inland Qld (gold), central Qld (blue), northern territory (green) and irrigated in the Kimberley (red).

Table 3. Assessment of the feasibility of expanding the use of improved forage sources under irrigation (IR) or rainfed (RF) conditions as a component of beef production systems in various regions of northern Australia. Feasibility rating system: *** - proven to highly likely, ** - possible potential but requires further testing, * - significant constraints to use, and O – unsuitable.

Forage options	Katherine-Kimberley		Pilbara-Central Aust		Barkley/NW Qld		Western Qld		North Qld	
	IR	RF	IR	RF	IR	RF	IR	RF	IR	RF
Cultivated short-term forages										
Winter cereals (e.g. oats, forage wheat)	**	0	*	0	**	0	***	0	**	0
Forage sorghum	***	**	**	0	***	*	***	**	***	***
Other summer grasses (e.g. millets)	**	*	**	0	**	0	**	*	**	*
Lablab	**	**	**	0	**	0	***	**	**	**
Butterfly pea	**	**	**	0	**	0	***	0	**	**
Centro (e.g. cavalcade)	***	***	**	0	***	*	0	0	***	*
Stylos (e.g. Verano)	***	***	**	0	**	0	0	0	***	***
Permanent perennial pastures										
Introduced perennial grasses (e.g buffel, sabi)										
Leucaena	***	**	0	0	**	0	**	0	**	**
Legumes (Verano/Seca)	***	***								

6. Conclusions

- Little data on the beef production potential by using improved pastures or forages outside the more endowed regions in southern and central Queensland.
- Significant potential to increase beef production via the use of improved pastures in suitable areas of north Qld, Northern Territory and Kimberley.
- The high production measured from winter forages, especially oats, in studies in the Kimberley under irrigation suggest that other regions in northern Australia might also utilise these crops to provide winter and early spring feed for fattening or tactical feeding of some stock classes.

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Appendix 4 – Northern beef enterprise model user guide

IATna

INTEGRATED ANALYSIS TOOL

for

NORTH AUSTRALIAN BEEF PROPERTIES

Users Guide
Version P1.04 – Feb 2012

Cam McDonald
CSIRO Ecosystem Sciences

CSIRO

CONTENTS

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1. Introduction

The IAT (Integrated Analysis Tool) is a decision support tool for north Australian beef and/or mixed farming enterprise, written in Microsoft© Excel. It is designed to help analyse the impact of any intended intervention strategy on a mixed enterprise farm. The IAT integrates animal, pasture and crop production with labour and land requirements, accounts for revenue and costs, and evaluates these against existing land, labour and financial resources. The tool does NOT find an optimal solution for the best strategy. It is up to the user to vary the inputs to determine which combination of farm activities give the best result for their particular interest (e.g. animal production, labour requirements, financial return). In fact, this is a key purpose of the IAT, to give the user an insight into the impact of particular changes on farm production, profitability or labour demand. For example, if the user changes the area of crop grown, what impact does this have on forage resources, labour requirements, financial return etc.

The output from the IAT is to be used as a guide only. If the output indicates incomes of $10 thousand and $5 thousand for two different strategies, this does NOT mean that a farmer will actually earn 10 thousand or 5 thousand by implementing the strategies. What it DOES mean, is that the strategy indicating an income of 10 thousand will probably be a much better strategy than the one which indicates an income of only 5 thousand.

The IAT consists of a single file (IATna.XLSM) but requires an additional parameter/database file. IATna.XLSM is the main program which contains all the VBA code for operating the tool. The parameter file contains all the input information regarding costs, revenue, labour, etc for each crop and forage type, or each animal type, along with worksheets containing the databases of crop and forage data. Output is put into worksheets in the IAT spreadsheet but output from particular analyses, along with the input settings used to derive the particular output can be saved to the parameter file. This can be useful for re-looking at different strategies at a later date. Also, the input settings can be reloaded back into the IAT at a later date if the user wishes to explore further options, using the previous strategy as a baseline.

2. Getting started and Exiting

Before opening the IAT, make sure that both the file IATna.XLSM and a parameter/database file (e.g. DUARINGA.XLSX) are in the same folder.

To open the IAT, double click on IATna.XLSM.

Upon opening, you will be presented with the screen as shown in Figure 1. This screen is referred to as the 'Main Menu'. If this does not fit your screen properly, then, at the top of the screen, click on 'View', click on 'Zoom', select a suitable size, input your own custom size, or select 'Fit selection', then click 'Ok'.

Before you can run the model you will need to open a parameter file (see below). If the program does not respond when you click on the buttons, you need to *Enable Macros* (see Troubleshooting).

To **EXIT** the IAT, click on the '**QUIT**' button. This will save and close both files.

NB. Before doing any proper analyses, make sure you go through ALL the input forms to ensure you have the parameter settings you want. You do not want to be including crops or animals in your analysis without realising it.

To do an analysis, select all your parameter settings as outlined in the sections below, then, on the Main Menu, click '*Run SIMULATION*'. When the IAT has completed its calculations, the 'Main Menu' will reappear, and the results of your analysis can be viewed by clicking the '*Graphical Output'* button, or selecting the particular output worksheet.

Figure 1. Opening screen (Main Menu) of IAT

2.1 Loading the parameter set

To load parameters, on the Main Menu, click on '*Specify INPUT file for crop, forage & parameter information*'. You will be prompted to enter the name of the parameter file. Type in the name of your parameter file (e.g. Duaringa.xlsx) and press Enter, or simply press Enter to accept the default name displayed. You will then be prompted to enter the name of the particular worksheet that contains all the parameters. Type in the name and press Enter, or simply press Enter to accept the default name displayed. The IAT will then copy the parameter set into the IAT 'Params' worksheet. Any subsequent editing of parameters will affect the parameters in the IAT, NOT in the original file.

If you have already done some analyses and have saved the output (see section 2.2), then you can re-load the parameters settings for that analyses, using the same method as outlined above. You may wish to do this if you have tried several

strategies and would like to go back to a previous strategy, as a baseline, and make some alterations to it.

2.2 Saving the current parameter set or output

If you have made changes to the parameter settings in the IAT and wish to save these to the original file, then click on the '*Save Parameters*' button. This will overwrite the parameters in the worksheet of the original file, from which the current parameters were loaded. For example, if you loaded your parameters from worksheet 'Base_run' of parameter file 'Barkly.xlsx', then clicking the '*Save Parameters*' button will overwrite the values in the 'Base-run' worksheet with those currently in the IAT.

If you want to save the parameters to a different worksheet, then click on the '*Save Output'* button. This will prompt you for a name for the model run (e.g. Run_1), type in a name and press Enter. All the output sheets and parameter sheet will be copied to the parameter file, identified with the name of the model run.

3. Entering/editing parameters

To edit any parameters, on the Main Menu, click on '*Edit Parameter information*'

The Setup menu shown in Form 3 will be displayed.

Form 3. Form for Setup menu. All parameters settings/changes are entered via this form.

3.11 Selecting a climate region

This affects which crops/forages are selected from the database. If you select climate region 2, then the model will look for crop/forage data for that region only. They do not have to be different climate regions, they could be different land types within a region.

On the '*Setup information*' form, click on the drop-down box next to 'Climate region' (see Form 3 above). A list of current climate regions/villages named in the parameters will be shown. Select the desired climate region/village.

If you wish to add to the list of available regions, or edit the names, see section 5.2.

3.12 Starting date and length of model run

The IAT uses the actual year and month to select crop/forage information from the database. The database can contain data for years and months before the specified starting date, but it will start at the specified date. Hence crop or forage yields in the starting year, but in an earlier month, will not be included in the analysis. Similarly, the model will continue on a monthly time-step for the specified number of years. Data beyond this time period will not be processed.

On the '*Setup information*' form, for each of the following prompts, enter a value in the adjoining text box (see Form 3).

Years to run model:
Start year:
Start month:

If there is no data for a crop or forage for a particular year or month within the specified period, an error message will be created when the model is run, and processing will be aborted.

3.2 Land settings

To input settings for land types and areas of different land types, etc, on the '*Setup information*' form, click on '*Farm land & areas*'. The '*Farm structure*' input form shown below will be displayed (Form 3.2).

Form 3.2. Input form for land unit parameters.

3.2.1 Farm land units

A farm can have up to 10 different land areas. Each of these can have a different soil type, if necessary, or they can be simply different units of the same soil type. The land units become important later because selected crop/forages are allocated to a land unit. Then given the soil type for that land type, specified here, the model searches for the relevant data crop/forage data for that soil type i.e. it searches for the soil type, NOT the land unit.

To edit the names of the land units, see section 5.7. These are merely names and have no effect on the running of the model.

For each land unit on the farm, you need to specify the soil type, the area (ha), and the percentage taken up with buildings, roads, paths, etc (i.e. unusable) for agriculture. In most cases this will be trivial. For example, if a land unit has 1000ha, and has 1% taken up by buildings, then there is only 990ha available for cropping (see crop specifications), and 10ha of land that carries nothing. Specifying a crop area of 1000ha of this land will create an error message, but processing will continue.

For each land unit :

Land unit name - select a land unit name from the drop down box
Soil type - select a soil type from the drop down box
Area (ha) – type in an area for this land unit

% buildings, paths – type in a value for the percentage of this land taken up by buildings, etc

3.2.1 Native pasture harvests/growth months

Forages can be harvested a number of times per year, or have a number months of growth, if grazed. Hence, for input, the number of harvests per year, or growth per month, must be specified. This can be any number, but because the model runs on a monthly time-step, it is usually no more than 12. Because native pastures are not specified elsewhere, the number of harvests, or growth months, are specified here.

Native pasture harvests – enter a value in the adjoining text box

3.2.2 Starting condition of land

This sets the overall land condition at the start of the model run. The grass basal area and land condition will change dynamically during the run, based on utilisation rate. The stocking rate will remain the same throughout the model run. The same conditions apply to all land units. These 3 parameters are used to select the appropriate annual production from native pastures, in order to align with the GRASP output.

Land condition (0-9) - these are the same land conditions as per the GRASP model, using the same annual adjustment formula, based on utilisation. In turn, the % perennial species is based on the land condition.
Stocking rate (AE/sq.k) – this is a fixed stocking rate, in Animal Equivalents (1 AE ≡ 450kg steer). 20 AE/sq.k ≡ 1AE/5ha.
Grass basal area(%) – this is the same as that used in GRASP, using the same annual adjustment formula, based on utilisation.

3.3 Labour supply and family structure

To input the age group, gender and number of people in the family available to do work, on the Main Menu, click on '*Edit Parameter Information*', then click on '*Family members and Labour supply*'. The input form (Form 3.3) will be displayed. Enter the number of people in each age/gender category, and the total number of days each category has available for work, in each month of the year. This includes both ON-farm and NON-farm work. We assume that work done helping other farmers will be compensated for when the other farmer helps them. Each month is assumed to 30.4 days, so enter work values based on that length of period. If values for all months are the same, then enter values for each category for month 1, then click on '*Copy month 1 across*'. This will copy the month 1value across all months for each person category.

Priority – this allocates an order of priority for the model to allocate work. Normally work is allocated first to those who can do the least number of activities (e.g. children or elderly), with those who can do the most activities allocated last (e.g. adult males). Hence the priority is normally set to children, then the elderly, then teenagers, then adults, however, users can change this if desired.

Family labour

Family members and labour supply

Full work days

		Number of persons	Priority	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Elderly	Male	0	4	10	10	10	10	10	10	10	10	10	10	10	10
	Female	0	3	10	10	10	10	10	10	10	10	10	10	10	10
Adults	Male	1	8	25	25	25	25	25	25	25	25	25	25	25	25
	Female	1	7	25	25	25	25	25	25	25	25	25	25	25	25
Teenagers	Male	1	6	25	25	25	25	25	25	25	25	25	25	25	25
	Female	2	5	25	25	25	25	25	25	25	25	25	25	25	25
Children	Male	1	2	0	0	0	0	0	25	25	25	0	0	0	0
	Female	0	1	0	0	0	0	0	25	25	25	0	0	0	0

Copy month 1 across

Non-Farm Work   **Hired Labour**   CLOSE

Form 3.3. Input form for family structure and labour pool, as well access to non-farm labour done by family, and labour hired. Note: there is no pay rate for on-farm work for family members.

3.3.1 Non-farm work

To input the age group and gender of people in the family doing non-farm work, click on '*Family members and labour supply*', then click on '*Non-Farm Work*' and a new form will appear (Form 3.3.1).

There are up to five different activities that can be specified. The same 5 activities apply to all categories of people. To select the activity, click on the drop down box below the '*Activity*' label. To change the name of any of the categories, see section 5.5.

To enter the number of days of non-farm work (e.g. working in a kiosk, driving a bus) each person category does in each month, select an activity, then enter values for each category for each month. Again, if the value for all months are the same, enter values for month 1 for each category and click '*Copy month 1 across*'. For each category, enter a pay rate per day. Remember to enter rates using the selected currency. If more than one activity, select another activity and repeat the above process.

Form 3.3.1 Input form for non-farm paid work.

3.2.2 Hired labour days

This is used to specify the amount of labour a farmer is prepared to hire, the pay rates, and which gender/age category (adult, teenager, or children). Click on '*Family members and labour supply* ' or on '*Labour activities & permissions*', then click on '*Hired Labour*'. The input form (Form 3.3.2) will be displayed. For each person category, enter the number of days labour the farmer is prepared to hire in each month. The pay rates are entered on another form (see below).

Labour can be hired at a fixed rate (number of days/month) or can be hired on demand. If the latter is chosen, then labour is hired when and only when there is no family labour available for the particular activity in the particular month.

To choose between these options, click on the box next to the label '*Labour Hire Fixed (Y) or on demand (N)*'. A tick indicates that labour hire is fixed.

Labour Hire

Hired Labour Details

No. days each month

		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Elderly	Male	0	0	0	0	0	0	0	0	0	0	0	0
	Female	0	0	0	0	0	0	0	0	0	0	0	0
Adults	Male	0	0	0	0	0	0	0	0	0	5	0	0
	Female	0	0	0	0	0	0	10	0	0	5	0	0
Teenagers	Male	0	0	0	0	0	0	0	0	0	0	0	0
	Female	0	0	0	0	0	0	0	0	0	0	0	0
Children	Male	0	0	0	0	0	0	0	0	0	0	0	0
	Female	0	0	0	0	0	0	0	0	0	0	0	0

☑ Labour Hire Fixed (Y) or on demand (N)

Copy month 1 across

Pay rates

CLOSE

Form 3.3.2 Input form for days hired labour per month, for each person category.

3.3.3 Hired labour pay rates

To enter the pay rate (/day) for hired labour, click on the '*Pay rates*' button at the bottom of the '*Labour Hire*' form (Form 3.3.2), and the '*Pay Rates'* form will be displayed (Form 3.3.3). Remember to enter pay rates in the selected currency.

Pay rates can vary during the year due to peak seasonal demand. To accommodate this, different pay rates can be entered for each month. For each person category, enter the pay rate for farm labour for each month. Again, if the value for all months are the same, enter values for month 1 for each person category and click '*Copy month 1 across*'.

Pay Rates

Pay rates for Hired Labour

Pay rates for Hired labour ($ per day)

		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Elderly	Male	50	50	50	50	50	50	50	50	50	50	50	50
	Female	50	50	50	50	50	50	50	50	50	50	50	50
Adults	Male	200	200	200	200	200	200	200	200	200	200	200	200
	Female	200	200	200	200	200	200	200	200	200	200	200	200
Teenagers	Male	100	100	100	100	100	100	100	100	100	100	100	100
	Female	100	100	100	100	100	100	100	100	100	100	100	100
Children	Male	20	20	20	20	20	20	20	20	20	20	20	20
	Female	20	20	20	20	20	20	20	20	20	20	20	20

Copy month 1 across   **CLOSE**

Form 3.3.3 Input form for monthly pay rates for hired labour for each person category.

3.4 Labour activities and permissions

On farms there are many activities to be completed. Sometimes, particular activities are done by a particular family member. Hence, in considering changes to a farming system it is vital to consider the impacts on family labour and whether or not particular family members have the capacity to do any extra work.

To specify which family members can do the various activities, on the '*Setup information*' form, click on '*Labour activities & permissions*'. The '*Labour specifics*' form will be displayed (Form 3.4). For each activity, click on the check boxes under each person category that can do the activity (a tick indicates they can do the activity).

Form 3.4. Input form for labour activity permissions for each person category.

3.5 Overheads and living costs

For any farm, there are considerable overhead costs in running the farm e.g maintenance of equipment, electricity charges, bank fees, government rates and taxes, etc. These costs are entered by clicking on the '*Farm overheads and & living costs*' button on the '*Setup information*' form. The '*Farm Overheads*' form will be displayed (Form 3.5).

Form 3.5. Input form for farm overheads, living costs and interest rate.

For each item on the list, enter an annual cost to the farm. These values are summed for an overall overhead cost, so if values for individual items are not known, then an overall value can be entered for any one of them.

In order to calculate a monthly cash flow, it is necessary to have an initial cash balance, a monthly living costs, and what interest rate is charged on overdrafts/borrowed money.

Initial cash on hand – this is the amount of money that the farmer has at the start of the analysis period.

Living cost/month – this is the amount of money it costs for the family to live each month. These are extra items they have to buy (e.g. food, clothes, school fees). This does not include any farm costs (e.g. seed or fertiliser). These are valued elsewhere by the model.

Interest rate% - this is the interest rate charged on any overdraft or borrowed money. If the monthly cash balance becomes negative, then interest is charged on that amount.

3.6 Grain, forage, tree and other crop information

There are 4 different types of crops that can be grown, and different information is required for each. The main crops are grain crops (e.g. rice, maize) and forage crops (e.g. Panicum, lucerne, lablab, elephant grass). The annual or monthly yields of these crops/forage are stored in the database (see later), and can vary from year to year (or month to month for forages). The other 2 categories are tree crops (e.g. bananas, cashews, coconuts) and vegetable crops (tomato, cucumber, chilli, tobacco). The annual yields of these crops are specified by the user and will be the same every year.

However the format for entering the data for each crop type is the same. Initially, the user selects which crops are grown on the farm, what area and what land. For each crop the user must specify all the input costs, labour requirements, revenue and home consumption.

3.6.1 Selecting grain crops grown and allocating to land

To select which grain crops are, on the '*Setup information*' form click on '*Grain crop details*', and the '*Crop sequence*' form will be displayed (Form 3.6.1).

Form 3.6.1. Input form for selecting the sequence of grain crop grown, and the area of land on which it is grown.

Up to 30 different crops can be grown at a time. These are numbered crops 1-30 under the heading 'Crop number'. The steps are:

Select the *Crop number*

Select the *Crop* from the drop down box (currently up to 30 different grain crops can be selected from

Select the *Land* – this is one of the land types set up in section 3.2 above. Note, by selecting the land type, the model then knows which soil type the crop is being grown on.

Area (ha) – enter the area of crop grown. The model will check the total area of crop/forages grown on any land type and check this against the area of that land type specified in 3.2 above, taking into account bund and interbund areas.

% residue kept – the crop residue can be ploughed back, burnt, or kept as forage for livestock. Indicate here what percentage of the crop residue (stover) is kept for livestock. The actual yield of stover will come from the 'Crop_inputs' database in the parameter file.

% sold – some farmers sell crop residue or forage (usually forage) if they have more than they need, or they need the cash. Indicate here what percentage of the crop residue is to be sold.

Once all the information above has been entered for each crop, click on '*Update Calendar*'. This will fill in the displayed calendar with the dates for each crop grown, along with the area of each and the land it is on. This allows for an easy check to see if there is any overlap i.e. using the same land for 2 crops at the same time. If there is an overlap, then you need to select different crops, or edit the approximate sowing and harvest dates for that particular crop (click on '*Edit Crop costs, labour & other details*' and edit '*Sowing month*' and '*Harvest month*'. Please note, the harvest month is approximate only, the actual harvest month will be taken from the 'Crop_inputs' database.

3.6.2 Selecting forage crops grown and allocating to land

Follow the same process as for selecting grain crops. There will be no difference in the inputs to the 'Crop sequence' form, but yields and harvest months will come from the 'Forage_inputs' database. The approximate harvest date should be for the final harvest. The '*% residue kept*' will be 90-100 normally, as the forage is being grown for animal feed.

3.6.3 Selecting tree crops grown and allocating to land

Follow the same process as for selecting grain crops. However there are some differences in the inputs to the '*Crop sequence*' form, and yields and harvest months are specified by the user on the '*Crop specification*' form (see 3.7 below).

There are 3 differences on the tree selection form, instead of the Area of crop, the number of trees are entered, instead % residue retained, the area per tree is entered, and , because there is no residue retention, there is none sold, so this is disabled.

No. trees – enter the number of trees grown
Sq.m per tree – enter the number of square metres taken up by each tree. For example, if grown along a 1 meter wide bund, with a tree every 10 meters, this value will be 10, if grown in a plantation, with trees every 10 metres in each direction (i.e. a 10x10 lattice) then this value will 100.

3.6.4 Selecting other crops grown and allocating to land

Follow the same process as for selecting grain crops. However there are some differences in the inputs to the '*Crop sequence*' form, and yields and harvest months are specified by the user on the '*Crop specification*' form (see section 3.7 below).

There are 2 differences on the other crops selection form. There is no residue retention, and hence there is none to be sold, so both of these are disabled.

3.7 Detailed crop specifications

For each crop grown, whether it is a grain, forage, tree or other crop, there are a number of inputs required for costs, labour, home consumption, sale price, etc. On the '*Crop sequence*' form, click on '*Edit Crop costs, labour & other details*', and the '*Crop Specifications*' form will be displayed (Form 3.7)

Form 3.7. Input form for detailed crop specifications.

To enter new detailed data or edit existing data for a crop, click on the drop down box next to the "*Select crop*' label and select the desired crop. Note – only those crops for the selected type of crop (grain, forage, tree or other) will be shown. For example, if the '*Crop sequence*' form was opened for grain crops, then if the '*Crop Specifications*' form is opened, only the grain crops will be displayed in the drop down box.

The same form is used for all crop types, however, some details are not required for some crop types and are disabled when the form is opened for those crop types.

Yield (kg/ha) - this is used for tree and other crops. Enter a value for the annual yield; the same value will be used each year. This prompt is disabled for grain and forage crops because the information will come from the respective databases.

Crop inputs (units/ha) and Cost per unit: (these apply to all crops)

Seed/plants – enter the units/ha of seed or number of units of plants/ha used for planting, and the cost per unit. The units could be kg, with a price per kg, or the units could be bags of seed or boxes of seedlings, with a price per bag or per box.

Chemical – enter the number of units/ha (e.g. litres or drums) of chemical used, and the price per unit

Water/Irrigation - enter the number of units/ha (e.g. kilolitres) of irrigation water used, and the price per unit

Planting - enter other planting costs (excluding seed and fertiliser), the number of units/ha, and the price per unit

Fertiliser 1 - enter the number of units/ha (e.g. kg, bags) of fertiliser (type 1, e.g. NPK) used, and the price per unit

Fertiliser 2 - enter the number of units/ha (e.g. kg, bags) of fertiliser (type 2, e.g. Urea) used, and the price per unit

Fertiliser 3 - enter the number of units/ha (e.g. kg, bags) of fertiliser (type 3, e.g. Superphosphate) used, and the price per unit

Harvesting – enter any harvesting costs, the number of units/ha of the product/service, and the price per unit

Other 2 – If there are other crop inputs, enter the number of units/ha (e.g. kg, bags) of the product used, and the price per unit

Sowing month – month in which the crop is usually sown. For perennial crops enter a value of -1. This will indicate to the model that there are no planting costs or labour for planting, and other costs and labour are spread over the whole year, excluding the harvest month. If not perennial, then costs are spread over the months from sowing to harvest.

Harvest month – month in which the crop is usually harvested. For forage crops, with multiple harvests, enter the usual month for last harvest. Note, for grain and forage crops the actual month of harvest will come from the database, in which case the entered value is used as a guide only.

Harvest per year – for forage crops only. Enter the number of harvests or growth periods during the year. This can be any number but because the model runs on a monthly time-step, it is usually no more than 12. If greater then 12, the harvest yields will be summed in months where more than 1 harvest occurs.

Sale price grain (/kg) – sale price per kg for grain (for grain and forage crops) or fruit (for tree and other crops)

Sale price forage (kg) – sale price of crop residue (grain crops) or forage (forage crops). Residues from tree and other crops are not sold, hence this parameter is disabled for those crops.

Establishment costs

These are 1–off (or cyclical) costs for establishment of perennial pastures/crops. The costs are NOT applied every year. The costs are applied in the first year of a run, then after each period of duration e.g with a duration period of 4 years, the costs will be applied in year 1, year 5, year 9, and so on.

Cost/ha – this is the total cost per ha to establishment the pasture or crop (ploughing, planting, seed, fertiliser, etc)

Labour/ha - this is the total amount of labour (man days per ha) to establishment the pasture or crop (for ploughing, planting, etc)

Duration – then number of years the pasture/crop will last before replanting is required.

Labour requirements: (labour requirements for each cropping activity, in man days/ha)
Land preparation – clearing land, or preparing for ploughing
Ploughing
Planting
Fertilising
Other1
Other2
Spraying
Irrigation
Tree management
Harvesting tree crops
Harvesting grain crops
Harvesting other crops
(Note: Harvesting of forage crops is accounted for under forage harvesting labour)
Post harvest
Transport
Storing residue
Other3

Labour for land preparation, ploughing, planting and fertilising is deemed to occur in the month of sowing; harvesting, post harvest, transport, storing residue and other labour are deemed to occur in the harvest month, with manuring, weeding, spraying, irrigation and tree management (if applicable) spread over the intervening months.

3.7.1 Forage components (tree and other crops only)

Some forage can come from leaf, fruit or stem of tree crops (e.g. bananas) or other crops (e.g. cucumbers). This does not apply to grain and forage crops as it is already accounted for in the crop residues/forage yields. To enter data for this, click the '*Forage components*' button on the '*Crop Specification*' form, and the form shown below (Form 3.7.1) will appear, with the name of the selected crop shown. To select a different crop, return to the '*Crop Specification*' form. To change from tree crops to other crops, return to the '*Setup information*' form.

Form 3.7.1. Input form for forage components available from tree and other crops.

For each of the categories, Leaf, Fruit and Other, enter values for:

Kg/tree Dry matter – kg of dry matter per tree harvested (per ha for other crops)
Harvest month – month of harvest (same for all components)
% nitrogen – estimate of N content of the forage component (used to determine the quality of the forage for animal feeding
Priority – this indicates which forage pool (from 1 to 10) the forage component is to be added to (see section 3.9.2 for more information on forage pools)

3.7.2 By-Products (all crops)

Some crops produce a by-product i.e. something other than the grain/fruit or residue for forage (e.g. tree legumes may produce forage as well as building or fencing material from the stems). To enter data for this, click the '*By products*' button on the '*Crop Specification*' form, and the form shown below (Form 3.7.2) will appear, with the name of the selected crop shown. To select a different crop, return to the '*Crop Specification*' form. To change the crop type, return to the '*Setup information*' form.

Form 3.7.2. Input form for crop by-products.

For each of two by-products, enter values for: (Note, values for kg/ha dry matter and harvest month for grain and forage crops will come from the database).

Kg/ha Dry matter – kg of dry matter per ha harvested (per tree for tree crops)
Price/kg – price per kg of dry matter of by-product
Harvest month – month of harvest
Kept on farm (kg/yr) – total amount kept for home consumption per year. Any excess will be sold at the specified price. This value is for the whole family, NOT per person.
Amount in store – amount already in store at start of model run. This will be taken into account in determining how much has to be kept and how much will be available for sale.

3.8 Purchased fodder

Up to 10 different fodders can be purchased within a year. These can be purchased either on a fixed basis, in a fixed month, or can be purchased as and when required i.e. when there is a fodder deficit on the farm (all fodder pools are empty). To enter data for purchased fodder, click on the *'Purchased fodder'* button on the *'Setup information'* form, and the form shown in Form 3.8 will appear.

Form 3.8. Input form for purchased fodder.

For each fodder lot (up to 10), enter the following data:

Fodder – select the particular fodder from the drop down menu.
No. units – enter the number of units purchased at a time. If purchased as required, then this is assumed to be 1
Month of year – enter month purchased (for fixed purchases). If purchased as required then this will be ignored
Pool 1-10 – enter the fodder pool the purchased fodder will be added to (see section 3.9.2 for more information on fodder pools)
As required – tick this box if you want fodder purchased only when the fodder pools are empty. If there are more than 1 fodder listed for purchase, then one unit of each will be purchased (i.e. 1 unit of each and every fodder, at a time) until any fodder deficit for the particular month is overcome.

To edit the names of the bought fodders, see section 5.8. However, remember to change the specifications below, to match the new fodder

3.8.1 Purchased fodder details

To determine the amount, cost and quality of purchased fodder, detailed information is required. This is entered by clicking on the '*Fodder details*' button on the '*Purchased fodder*' form. The '*Purchased fodder details*' form (Form 3.8.1) will appear.

Form 3.8.1. Input form for detailed specifications of purchased fodders.

Fodder – click on the drop down menu and select the desired fodder.
% dry matter – enter an estimate of the % dry matter for the fodder
% digestibility – enter an estimate of the % digestibility for the fodder
% nitrogen – enter an estimate of the % nitrogen for the fodder
Unit size (kg or l) – enter the weight (kg) or volume (l) of the purchased units (e.g. bales, or drums)
Unit cost – cost of per unit
Labour – number man days to obtain the purchased fodder
Other costs – any other costs (this is an overall cost not a cost per unit)

3.9 Ruminant animal information

To input information on the number of ruminant animals a farmer has, the type of animals (cows, bulls, calves), management, milking and supplementary feeding, on

the Main Menu, click '*Ruminant numbers & management*'. The '*Ruminant animals*' input form (Form 3.9) will be displayed.

3.9.1 Ruminant animal numbers, age and value

Animals are grouped into 17 categories, sucklings (animals less than the specified weaning age, weaners (animals aged between the weaning age and 12 months), breeders aged from >1 to <10 years old, male animals from >1 to <4 years old, and breeding sires. For sucklings and weaners, each category is divided into male and female. What is input here is the number of animals in each category at the start of the analysis.

> **Note**: Because animal numbers can be very low on some small farms, the IAT works in fractions of animals. For example, if there are only 2 cows and the calving rate is 80%, then 1.6 calves are born. While this is not possible physically, it allows better comparisons to be made on very small farms. This will have little effect for large herds.

Breed or ruminant type

To select the desired breed of cattle or other ruminant type, click on the drop-down box below the '*SELECT BREED*' heading. Names of ruminants should NOT be changed without recalibration of the model. This is because the ruminant coefficients for growth, gestation and mortality are specific to the named breed/ruminant type. If it is known that these parameters are the same (or very similar), then changing the name would be acceptable. Alternatively an additional ruminant type could be added to the list (see section 5.1)

Form 3.9.1 Input form for ruminant animal numbers at start of run.

Animals <=12 months old

> **NB. In order to maintain all cows with similar calving dates, have either sucklings or weaners, but NOT both**

For each category of animal <=12 months old (male and female sucklings or weaners), enter the following:

No. – enter the number of animals
Weight (kg) – enter the weight of the animals
Age (months) – enter the age of the animals
Value (/kg) – enter the price/kg for these animals if they were to be sold

Animals >12 months old

For each category of animal >12 months old (male and female), enter the following:

No. – enter the number of animals
Weight (kg) – enter the weight of the animals
Value (/kg) – enter the price/kg for these animals if they were to be sold

Except for breeding sires, the age of these animals will be determined by the age of the sucklings/weaners and the minimum mating age for breeding females. For example: if sucklings are 4 months old, and the minimum mating age is 18 months,

then the breeding animal must be 31 months old, or some multiple of 12 months plus 31 i.e. 43, 55, etc. This is why the model starts with either sucklings or weaners, but not both.

Sire age (months) – enter age of sires (all sires are deemed to be the same age)

3.9.2 Ruminant feeding system

To specify the ruminant feeding system (grazing, cut and carry, or both), on the '*Ruminant animals*' form, click on '*Grazing and Lot feeding*'. The '*Ruminant feeding*' input form (Form 3.9.2) will appear.

If not already selected, select the desired breed of cattle or other ruminant type by clicking on the drop-down box next to the '*SELECT BREED*' heading. The current settings for that breed/ruminant type will be displayed.

Form 3.9.2. Input form for ruminant feeding systems, lot feeding amounts, and labour requirements for forage harvesting, rationing of fodder pools.

Feeding system – click on the drop down box next to the heading and select 1 of the 3 options. Depending on the system selected, other options will be displayed or disabled.
Grazing (hours/day) - If 'Both' has been selected as the feeding system, then the parameter for the number grazing hours per day will be enabled. This

determines the potential animal intake based on a normal grazing day of 8 hours. Enter the number of hours per day animals are allowed to graze (maximum of 8).

Feed trough available(Y/N) – If lot feeding is merely dumped on the ground, then inevitably, there will be wastage due to trampling, etc. However, if a feed trough is available, it is assumed that there is no wastage.

Lot feeding

Forage fed (kg/day) – enter the number kg/day of forage fed to the selected breed/animal type, in each month. This is the total amount fed to all animals of this breed/ruminant type (excluding 'Trade' animals, see section 3.9.7). M1 to M12 represent the months January to December. If the values are the same for all months, enter a value for M1 and click '*Copy month 1 across*'.

Wastage % - if there is no feed trough, this parameter will be enabled. Enter an estimate for the percentage of lot fed forage wasted .

Fodder pools (P1-P10) - % limits of use

There are 10 fodder pools from which forage for feeding animals can be taken. New growth from native pasture is allocated to pool 1 in the month of growth, then, any that has not been eaten, steps down through the pools each month, declining in quality each month (by 0.4% N) and losing 15% as detachment. Crop residue and forage crop harvests are allocated to the various fodder pools (priority), as determined by the user, in the databases for crop and forage yields, and selected by the user on the input form for tree and other crop forage components. While different crops can be allocated to any of the fodder pools, as the best quality forage is allocated to fodder pool 1 (priority 1), with lower quality forage to pool 2, and so on, wheat or sorghum straw might be allocated to pool 5 or 6, depending on its quality. These residues will then proceed to lose quality and quantity at the same rate as for native pasture.

% limits of use - For each pool (1-10) indicate the maximum percentage that can be fed to animals e.g. if 20kg/day is fed to animals, and you limit the use of pool 1 to 20%, and pool 2 to 50%, then 4kg will be taken from pool 1, 10kg from pool 2, and the remaining 6kg from other pools, assuming there is sufficient feed in the pools. Set to 100% if no limit on the pool. If all set to 100, the model will select fodder from pools 1-10 in that order, if forage is available.

Fixed – If some pools are limited, then these limits can be fixed or flexible. If fixed, then if there is no other fodder available, then the feed taken from the pool will still be limited, and any shortfall will be purchased (if applicable) or the farm will show a fodder deficit. If this box is not ticked, then the limits are flexible. In which case, if there is no other feed available, then the farmer will exceed the specified limit in order to feed their animals.

Labour rate for forage harvesting

This rate is applicable to all breeds/ruminant types, and is the time taken to cut 1 tonne dry matter.

Hours/day to cut1 tonne – for each month (M1 to M12), enter the time taken to cut and collect 1 tonne of dry matter. This probably won't vary during the year, so, if the same for all months, enter a value for M1 and click '*Copy month 1 across*'.

The model will determine the actual time taken based on this value and the specified amount of forage fed.

Forage harvesting costs/day – if there are any forage harvesting costs (e.g. fuel, if not accounted for elsewhere), then enter the cost per day here.

3.9.3 Ruminant management costs and labour

To specify the ruminant management parameters (weaning, culling, mating age, etc), on the '*Ruminant animals*' form, click on '*Herd management*'. The '*Ruminant management*' input form (Form 3.9.3) will appear.

If not already selected, select the desired breed of cattle or other ruminant type by clicking on the drop-down box next to the '*SELECT BREED*' heading. The current settings for that breed/ruminant type will be displayed.

Form 3.9.3. Input form for ruminant management, costs and labour.

Weaning age (months) – enter the age at which suckling animals are weaned, '*or Weight (kg)*', the weight at which animals are weaned. The model will wean animals when they reach the specified age or weight, whichever comes first.
Selling age (months) – enter the age at which animals are normally sold, '*or Weight (kg)*', the weight at which animals are sold. The model will sell animals when they reach the specified age or weight, whichever comes first.
Same for females? – if not ticked, young females not required for replacement of culled breeders will be sold at 12 months of age (i.e. when they transfer out of

the weaner category). If ticked, then excess females are transferred into the young male category and are sold at the age/weight as per young males.

Maximum age for breeders (months) – age at breeding animals are culled because of age (normally 10 years/ 120 months). Animals can be kept longer if desired, and the average age of breeders in the 9-10 category will exceed 10 years.

Culling rate for dry breeders (%) – indicate the percentage of dry breeders that will be culled. The conception/birthing rate is determined at the due date for parturition (birthing). The percentage which do not give birth, can be culled, and will be replaced by young females, if available. For example, if the birthing rate is 70%, and the culling rate is 50%, then 15% of breeders will be culled and replaced. Note: once birthing rate (ignoring twinning) drops below 67%, then there will be insufficient young females to replace all dry breeders, so culling rate has to be reduced below 100%, or other females will need to be purchased.

Maximum number of breeders – maximum number of breeders the farmer wants to keep. If this value is higher than the number of breeders indicated at the start, then young females will be kept until the desired number is reached. This allows the user to increase the number of cows over time. This is applicable if some intervention has produced an increase in the forage available. The farmer may not have the resources to buy more cows immediately, so they can build up gradually. This will lower their income in the early years as they will have less animals to sell.

Minimum mating age (months) – minimum age at which young females are mated. Often this is determined by the age at which they normally have their first birth, and subtracting the gestation period.

Twinning rate (%) – for sheep and goats, twins are common, so there can be a birthing rate in excess of 100%, even though not all breeders gave birth. Enter an estimated value for twinning, as a percentage of the conception rate. The model determines the conception rate, then adds the twinning rate to determine the birthing rate (%birth rate=%conception rate + %conception rate*%twinning rate/100). The percentage of breeders which did not conceive can still be culled, even though the birthing rate may be over 100%.

Seasonal mating (Y/N) – many farmers use continuous mating (bulls run with cows all or most of the year. While nearly all breeders will eventually conceive (i.e. conception rate of 100%), there will variable periods between pregnancies, and the average inter-calving-interval will be greater the normal 12 months (for cattle). Using seasonal sets the inter-calving interval to 12 months, with a variable conception rate.

Distance to market (km) – enter number of kilometres to usual market for sale animals

Truck cost ($/km) – enter cost per kilometre for particular transport truck hired

No. animals per load – estimate the number of animals of standard size (SRW) that can be carried on the truck. The model will then determine the how many animals can be carried per load for the particular animals being sold, and calculate a cost per animal.

Maximum age for sires (months) – age at which breeding sires are to be culled and replaced. Sires will be sold at the specified price/kg when they reach this age.

Cost of replacing Sire – cost of replacing sires. This is the cost per animal.

Base mortality rate (%) – this the base mortality for the herd, even animals are well fed, and proper animal husbandry practices are followed

Value of animal wool per kg – sale price per kg for animal wool

Value of cashmere per kg – sale price per kg for animal cashmere

Home consumption number – number of animals of the selected breed/ruminant type killed for home consumption. It is assumed all animals killed will be from the 1 category.

Home consumption category – category of animal of the selected breed/ruminant type killed for home consumption. Select animal category from the drop down menu.

Costs per animal

Veterinary cost (/year) – average cost of veterinary services per animal per year
Vaccine & drench costs - average cost of vaccines & drenches per animal per year
Dip & spray costs - average cost of dips & sprays per animal per year
Yard fees – cost per animal sold
MLA R&D fee - cost per animal sold
Commission (%) – agents commission for sale animals

Labour requirements (man days/month)

The following values are for the whole herd (of the selected breed/ruminant type), not per animal.

Feeding (/herd) – man days per month spent feeding (excluding lot feeding) animals.
Mustering (/herd) – man days per month spent mustering animals
Transport (/herd) – man days per month spent transporting animals
Other (/herd) – man days per month doing other activities for the selected breed/ruminant type

3.9.4 Ruminant supplement feeding

To specify the ruminant supplements fed, on the '*Ruminant animals*' form, click on '*Supplements*'. The 'S*upplementary feeding of Ruminants*' input form (Form 3.9.4) will appear.

Up to 30 different supplements can be selected from, however only 5 different supplements can be fed to a particular breed/ruminant type at any one time. These can be the usual urea/molasses licks or can be forage e.g. lucerne hay. These are energy/protein supplements and will have an effect only if the animals are deficient in energy or protein. Supplying a P supplement will have no effect unless combined with energy or protein supplement.

If not already selected, select the desired breed of cattle or other ruminant type by clicking on the drop-down box next to the '*SELECT BREED*' heading. The current settings for that breed/ruminant type will be displayed.

Supplement – click on the drop down menu under the '*Supplements*' heading to select a particular supplement to be fed.
Kg or litres fed – for each ruminant category, enter the quantity (in kg or litres) fed per animal per day. It is assumed that all animals older than 1-2 years will be fed the same amount.
Start month – month of the year in which supplementary feeding commences (January=1)
End month – month of the year in which supplementary feeding ceases (January=1)
Lactation only – if this box is ticked then breeders are fed supplement only during their period of lactation

Supplement feeding

Supplementary feeding of ruminants

Kg or litres fed to each animal type per day

Supplement	Suckling Female	Suckling Male	Weaner Female	Weaner Male	1-2yo Female	1-2yo Male	Older Female	Older Males	Sires	Start month	End month	Lactation only
Urea	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	5	11	☐
None	0	0	0	0	0	0	0	0	0	0	0	☐
None	0	0	0	0	0	0	0	0	0	0	0	☐
None	0	0	0	0	0	0	0	0	0	0	0	☐
None	0	0	0	0	0	0	0	0	0	0	0	☐

Edit Supplement Specifications

SELECT BREED

B.indicus

CLOSE

Form 3.9.4. Input form for feeding of supplements to ruminants

3.9.5 Supplement details

To determine the benefits and cost of supplements, detailed information is required. This is entered by clicking on the '*Edit Supplement details*' button on the '*Supplementary feeding of Ruminants*' form. The '*Supplement details*' form (Form 3.9.5) will appear.

Supplement – click on the drop down menu and select the desired supplement. To change the name of a supplement, see section 5.9. However, remember to change the specifications below, to match the new supplement.

% dry matter – enter an estimate of the % dry matter for the supplement
% digestibility – enter an estimate of the % digestibility for the supplement
% nitrogen – enter an estimate of the % nitrogen for the supplement
Unit size (kg or l) – enter the weight (kg) or volume (l) of the purchased units (e.g. bales, or drums)
Unit cost – cost of per unit

Form 3.9.5. Input form for supplement detail specifications

3.9.6 Ruminant milking and manure composting

In rare cases, some cattle or buffalo may be milked, and/or manure collected, composted and sold or used on the farm.

To enter data for milk and manure collection, click on the '*Milking & manure options*' button on the '*Ruminant animals*' form, and the '*Milking & manure composting options*' form will appear (Form 3.9.6).

If not already selected, select the desired breed of cattle or other ruminant type by clicking on the drop-down box under the '*SELECT BREED*' heading. The current settings for that breed/ruminant type will be displayed.

Milking Options

Breeders milked (Y/N)   - tick this check box if breeders for the selected breed/ruminant type are to be milked. If not milked, all other parameters are ignored.
Value of milk/litre – price received by farmer for milk
Home consumption L/day – litres of milk per day used for home consumption
Milking labour (hrs/breeder/day) – time taken to milk each breeder
Costs per cow/month – any extra costs per cow per month (this is not supplements or fodder)
Maximum production (litres/breeder/day) – this is the maximum production per breeder per day during the lactation period. This generally occurs around day 30 of the lactation period, and slowly decreases after that.
Period of milking (months) – number of months cows are milked
Percentage of breeders milked – in some cases not all breeders are milked.

Manure composting options

The model determines the amount of ruminant manure produced, based on the intake of the animals and the average digestibility of the forage supply.

% manure composted – not all manure will be available for composting. Enter an estimate of the percentage of the total amount that will be available for collection

Value (/100kg fresh) – manure is generally sold in a 'fresh' form i.e. not dried. Hence it is easier to get a price for fresh composted manure than dry.

Labour (days/100kg fresh) – manure needs turning over every so often, and may need bagging for sale. An estimate can be determined from the total time spent on manure turning and bagging and the number of bags produced.

Costs (/100kg fresh) – often some additives are combined with the manure to improve the composting process. Enter a price for the additive. Again, an estimate can be obtained from the total cost and the number of bags produced.

Form 3.9.6. Input form for ruminant milk and manure parameters.

3.9.7 Ruminants traded

All the previous information provided for ruminants was for breeding ruminants. Many farmers also buy and sell animals (trade) each year.

To enter information on ruminants traded during the year, click on '*Ruminants traded*' on the '*Ruminant animals*' form, and the '*Details of Ruminant animals Traded*' form (Form 3.9.7) will appear.

Up to 10 trades can be completed within in any one year. Each trade can be a different cattle breed/ruminant type and/or animal category. It is assumed that the same trades will be done each year of the model run. Growth rates of the purchased animals are determined using the same animal growth model used for breeding animals.

Select trade – click on the drop down menu to select the trade number (1-10)
Feeding system – click on the drop down menu to select the feeding system used for the selected cattle breed/ ruminant type
Breed of animal – click on the drop down menu to select the cattle breed/ ruminant type for the selected trade.
Category of animal - click on the drop down menu to select the category of animal within the selected breed/ruminant type.
Number of animals traded – number of animals purchased
Initial weight (kg) – weight of animals at time of purchase
Age at purchase (months) – age of animals at time of purchase
Purchase price (/kg LWT) – purchase price, per kg liveweight
Month of purchase – month of the year animals purchased (January = 1)
Sale criteria (months) – number of months animals kept, unless they reach sale weight prior to this
Sale criteria (weight) – weight (kg) animals must reach before sale, unless the sale month is reached prior to animals attaining this weight.
Forage fed (kg/day) – kg of forage fed to these animals per day. Fodder pool priority will be the same as for breeding animals and labour will be determined based on the time specified for forage harvesting for breeding animals. Similarly, any supplements specified earlier for the selected breed/ruminant type and animal category, will be applied to the traded animals as well.

Form 3.9.7. Input form for information regarding ruminant animals traded (bought and sold) during the year.

Costs per animal/month

Yard fees, MLA R&D fees and commission are set the same as for sales from the breeding herd. Note the costs below are monthly not yearly as for the breeding herd.

Feed – costs/animal/month for any extra feed purchased for these animals. This does not include supplements or bought fodder specified elsewhere
Veterinary – average cost of veterinary services per animal per month
Transport – average cost of transport per animal per month
Other - average of any other costs per animal per month

Labour requirements (man days/month)

Feeding – man days per animal per month spent feeding animals (excluding lot feeding).
Mustering – man days per herd per month spent herding the selected trade animals
Transport – man days per herd per month spent transporting the selected trade animals

Other – man days per herd per month doing other activities for the selected trade animals

3.10 Non-ruminant animal information

Non-ruminant animals (e.g. pigs, chickens) can be kept for breeding and/or can be traded. However, unlike ruminant animals, there is no growth or reproduction model for these animals. The user must specify the reproduction rate for breeding animals, and their sale price, and purchase and sale prices if animals are traded.

It is assumed that the same number of animals and the same reproduction rate occur every year. Hence the costs and revenue from these activities will be the same every year. The same applies to any non-ruminant animals traded.

To enter details regarding non-ruminant animals, click on the '*Non-ruminant animal numbers & management*' button on the '*Setup information*' form, and the '*Non-ruminant animals*' form (Form 3.10.1) will appear.

3.10.1 Details of non-ruminant animals bred

SELECT ANIMAL TYPE - select an animal type from the drop down menu under the '*SELECT ANIMAL TYPE*' heading. To change the names of the listed animals, see section 5.10.

Number breeding females – enter the number of breeding females kept. This, along with the reproduction rate will determine the animal production for the year.

Number mature males – enter the number of mature males kept for mating purposes. This affects the feeding costs only.

Reproduction rate – number of juveniles bred by each breeding female per year. Currently the model is not set up to handle multiple breeding cycles within 1 year, so if more than one breeding event per year, add the two together. However, all the sales will occur in the same month. It is assumed that half the number of bred animals will be female, and half the number male.

Sale price per female – sale price of females sold (price for whole animal, not per kg)

Sale price per male – sale price of males sold (price for whole animal, not per kg)

Home consumption – number of animals used for home consumption

By-product weight (kg) – weight of any by-product produced from this activity. This is the total amount produced for all these animals (not per animal).

By-product value (/kg) – value of by-product per kg

Fodder fed per day (kg) – Amount of farm fodder fed to these animals per day. This is the total for all these animals from the fodder pools (see below for any rationing).

Sale month - Month of the year when growing animals are sold (January=1)

Months kept – number of months growing animals are kept before sale. This, and the sale month, determine the months in which fodder, costs and labour are allocated for juveniles.

Form 3.10.1. Input form for parameters for breeding non-ruminant animals, such as pigs and chickens.

Fodder pools (P1-P10)

For a more detailed description of the fodder pools, see section 3.9.2 above.

% limits of use - For each pool (1-10) indicate the maximum percentage that can be fed to these animals e.g. if 20kg/day is fed, and you limit the use of pool 1 to 20%, and pool 2 to 50%, then 4kg will be taken from pool 1, 10kg from pool 2, and the remaining 6kg from other pools, assuming there is sufficient feed in the pool. Set to 100% if there is no limit on the pool.

Fixed – If some pools are limited, then these limits can be fixed or flexible. If fixed, then if there is no other fodder available, then the feed taken from the pool will still be limited, and any shortfall will be purchased (if applicable) or the farm will show a fodder deficit. If this box is not ticked, then the limits are flexible. In which case, if there is no other feed available, then the farmer will exceed the specified limit in order to feed their animals.

Costs per animal/month

For costing, it is assumed that breeding females and adult males are kept all year. Juveniles, which each count as half an animal, are included in the months they are kept only.

Feed – costs/animal/month for any extra feed purchased for these animals. This does not include supplements or bought fodder specified elsewhere.
Veterinary – average cost of veterinary services per animal per month
Mating – average cost for mating services per breeder (if applicable)
Supplements – average cost of supplements per animal per month
Other - average of any other costs per animal per month

Labour requirements (man days/month)

Feeding(/herd) – man days per animal per month spent feeding (excluding lot feeding) animals.
Herding (/herd) – man days per herd per month spent herding these animals
Transport (/herd) – man days per herd per month spent transporting these animals e.g. for sale
Other (/herd) – man days per herd per month doing other activities for these animals

3.10.2 Details of non-ruminant animals traded

All 'non-ruminant' animals can be traded, however, the model allows for only one trade per animal type per year. It will be assumed that the same number of animals is traded every year, for the same purchase and sale price.

To enter details regarding non-ruminant animals traded, click on the '*Trade animal*' button on the '*Non-ruminant animals*' form, and the '*Non-ruminant Trade animals*' form (Form 3.10.2) will appear.

SELECT ANIMAL TYPE – if not already selected, select an animal type from the drop down menu under the '*SELECT ANIMAL TYPE*' heading.
Number animals traded – enter the number of animals purchased.
Purchase price – price paid to buy animals (whole animals, not per kg)
Purchase month – month in which animals are purchased (January=1)
Sale price – sale price of animals (price for whole animal, not per kg)
Sale month - month of the year when animals are sold (January=1). This, combined with the purchase month, determine the months in which fodder, costs and labour are allocated for these animals
Fodder fed per day (kg) – Amount of farm fodder fed to these animals per day. This is the total for all these animals from the fodder pools. The same rationing is applied as that for breeding this animal type.

Feeding costs per animal per month, descriptions are the same as for breeding animals of this type (section 3.10.1)

Labour (man days per month), descriptions are the same as for breeding animals of this type (section 3.10.1).

Form 3.10.2. Input form for non-ruminant animals traded

4. Displaying Output

Every time a user runs a new scenario, by clicking the '*RUN SIMULATION*' button on the Main Menu, the IAT will pause briefly as it runs, then show brief glimpses of the output sheets as it writes the output, and then return to the Main Menu.

Output can be viewed in 2 ways:
- by going directly to each of the 5 output sheets (Monthly_output, Annual_output, Ruminant_output, Labour_output, and Fodder_output)
- by viewing the graphical output. On the Main Menu, click on '*Graphical Output*'.

4.1 Output sheets

4.1.1 Monthly output

This sheet provides the monthly whole farm values for:
Cash in – all revenue received

Cash out – all costs
Cash balance – previous balance + revenue – all costs
Labour costs – cost of hired labour
Overheads – monthly average
Interest – interest charges on overdraft if cash balance negative

For each crop grown:
Costs
Revenue
Value of home consumption
Number kg remaining in store, if kept for home consumption
Number of days labour spent on the crop

For each ruminant type:
Costs
Revenue
Milk production (litres)
Value of any home consumption
Number of days labour spent on the animals

For whole farm:
Total cost of bought fodder
Total number of days labour for forage harvesting

For each 'non-ruminant' animal type:
Costs
Revenue
Value of any home consumption
Number of days labour spent on the animals

For whole farm:
Total Methane production
Total ruminant Manure produced
Total amount of composted manure produced
Total fodder usage
Cost of any home consumption shortfall

4.1.2 Annual output

This sheet provides the annual cost, revenue, value of home consumption (HomeCon), and gross margin (GM-HC, gross margin ignoring the value of home consumption) for :

Each crop grown (grain, forage, tree, or other)
Each ruminant breed/type kept
Each non-ruminant animal kept
For the whole farm

The annual cost of Bought fodder is listed separately as it is difficult to realistically attribute the cost to any of the animal activities in particular.

4.1.3 Ruminant output

For each ruminant category (juveniles, weaners, breeders, etc), for each ruminant breed/type kept, monthly values are listed for:

Weight (kg)
Number of animals
Age (months)

4.1.4 Fodder output

For each of the 10 fodder pools, monthly values (kg of fodder, not kg/ha) are listed for:

Fodder input to the pool (kg), plus total input
Fodder output from each pool, plus total output
Fodder balance of each pool at the end of the month, plus total balance

4.1.5 Labour output

Labour activities

For each of the 16 crop labour activities and 6 animal labour activities, monthly values (in man days) are given for :

Total demand/need for the whole farm
Balance for the month – this is the balance of labour required for each activity. If it is 0, then all the demand has been met, if it is non-zero, then there is a shortfall of labour for that activity.

People categories

For people category (male and female, elderly, adult, etc), monthly values are given for:

Supply – the number of days labour each category could provide
Non-farm – the number of days each category had committed to non-farm labour
Balance – number of surplus days labour for each category after deducting the non-farm labour and meeting any on farm demand. If the value is positive, then they had surplus time, if zero, then either the category did not provide any labour, or it was all used.
Hired – number of days of hired labour for each category. If hired labour was set as fixed, this will be the number of days specified by the user. If not fixed, then it will be the number of days required to meet demand.
Hired-Bal – the balance of labour for each hired category after adjusting for demand.

Whole farm

Whole farm monthly values for:

All crop activities
All animal activities

Whole family supply
Whole family off-farm labour
Whole family balance (supply, less off farm, less on farm demand)
Total hired labour

4.2 Graphical output

To view output in graphical form, on the Main Menu, click on '*Graphical Output*'. The '*Graphs*' form (Form 4.2) will appear.

To view graphical output, click on the drop down menu next to one of the headings and select the particular item of interest, then click the '*Show graph*' button adjacent to the drop down menu.

4.2.1 Annual Costs/revenue

To view annual costs, revenue, home consumption and gross margin (as per the 'Annual output' sheet described above, click on the drop down menu next to the heading "Annual Cost/Revenue'.
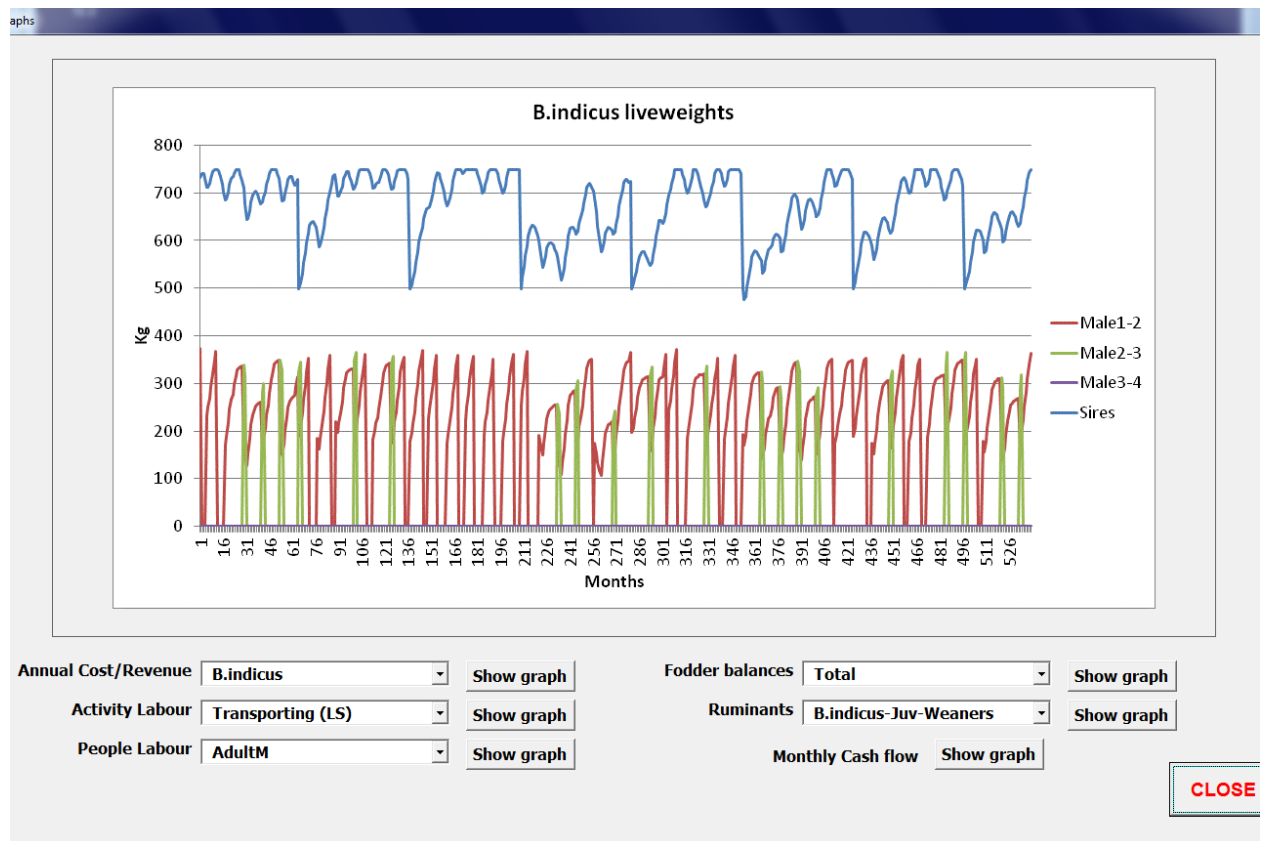
Form 4.2. Form to display output data graphically

4.2.2 Activity Labour

To view monthly labour demand and balance for each activity, as per the 'Labour output' sheet described above, click on the drop down menu next to the heading 'Activity Labour'. This graph will show the demand, and any outstanding balance. If the demand has all been met, then the balance will be zero.
-

4.2.3 People Labour

To view monthly labour demand and balance for each people category, as per the 'Labour output' sheet described above, click on the drop down menu next to the heading 'People Labour'. This graph will show the outstanding balance for the selected category, and any hired labour for that category.

4.2.4 Fodder balances

To view monthly fodder input, output and balances for each fodder pool or the whole farm, as per the 'Fodder output' sheet described above, click on the drop down menu next to the heading 'Fodder Balances'. This graph will show the values in kg (not kg/ha)

4.2.5 Ruminant weights

To view monthly live weights for each animal category for each ruminant breed/type, as per the 'Ruminant output' sheet described above, click on the drop down menu next to the heading 'Ruminants'. The ruminant categories are grouped into 3 groups: juveniles and weaners (male and female); all older females; all older males.

4.2.6 Monthly cash flow

Click on the '*Show graph*' button next to the heading to display the monthly cash in, cash out and cash balance for the whole farm, as described for the 'Monthly output' sheet above.

5. Adding new information to the IAT

At times you will want to add new crops, forages or native pasture information to the IAT. This can be done by direct access to the worksheet databases only. Some can be single entries, but others require information over the number of years in the analysis.

5.1 Adding a new ruminant or changing the name of an existing ruminant

The ruminant 'name' is merely a name for the convenience of the user, but the model uses the ruminant 'number' to select the relevant coefficients and specifications from

the 'Params' sheet. Currently the IAT allows for up to 20 ruminants for any particular parameter set.

> **N.B.** If changing ruminant names, remember that the matching data in the 'Params' sheet, for the particular ruminant selected, may no longer be relevant. For example, if renaming a breed of cattle to a sheep, then the expected mature weight and the gestation period will be different. Similarly, if adding a new ruminant, new coefficients and specification values will need to be added. The specifications can be entered via the input forms, but the *coefficients* have to be entered directly on the 'Params' sheet and should be done only by someone competent in parameterising ruminant growth, fertility and mortality.

To add a new ruminant name to the list, or change the name of an existing ruminant, go to the 'Params' sheet in the IAT and edit the names in column B, rows 5 to 24. Remember to click 'Save parameters' on the Main Menu to save the new ruminant names to the attached parameter file.

5.2 Adding a new climate region or changing the name of an existing region

The climate zone 'name' is merely a name for the convenience of the user, but the model uses the zone 'number' to select crop, forage and native pasture data from the databases. Currently the IAT allows for up to 20 climate zones for any particular parameter set. To add a new zone to the list, or change the name of an existing zone, go to the 'Params' sheet in the IAT and edit the names in column E, rows 5 to 24. Note which number is next to this new zone as you will need this number when specifying new data in the crop and forage databases. Remember to click 'Save parameters' on the Main Menu to save the new zone names to the attached parameter file.

N.B. If changing zone names, remember that the matching data in the crop and forage databases, for the particular zone number, may no longer be relevant.

5.3 Adding a new soil type or changing the name of an existing soil type

The soil type 'name' is merely a name for the convenience of the user, but the model uses the soil type 'number' to select crop and forage data from the databases. Currently the IAT allows for up to 20 soil types for any particular parameter set. To add a new soil type to the list, or change the name of an existing soil type, go to the 'Params' sheet in the IAT and edit the names in column K, rows 5 to 24. Note which number is next to this new soil type as you will need this number when specifying new data in the crop and forage databases. Remember to click 'Save parameters' on the Main Menu to save the new soil type names to the attached parameter file.

N.B. If changing soil type names, remember that the matching data in the crop and forage databases, for the particular soil type number, may no longer be relevant.

5.4 Adding/changing the name of a non-farm labour type

The non-farm labour 'name' is merely a name for the convenience of the user. Currently the IAT allows for up to 5 non-farm labour types for any particular parameter set. To add a new labour type to the list, or change the name of an existing labour type, go to the 'Params' sheet in the IAT and edit the names in column N, rows 5 to9. Remember to click 'Save parameters' on the Main Menu to save the new non-farm labour names to the attached parameter file.

5.5 Changing a land unit name

The land unit 'name' is merely a name for the convenience of the user. To change the name of a land unit, go to the 'Params' sheet, and scroll down column B until you find 'Land specifications' and edit the name/s below the heading. Up to 10 names are available. Remember to click 'Save parameters' on the Main Menu to save the new crop names and specifications to the attached parameter file.

5.6 Changing a bought (purchased) fodder name

The bought fodder 'name' is merely a name for the convenience of the user. To change the name of a bought fodder, go to the 'Params' sheet, and scroll down column B until you find 'Bought fodder specs' and edit the name/s below the heading. However, remember to check/change the specifications to make sure they are suitable for the new fodder. Up to 10 names are available. Remember to click 'Save parameters' on the Main Menu to save the new crop names and specifications to the attached parameter file.

5.7 Changing a supplement name

The supplement 'name' is merely a name for the convenience of the user. To change the name of a supplement, go to the 'Params' sheet, and scroll down column B until you find 'Supplement specifications' and edit the name/s below the heading. However, remember to check/change the specifications to make sure they are suitable for the new supplement. Up to 30 names are available. Remember to click 'Save parameters' on the Main Menu to save the new crop names and specifications to the attached parameter file.

5.8 Changing a non-ruminant name

The non-ruminant 'name' is merely a name for the convenience of the user. To change the name of a non-ruminant animal, go to the 'Params' sheet, and scroll down column B until you find 'Other animals' and edit the name/s below the heading. However, remember to check/change the specifications to make sure they are suitable for the new animal. Up to 10 names are available. Remember to click 'Save parameters' on the Main Menu to save the new crop names and specifications to the attached parameter file.

5.9 Adding/changing a crop name and details

To add the name of a new crop (grain, forage, tree or other) go to the 'Params' sheet, and scroll down column B until you find 'Grain crop specifications' (substitute Tree, Forage or Other in place of 'Grain' for those crops) and add the name to the existing names below the heading. Up to 30 names/crops can be entered for Grain and Forage crops, and up to 10 for Tree and Other crops. The crop specification information can be entered directly into the 'Params' sheet, to the right of the new name, or can be entered via the '*Crop specification*' input form (see section 3.7 above). Similarly, a crop name can edited/changed using the same method, however, remember to check/change the specifications to make sure they are suitable for the new crop. Remember to click 'Save parameters' on the Main Menu to save the new crop names and specifications to the attached parameter file.

Make a note which number is next to any new grain or forage crops as you will need this number when specifying new data for the crop in the crop database (see 5.10 and 5.11 below).

5.10 Changing the name of a ruminant category

N.B. These 'names' should not be changed as the categories have specific meaning the model.

This refers to category names such as juveniles, weaners, etc. However, animals move from category to another, and hence these names should not be changed. For example, juveniles (categories 1 and 2) become weaners (categories 3 and 4) at weaning age, then weaners become 1-2 year old females and males (categories 5 and 14) after 12 months.

5.11 Changing the name of an on-farm labour category

N.B. These 'names' should not be changed as the categories have specific meaning the model.

This refers to category names such as planting, harvesting, etc. However, labour is done at specific stages during the growth of a crop, and hence these names should not be changed. For example, ploughing and planting labour is allocated to the month of sowing, while harvest labour is allocated to the harvest month, and some are distributed across the intervening months.

5.12 Adding new grain/forage crop data or native pasture data to the databases

For food grain crops similar to rice or maize, you will need information on yields of grain and stover biomass, as well as nitrogen content of the biomass, and the harvest date (month of the year), as well yields of by-products (if any), the harvest year, and an allocation to a fodder pool (priority number). You will need as many years of data as you wish to analyse. For forage crops, you will need data for individual harvests during the year. The crops are identified by the climate zone, the

soil type, the crop number and the year. If the data is for a new food crop, you will need to add a new crop name and details (see section 5.7).

To enter the necessary data, open the desired parameter workbook, select the 'Crop_inputs' sheet (Figure 2) or 'Forage_inputs' sheet (Figure 3), and scroll to the bottom.

5.12.1 Crop data

The name of the sheet in the parameter file **MUST** be '**Crop_inputs**'.

Climate	Soil No.	CropNo	CropName	year_no	YEAR	Month	grain_wt	stover_wt	stover_%n	Priority	ByProd1	ByProd2
3	3	1	Rice-wet season	1	2001	10	2677	4016	0.700	4		
3	3	1	Rice-wet season	2	2002	10	2733	4100	0.700	4		
3	3	1	Rice-wet season	3	2003	10	2783	4175	0.700	4		
3	3	1	Rice-wet season	4	2004	10	1757	2636	0.800	4		
3	3	1	Rice-wet season	5	2005	10	2720	4080	0.700	4		
3	3	1	Rice-wet season	6	2006	10	2645	3968	0.700	4		
3	3	1	Rice-wet season	7	2007	10	1855	2782	0.800	4		
3	3	1	Rice-wet season	8	2008	10	1767	2651	0.800	4		
3	3	1	Rice-wet season	9	2009	10	2640	3960	0.700	4		
3	3	1	Rice-wet season	10	2010	10	3574	5361	0.600	4		
3	3	2	Rice-dry TRANS	1	2001	5	3210	4816	0.700	4		
3	3	2	Rice-dry TRANS	2	2002	5	2913	4370	0.700	4		
3	3	2	Rice-dry TRANS	3	2003	5	2990	4484	0.700	4		
3	3	2	Rice-dry TRANS	4	2004	5	2092	3137	0.800	4		
3	3	2	Rice-dry TRANS	5	2005	5	2964	4446	0.700	4		
3	3	2	Rice-dry TRANS	6	2006	5	3045	4568	0.700	4		
3	3	2	Rice-dry TRANS	7	2007	5	1957	2935	0.800	4		
3	3	2	Rice-dry TRANS	8	2008	5	1945	2917	0.800	4		
3	3	2	Rice-dry TRANS	9	2009	5	2992	4488	0.700	4		
3	3	2	Rice-dry TRANS	10	2010	5	4000	6000	0.600	4		
3	3	3	Rice-dry BCAST	1	2001	5	3210	4816	0.700	4		
3	3	3	Rice-dry BCAST	2	2002	5	2913	4370	0.700	4		
3	3	3	Rice-dry BCAST	3	2003	5	2990	4484	0.700	4		
3	3	3	Rice-dry BCAST	4	2004	5	2092	3137	0.800	4		
3	3	3	Rice-dry BCAST	5	2005	5	2964	4446	0.700	4		
3	3	3	Rice-dry BCAST	6	2006	5	3045	4568	0.700	4		
3	3	3	Rice-dry BCAST	7	2007	5	1957	2935	0.800	4		
3	3	3	Rice-dry BCAST	8	2008	5	1945	2917	0.800	4		
3	3	3	Rice-dry BCAST	9	2009	5	2992	4488	0.700	4		
3	3	3	Rice-dry BCAST	10	2010	5	4000	6000	0.600	4		

Figure 2. Layout of data in the grain crop database.

Climate zone – (column A) the region/village number in which the crop is grown
Soil No. – (column B) the number of the soil type to which the crop data refers
CropNo – (column C) the crop number. Have a different number for each crop or variant of a crop e.g. rice fertilised, rice unfertilised, etc.
Crop name – (column D) (optional crop name) not needed by the model, used merely for ease of finding data.
Year_no – (column E) the year sequence, normally 1 to 'n' (again, this is not used by the IAT, it is merely for ease of finding data).
Year – (column F) the actual harvest year. This is used by the model to find the relevant data.
Month – (column G) the harvest month for the crop (December=12).

Grain_wt – (column H) the yield of grain from the crop, expressed in kg/ha. If you have data expressed in some other units, convert to kg/ha for entering in the database.

Stover_wt – (column I) the biomass of the crop residue (excluding grain), expressed in kg/ha. Again, if you have data expressed in some other units, convert to kg/ha for entering in the database.

Stover_%n – (column J) the nitrogen content (%) of the crop residue (i.e. excluding the grain) at harvest time. This is used in determining the quality of the crop residue for animal feed.

Priority – (column K) the fodder pool into which the any crop residue will be input. Currently there are 10 fodder pools in the model, and feeding can be rationed (limited) from the individual fodder pools. All residues can go into one pool, or if the user wishes to track the use of particular crops, then each crop (up to 10) can go into a different pool.

ByProd1 - (column L) the yield of the first of 2 by-products from the crop, expressed in kg/ha. If you have data expressed in some other units, convert to kg/ha for entering in the database.

ByProd2 - (column M) the yield of the second of 2 by-products from the crop, expressed in kg/ha. If you have data expressed in some other units, convert to kg/ha for entering in the database.

5.12.2 Forage data

The name of the sheet in the parameter file **MUST** be '**Forage_inputs**'.

Climate zone – (column A) the region/village number in which the crop is grown

Soil No. – (column B) the number of the soil type to which the crop data refers

ForNo – (column C) the crop number. Have a different number for each crop or variant of a crop e.g. rice fertilised, rice unfertilised, etc.

Forage name – (column D) (optional crop name) not needed by the model, used merely for ease of finding data.

Year_no – (column E) the year sequence, normally 1 to 'n' (again, this is not used by the IAT, it is merely for ease of finding data).

Year – (column F) the actual harvest year. This is used by the model to find the relevant data.

Cut_no – (column G) the number of the harvest (1..n)

Month – (column H) the harvest month for the forage crop (December=12).

Growth – (column I) the biomass of the harvested forage or growth, expressed in kg/ha. Again, if you have data expressed in some other units, convert to kg/ha for entering in the database.

Forage_%n – (column J) the nitrogen content (%) of the crop residue (i.e. excluding the grain) at harvest time. This is used in determining the quality of the crop residue for animal feed.

Priority – (column K) the fodder pool into which the any crop residue will be input. Currently there are 10 fodder pools in the model, and feeding can be rationed (limited) from the individual fodder pools. All residues can go into one pool, or if the user wishes to track the use of particular crops, then each crop (up to 10) can go into a different pool.

ByProd1 - (column L) the yield of the first of 2 by-products from the crop, expressed in kg/ha. If you have data expressed in some other units, convert to kg/ha for entering in the database.

ByProd2 - (column M) the yield of the second of 2 by-products from the crop, expressed in kg/ha. If you have data expressed in some other units, convert to kg/ha for entering in the database.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Climate	Soil No.	CropNo	ForageName	year_no	YEAR	cut_no	month	Harvested wt	Forage_%n	Priority	ByProd1	ByProd2				
71	3	3	1	Panicum	1	2001	10	10	0	0.0	2						
72	3	3	1	Panicum	1	2001	11	11	0	0.0	2						
73	3	3	1	Panicum	1	2001	12	12	0	0.0	2						
74	3	3	1	Panicum	2	2002	1	1	0	0	2						
75	3	3	1	Panicum	2	2002	2	2	0	0	2						
76	3	3	1	Panicum	2	2002	3	3	0	0	2						
77	3	3	1	Panicum	2	2002	4	4	828	2.1	2						
78	3	3	1	Panicum	2	2002	5	5	1760	1.8	2						
79	3	3	1	Panicum	2	2002	6	6	1554	1.6	2						
80	3	3	1	Panicum	2	2002	7	7	620	1.4	2						
81	3	3	1	Panicum	2	2002	8	8	206	1.2	2						
82	3	3	1	Panicum	2	2002	9	9	206	1.2	2						
83	3	3	1	Panicum	2	2002	10	10	0	0.0	2						
84	3	3	1	Panicum	2	2002	11	11	0	0.0	2						
85	3	3	1	Panicum	2	2002	12	12	0	0.0	2						
86	3	3	1	Panicum	3	2003	1	1	0	0	2						
87	3	3	1	Panicum	3	2003	2	2	0	0	2						
88	3	3	1	Panicum	3	2003	3	3	0	0	2						
89	3	3	1	Panicum	3	2003	4	4	850	2.1	2						
90	3	3	1	Panicum	3	2003	5	5	1808	1.8	2						
91	3	3	1	Panicum	3	2003	6	6	1594	1.6	2						
92	3	3	1	Panicum	3	2003	7	7	638	1.4	2						
93	3	3	1	Panicum	3	2003	8	8	212	1.2	2						
94	3	3	1	Panicum	3	2003	9	9	212	1.2	2						
95	3	3	1	Panicum	3	2003	10	10	0	0.0	2						
96	3	3	1	Panicum	3	2003	11	11	0	0.0	2						
97	3	3	1	Panicum	3	2003	12	12	0	0.0	2						
98	3	3	1	Panicum	4	2004	1	1	0	0	2						
99	3	3	1	Panicum	4	2004	2	2	0	0	2						
100	3	3	1	Panicum	4	2004	3	3	0	0	2						
101	3	3	1	Panicum	4	2004	4	4	594	2.1	2						
102	3	3	1	Panicum	4	2004	5	5	1264	1.8	2						
103	3	3	1	Panicum	4	2004	6	6	1116	1.6	2						
104	3	3	1	Panicum	4	2004	7	7	446	1.4	2						
105	3	3	1	Panicum	4	2004	8	8	148	1.2	2						
106	3	3	1	Panicum	4	2004	9	9	148	1.2	2						
107	3	3	1	Panicum	4	2004	10	10	0	0.0	2						
108	3	3	1	Panicum	4	2004	11	11	0	0.0	2						
109	3	3	1	Panicum	4	2004	12	12	0	0.0	2						
110	3	3	1	Panicum	5	2005	1	1	0	0	2						
111	3	3	1	Panicum	5	2005	2	2	0	0	2						
112	3	3	1	Panicum	5	2005	3	3	0	0	2						
113	3	3	1	Panicum	5	2005	4	4	842	2.1	2						
114	3	3	1	Panicum	5	2005	5	5	1792	1.8	2						
115	3	3	1	Panicum	5	2005	6	6	1580	1.6	2						
116	3	3	1	Panicum	5	2005	7	7	632	1.4	2						
117	3	3	1	Panicum	5	2005	8	8	210	1.2	2						
118	3	3	1	Panicum	5	2005	9	9	210	1.2	2						
119	3	3	1	Panicum	5	2005	10	10	0	0.0	2						
120	3	3	1	Panicum	5	2005	11	11	0	0.0	2						
121	3	3	1	Panicum	5	2005	12	12	0	0.0	2						
122	3	3	1	Panicum	6	2006	1	1	0	0	2						
123	3	3	1	Panicum	6	2006	2	2	0	0	2						
124	3	3	1	Panicum	6	2006	3	3	0	0	2						
125	3	3	1	Panicum	6	2006	4	4	866	2.1	2						
126	3	3	1	Panicum	6	2006	5	5	1840	1.8	2						
127	3	3	1	Panicum	6	2006	6	6	1624	1.6	2						
128	3	3	1	Panicum	6	2006	7	7	650	1.4	2						
129	3	3	1	Panicum	6	2006	8	8	216	1.2	2						
130	3	3	1	Panicum	6	2006	9	9	216	1.2	2						
131	3	3	1	Panicum	6	2006	10	10	0	0.0	2						
132	3	3	1	Panicum	6	2006	11	11	0	0.0	2						
133	3	3	1	Panicum	6	2006	12	12	0	0.0	2						
134	3	3	1	Panicum	7	2007	1	1	0	0	2						
135	3	3	1	Panicum	7	2007	2	2	0	0	2						

Params / Crop_inputs / **Forage_inputs**

Figure 3. Layout of data in the forage crop database.

5.12.3 Native pasture data

The name of the sheet in the parameter file **MUST** be '**Native_inputs**'.

The input data for native pasture growth comes from the GRASP model. Grasp is run over a number of years for each region with the grass basal area and land condition parameters reset at the beginning of each year, and at a fixed stocking rate. Grasp is run numerous times at a range of grass basal area, land condition and stocking rate settings for each year of available climate data for the region. The IAT selects the initial data based on the starting parameters input by the user (on the 'Land Specifications' form), then adjusts the grass basal area and land condition each year

based on the utilisation rate for that year (using the same formulation that is used in Grasp). It then selects the input data for the following year based on the revised grass basal area and land condition and the fixed stocking rate e.g. if it starts with a land condition of 3 in 1961, and this is revised to a land condition of 4 at the end of 1961, then the IAT will select data for land condition 4 for 1962.

A number of inputs from Grasp are included for calculating ecological summaries.

Region – (column A) the region or climate zone number to the data refers

Soil – (column B) the number of the soil type to which the data refers

ForNo – (column C) the number of the native pasture type (if more than one, e.g. speargrass). Have a different number for each crop or variant of a crop e.g. rice fertilised, rice unfertilised, etc.

Forage name – (column D) (optional crop name) not needed by the model, used merely for ease of finding data.

GrassBA - grass basal area category. Currently the IAT uses values of 1, 3 and 5 only. Any other values will be interpolated to the nearest of these values.

Land_condition – land condition category. Currently the IAT uses values of 0, 2, 4…10 in steps of 2 only. Any other values will be interpolated to the nearest of these values.

Stk.rate – the stocking rate category (AE/sq.km). The IAT can use any stocking rate that is in the database.

Year_no – (column E) the year sequence, normally 1 to 'n' (again, this is not used by the IAT, it is merely for ease of finding data).

Year – (column F) the actual harvest year. This is used by the model to find the relevant data.

Cut_no – (column G) the number of the harvest (1..n)

Month – (column H) the harvest month for the forage crop (December=12).

Growth – (column I) the biomass of the harvested forage or growth, expressed in kg/ha. Again, if you have data expressed in some other units, convert to kg/ha for entering in the database. The N content of new native pasture growth is determined by the month in which it is grown, and it all goes into forage pool 1. Hence there are no values for N content and Priority as there are for Crop and Forage data.

ByProd1 - (column L) the yield of the first of 2 by-products from the crop, expressed in kg/ha. If you have data expressed in some other units, convert to kg/ha for entering in the database.

ByProd2 - (column M) the yield of the second of 2 by-products from the crop, expressed in kg/ha. If you have data expressed in some other units, convert to kg/ha for entering in the database.

Other land condition inputs:

Utilisn – calculated utilisation rate (no longer used by the IAT)

Soilloss – kg/ha soil loss as determined by Grasp

Cover - % ground cover as determined by Grasp

TreeBA - % tree basal area (currently fixed for each region)

Perennials - % perennials as determined by Grasp (now done in the IAT so not required)

Rainfall – Monthly rainfall (mm) input to Grasp (used in calculating efficiency of capture of rainfall)

Runoff – Monthly runoff (mm) as calculated by Grasp (used in calculating efficiency of capture of rainfall)

6. Trouble shooting

6.1 Function buttons do not work when first used

If none of the function buttons work when you try to use the IAT the first time, then it is probably because the macros have not been enabled. If you clicked enable when opening the program, but it still does not work, then you need to change the security setting in Excel. You will only need to do this once because it is a security setting in Excel and has nothing to do with the IAT. To change your security setting in Excel:

For Excel 2007:

If in Full Screen mode, click on the green Excel icon in the top left hand corner of the screen, then click restore.

Click *Developer, Macro Security, Macro Settings*
Select *Enable all macros* level of security
Click *Ok*

Close the IAT and Excel, then re-open it, and everything should work.

6.2 Function buttons do not work after a debug error

If the program has stopped while running and given an error message which includes a button with '*Debug*' on it, then the program will have paused and you will have to reset it.

For Excel 2007:

Click *Developer, Visual Basic*
This will open a new window
Click *Run, Reset*
Then close the window

6.3 Additional help

For additional help on using the model, more detailed explanation of the functioning of the model, or to report any errors detected in the model, please contact :

Cam McDonald
CSIRO Ecosystem Sciences
Email: cam.mcdonald@csiro.au

Appendix 5 – Indices of environmental condition

Indicators and their application to determine attributes of environmental condition

Attribute A1 Soils and Hydrology

Indicator A1.1 Severity of erosion

Rationale: soil erosion is a major form of degradation and can result from increased grazing pressure reducing ground cover. Land in good condition has little or no erosion.

Assessment: the monthly estimates of soil movement from GRASP are summed and annual average calculated and used as follows.

-3	Severe erosion (> 5 t/ha/an)
-2	3-5
-1	1-3
0	0.7-1
+1	0.4-0.7
+2	0.1-0.4
+3	Little or no erosion (< 0.1 t/ha/an)

Indicator A1.2 Soil surface condition and infiltration

Rationale: good soil surface condition is important for a healthy soil indicating a favourable environment for soil animals and high infiltration. Runoff (the reverse of infiltration) has been used to derive the values for this indicator.

Assessment: the estimates of rainfall and runoff from GRASP are used to express runoff as a percentage of rainfall, the annual average calculated and used as follows.

-3	Excessive runoff (>50% of rainfall)
-2	30-50
-1	20-30
0	15-20
+1	10-15
+2	5-10
+3	Little runoff (<5% of rainfall)

Attribute A2 Vegetation

Indicator A2.1 Proportion of desirable species

Rationale: pastures are the drivers of animal production and a high proportion of desirable species favours animal production. Where pastures contain less than 70% desirable species they are likely to be poor condition with a high proportion of weeds, Such pastures are likely to deteriorate further, and may need management (e.g. spelling) to improve. The perennial tussock grasses are the most important desirable species in native pastures and their proportion is used for this indicator

Assessment: proportion of perennial grass from GRASP.

-3	<20% Perennial grass
-2	20-40
-1	41-60
0	61-70
+1	70-80
+2	81-85
+3	>85%

Indicator A2.2 Ground cover level

Rationale: ground cover contributes to soil health in a number of ways – protecting the soil surface from raindrop impact, slowing the flow of water over the soil increasing infiltration, moderating soil temperatures, and providing food and suitable environment for soil animals and micro-organisms.

Assessment – GRASP estimates of ground cover.

-3	0-20% ground cover
-2	21-30
-1	31-40
0	41-50
+1	51-60
+2	61-70
+3	71-100

Indicator A2.3 Tree/grass balance

Rationale: most original vegetation in the northern grazing lands was an open woodland or grassland but in some areas there has been an increase in woody species (both native and exotic) leading to a thickening of woody species and a reduction in the grass layer. The indicator is estimated by the impact of the increased tree cover on grass growth.

Assessment – using GRASP output calculate pasture growth under the scenario (G_S) and also the growth that would have occurred with TBA at the value for that location in natural vegetation (G_N); express G_S as a percentage of G_N and use these values as follows.

-3	<50
-2	51-70
-1	71-80
0	81-85
+1	86-90
+2	91-95
+3	100

Attribute A3 Atmosphere (greenhouse gases)

Indicator A3.1 Methane emissions from grazing cattle

Rationale: grazing cattle are a major source of methane which is produced by anaerobic microbial fermentation when hydrogen is converted to methane. Methane production is closely related to energy intake and is calculated in the IAT.

Assessment: the estimated methane output per animal from the IAT is combined with stocking rate to calculate the property emissions in g methane/ha/day and used as follows. Note that 250 g is the approximate methane emissions from a 450 kg animal gaining 0.5 kg per day.

-3	High emissions (> 250 g methane/ha/day)
-2	101-250
-1	21-100
0	11-20
+1	6-10
+2	1-5
+3	No emissions (<0.1 kg/ha)

Indicator A3.2 Soil carbon sequestration

Rationale: Soil organic carbon levels are related to land condition and decline as land condition declines. The amount of carbon present in a soil depends on the input of organic material and the breakdown of this material. The level varies between sites and is positively related to rainfall and clay content, and negatively related to temperature and soil pH. The estimates are based on uneaten pasture (i.e. growth minus intake) and assuming 40% of the carbon in uneaten pasture is stored in the soil.

Assessment: use the pasture growth (G as kg/ha) and animal intake (I as kg/ha) from GRASP to estimate the carbon input to soil = (G-I) * 0.4 * 0.46. This indicator is calculated as the average over all years of the simulation run, not just the final half.

-3	Nil (No carbon input)
-2	0-40
-1	40-100
0	100-200
+1	200-600
+2	600-1000
+3	> 1000 kg C/ha (High carbon input)

Indicator A3.3 Carbon storage in trees

Rationale: Woody vegetation can store large amounts of carbon. The amount of carbon in woody vegetation is taken as proportional to TBA based on the equation of Burrows *et al.* (2002) where above ground biomass (t/ha) = 6.286*TBA (m^2/ha) and assuming biomass is 46% carbon. The value for each assessment was based on the change in TBA over the period; hence tree clearing gives big release of carbon and growth of trees adds to the inputs to the system.

Assessment: use the TBA values from GRASP/IAT. This indicator is calculated as the average over all years of the simulation run, not just the final half.

-3	> -400 kg/ha (Large carbon release)
-2	-200 to -400
-1	-10 to -200
0	No or little carbon input or release (-10 to +10 kg/ha)
+1	10 to 100
+2	100 to 150
+3	High carbon input (> 150 kg/ha)

Indicator A3.4 GHG emissions from fire

Rationale: methane and nitrous oxide are emitted during fires (also CO_2 but we assume this is taken up by the vegetation the following year). The level depends on fire amount and intensity.

Assessment – calculate area burnt, fuel load (TSDM from GRASP on the day of the fire), burning efficiency, fire frequency, emission factors and convert to CO_2 Equivalents (see Appendix for details). Note: with a fuel load of 2.5 t/ha, burning the whole property every 3 years would release 1.1 t/ha CO_2-eq per hectare each year. This indicator is calculated as the average over all years of the simulation run.

-3	High GHG emissions (> 1.0 t/ha CO_2-eq)
-2	0.8-1.0 t/ha CO_2-eq
-1	0.6-0.8 t/ha CO_2-eq
0	0.4-0.6 t/ha CO_2-eq
+1	0.2-0.4 t/ha CO_2-eq
+2	0-0.2 t/ha CO_2-eq
+3	No GHG emissions