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Options for addressing under-nutrition in northern Australian cattle

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Abstract

This project supported a mid-career researcher at The University of Queensland (UQ) to build and maintain capacity in ruminant nutrition research for the northern Australian beef cattle industry. The project required that the researcher conduct and report on at least five experiments over five years addressing the issue of under-nutrition in northern Australian cattle. The researcher was required to obtain funding for the experiments through competitive funding schemes from various research funding bodies [MLA and the Australian Centre for International Agricultural Research (ACIAR)]. Over the five year term of the project the researcher has been involved in five additional MLA funded projects and six ACIAR funded projects, some of which are ongoing. The range of research undertaken includes experiments examining the response of various classes of livestock to diets or management practices within northern Australian and south-east Asian beef cattle production systems, on-farm monitoring of cattle production systems in south-east Asian countries and increasing the understanding of the underlying biology behind animal responses, specifically gene expression studies, across a range of ruminant nutrition models. The researcher has authored or co-authored 13 refereed publications, 28 abstracts in conference proceedings, 8 final reports and 1 book chapter, and contributed to 1 monograph over the five year term of the project.

Executive summary

This project was established to build the capacity to conduct research relevant to the northern Australian beef cattle industry. The project supported the appointment of Dr Simon Quigley as a Senior Research Officer at The University of Queensland to undergo training in ruminant nutrition research relevant to the northern Australian beef cattle production systems. Simon Quigley was involved in the design and conduct of a range of nutrition focussed research projects, including several as Chief Investigator, developed networks with other researchers involved in northern beef research, supervised post-graduate students and published scientific findings in peer-reviewed journals and in conference proceedings. The project developed the capacity of Simon Quigley to the point where he has been successful in independently receiving and managing research projects that are of direct relevance to the northern beef industry (e.g. MLA funded projects related to phosphorus supplementation) and from a range of funding sources (i.e. MLA, ACIAR, UQ). Over the five year term of the project Simon Quigley has been involved in five additional MLA funded projects and six ACIAR funded projects, some of which are ongoing. The range of research undertaken includes experiments examining the response of various classes of livestock to diets or management practices within northern Australian and south-east Asian beef cattle production systems, on-farm monitoring of cattle production systems in south-east Asian countries and increasing the understanding of the underlying biology behind animal responses to various nutritional challenges, specifically gene expression studies, across a range of ruminant nutrition models.

The project will broadly be of benefit to the northern Australian beef industry as it has developed capacity for the conduct of ruminant nutrition research which can potentially be utilized in the future. The researcher is likely to play a continued role in ruminant nutrition research in the future as new opportunities and challenges for the northern beef production systems emerge.

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1 Background

The purpose of this project was to support a Postdoctoral Fellow (subsequently referred to as 'Researcher') under the supervision of Prof. Poppi at UQ to build and maintain capacity in ruminant nutrition research for the northern Australian beef industry. Dr Simon Quigley was appointed to the position of Senior Research Officer at UQ and commenced his role on 2-January-2009. Prior to this Simon Quigley was employed as a Research Officer at The University of Queensland (2005 to 2008), spent time as an Australian Youth Ambassador for Development (2004 to 2005) and conducted post-graduate studies at The University of Adelaide (2000 to 2004) and was awarded his PhD in 2005 ('The effects of nutrition on myogenesis in sheep').

Cattle in the northern Australian production system suffer from the effects of restricted protein nutrition both yearly (during the dry season) and during periodic events such as droughts. This leads directly to variability in the productivity of northern beef production systems and indirectly to poorer quality meat from these systems as animals take longer to achieve target market weights. Strategic supplementation is one option for overcoming this challenge, though the response can be inconsistent due to such variables as animal genotype, rumen microbial flora, supplement type and digestion characteristics.

The work of the UQ group (Poppi and McLennan with colleagues from The Department of Agriculture, Forestry and Fisheries, Queensland (QDAFF), The Department of Primary Industry and Fisheries, NT (DPIF), CSIRO and industry has focussed on supplementation strategies to improve growth rates and reproduction performance of cattle in northern Australia. In addition they have an extensive research program in Indonesia funded by ACIAR examining the same issues within their domestic cattle industry. This was the first project by MLA to support and develop a mid-career researcher with benefit to the northern Australian beef industry using this established network of researchers. Simon Quigley worked closely with Prof. Poppi and received specialised training in nutrition research relevant to the cattle production systems of northern Australia. Simon Quigley was actively involved in programs that were funded by the Northern Beef Program of MLA and by ACIAR.

2 Project objectives

1. Train a Researcher in nutrition research to benefit the northern cattle industry to a level where the appointee is independently receiving competitive research grants and is on track to establish a career in this discipline.

2. The Researcher will have developed into a major contributor to the outcomes achieved in the MLA northern beef nutrition program.

3. Contribute to research in the northern beef nutrition program, with the first three experiment objectives:

    a) Identify groups of genes responsible for the regulation of feed intake of sheep consuming low crude protein diets.

    b) Determine the impact of an 'immune challenge' and dietary protein at weaning on liveweight gain of steers.

    c) Determine the impact of lactation status in the dry season on body composition changes of *Bos indicus* cows.

Continuation of this project into years 4 and 5 is subject to a **go/no go** decision based on progress and funding success for operating budget. The experimental objectives for years 4 and 5 will be developed during year 3 in agreement with the MLA manager.

4. Publish an average of two peer reviewed scientific papers per year of funding, with one of these as first author.

3 Methodology

Simon Quigley was appointed to the position of Senior Research Officer at UQ and commenced in that position on 2-January-2009, with the appointment concluding on 31-December-2013. Operating funding for the initial experiment was included in the budget of the current project, with funding for all subsequent projects sourced through competitive funding application processes. Simon Quigley was successful in gaining funding of either stand-alone projects or for components of much larger projects in which he contributed to the development of the project proposal and was actively involved in the research components. Simon Quigley remains employed at UQ with funding from a number of ACIAR projects with this funding currently expected to cease on 30-June-2015.

The detailed methodology for the individual experiments/activities is not included within this report as many of these are described in final reports and scientific papers published elsewhere. A brief description of each of the projects, or activities within projects, is listed along with the role of Simon Quigley in each case.

4 Results

Objective 1. Train a Researcher in nutrition research to benefit the northern cattle industry to a level where the appointee is independently receiving competitive research grants and is on track to establish a career in this discipline.

Simon Quigley worked within the UQ ruminant nutrition group and took responsibility for the management and conduct of the projects listed below. This was an experienced person (PhD with three years post-PhD experience, a mid-career scientist). Training was specifically in nutrition focussed on conditions within northern Australia. The more important aspect was the participation of Simon Quigley in workshops and discussions, within and outside the group, to identify key issues, develop projects to address these issues and source funding to conduct the research. The methodology of successful project development was a key learning outcome. In addition, Simon Quigley co-supervised/co-supervises seven postgraduate students and has experienced the role of supervisor.

Over the course of the project Simon Quigley, in addition to contributing to the development of several other research projects, was successfully awarded the following projects specifically to him from funding bodies as listed below,

- B.NBP.629 - Factors associated with divergent post-weaning growth in northern Australian cattle herds (MLA)
- B.NBP.537 - Validation and demonstration of a diagnostic tool for phosphorus status of beef cattle (MLA)
- B.NBP.565 - Re-alimentation of cattle of varying phosphorus status (MLA)
- LPS/2013/017 - Improving nutrition during pregnancy and lactation to achieve production targets for Bali cattle (ACIAR)
- Prenatal programming of the appetite regulatory network and neonatal survival in sheep fed low crude protein diets (UQ)

Objective 2. The Researcher will have developed into a major contributor to the outcomes achieved in the MLA northern beef nutrition program.

Simon Quigley has become a major contributor to the MLA northern beef nutrition program as evidenced by:

- The above research grants from MLA and ACIAR awarded to him as Chief Investigator, plus a number of other projects on which he was a major contributing scientist
- His participation in workshops organised by MLA (e.g. Phosphorus related workshops and meetings)
- His participation in workshops organised by ACIAR. Whilst ACIAR's role is in research in developing countries the work has direct application to northern Australia and specific experiments in northern Australia have been conducted (e.g. changes in body composition of the cow in the NT)
- His new project development with ACIAR (e.g. Improving reproductive performance of cows and performance of fattening cattle in low input systems of Indonesia and northern Australia (LPS/2008/038), Improving nutrition during pregnancy and lactation to achieve production targets for Bali cattle (LPS/2013/017), Enhancing smallholder beef production in Timor Leste (LPS/2009/036), Improved beef supply chains in Vanuatu (in development)
- His new project development with MLA (e.g. B.NBP.629, B.NBP.537, B.NBP.565)
- His linkages with industry (Ridley Agri-products) and government agencies [DPIF, QDAFF, South Australian Research and Development Institute (SARDI) and CSIRO]
- His linkages with endocrine, gene expression and gene network groups [Nattrass (SARDI), Dalrymple (CSIRO) and Anderson (UQ)]. This new work includes sequencing of the entire transcriptome of muscle and fat samples that were collected from a range of controlled experiments establishing unique scenarios of low crude protein diets and various supplementation strategies. This is novel work not previously attempted
- His involvement in the new work on skeletal growth led by Kidd (UQ) but where he provides an equal and major contribution to the direction of the research and its conduct. This is work done within the MLA funded project Enhancing compensatory gain by increasing skeletal growth in the dry season (B.NBP.692) and the ACIAR funded NT Weaner Growth experiment (AH/2011/054, Improving the livelihoods of smallholders in the Central Dry Zone of Myanmar through research on animal production and health)
- His series of publications (listed in the Results section of this report)
- His leadership role within the UQ nutrition group whereby that group relies on him to initiate novel ideas and initiate and manage new projects. He is the senior person to ensure projects are done properly, to supervise students and technical staff, to meet milestones for agencies and to write final reports and scientific papers. His efforts have contributed enormously to the success of the group obtaining research grants and successfully conducting the research and publishing it to the satisfaction of the funding agencies, largely MLA and ACIAR

Objective 3. Contribute to research in the northern beef nutrition program.

The project was initiated with the objective of the Researcher working on five discrete experiments over the five year period of the project. The activities that the Researcher was involved in were much more wide reaching than that. Rather than list the five experiments only, the following section briefly outlines the projects and activities within projects that Simon Quigley either contributed to or was responsible for and a brief description of each project, or activity within a project. A more detailed description of the activities, results and implications are presented in various Final Reports and are therefore already available and will not be repeated here. How these activities relate to the project objectives is also indicated where relevant.

Project B.BSC.0071

Gene expression in the hypothalamus of sheep fed diets of variable crude protein to metabolisable energy content (Objective 3a).

This experiment was funded within MLA project B.BSC.0071, January-2009 to December-2013. Simon Quigley was responsible for the conduct of the experiment and sample analysis and interpretation of findings.

The experiment involved feeding lambs a series of diets with different metabolisable energy (ME) to crude protein (CP) ratios. Gene expression studies on three regions of the sheep hypothalamus and liver were conducted using a candidate gene approach. Other tissue samples (subcutaneous, omental and renal adipose tissue, heart, adrenals, rumen, abomasum, duodenum and jejunum and *longissimus dorsi*, *soleus* and *semitendinosus* muscles) are stored at -80^{o}C for future gene expression studies (not within this project). Plasma insulin-like growth factor-1, ghrelin, glucose, urea, albumin and creatinine and rumen ammonia concentrations have been determined. Since this experiment was conducted the development of Next Generation Sequencing (NGS) technology has developed. RNA samples of two regions of the hypothalamus will be submitted for RNA-seq analysis to determine differential RNA expression across the entire transcriptome, which is a far more powerful approach than the candidate gene approach used initially. Results indicated that the abundance of candidate gene mRNA's was influenced by total energy intake rather than the protein content of the diet *per se*. Differences in abundance of mRNA's were evident between the different regions within the hypothalamus.

Project B.NBP.629

Factors associated with divergent post-weaning growth in northern Australian cattle herds (Objective 3b).

This experiment was funded by MLA, June-2010 to December-2012, and was conducted in collaboration with the Department of Primary Industries, NT. Simon Quigley was the Chief Investigator on the project and responsible for sample analysis, analysis and interpretation of data and submission of the final report. The final report was accepted by MLA in December-2012.

This project examined factors associated with divergence in post-weaning growth in *Bos indicus* steers in northern Australia. Steers that were similar in liveweight (LW) (145 kg) at weaning but different in LW 91 days after weaning (148 and 163 kg, for lowest and highest LW gain) had similar LW gain when fed either a low (Mekong grass hay; 0.28 kg/day) or moderate (cavalcade hay; 0.47 kg/day) CP diet in pens. Steers that gained more LW over this post-weaning period had higher LW gain over the subsequent wet season than steers that had the lowest LW gain post-weaning although the differences were small practically (0.58 vs. 0.55 kg/day respectively over the wet season). Approximately 12 months after weaning there was only 12 kg difference in LW between steers that had the highest and lowest LW gain after weaning. There were no differences in circulating concentrations of albumin, creatinine, glucose, insulin-like growth factor-1 (IGF1) or urea between steers of different post-weaning LW gain, at weaning, 91 days post-weaning or after feeding low or higher CP diets. Serum concentrations of IGF1, urea and glucose were elevated in steers fed the higher CP diet. The reasons for the divergence in LW gain post-weaning are likely to be related to variability in responses to marking and weaning, grazing behaviour or supplement intake rather than genetics or health status.

Project B.NBP.537

Validation and demonstration of a diagnostic tool for phosphorus status of beef cattle.

This project was funded by MLA, June-2010 to December-2013, and was conducted in collaboration with the Department of Primary Industries, NT. Simon Quigley was the Chief Investigator on the project and responsible for conduct of the pen experiment (Activity 1 below),

sample analysis, interpretation of data and submission of the final report. The final report was submitted to MLA in December-2013 and accepted in June-2014.

Activity 1. Liveweight gain, feed intake and plasma phosphorus (P) and faecal P in steers in response to dietary P content

Bos indicus crossbred steers were offered treatment diets of increasing P content (0.9, 1.3, 1.8, 2.0 and 2.4 g P/kg DM; n=6/treatment) for 172 days. Dry matter (DM) intake, LW and various indicators of P intake were measured in the plasma and faeces. DM intake and LW gain of steers increased with increasing P intake. Steers fed a high P diet (2.4 g P/kg DM) gained an additional 120 kg W than steers fed a low P diet (0.9 g P/kg DM) over 172 days. Reductions in DM intake and LW gain in response to the 0.9 g P/kg DM diet were observed after 5 weeks of treatment feeding. The influence of dietary P content on ME intake was the key driver of the response of LW gain to P intake. Plasma inorganic P (PiP) responded immediately to P intake and was relatively stable across the experimental period. PiP was a better indicator of diet P content and P intake than the concentration of P in the faeces (FecP). There was no difference between FecP, FecP:ME and FecP:CP in response to P intake under conditions when diet ME and CP were relatively constant across the experiment and between treatments. FecP and its associated ratios with diet quality (ME and CP) did not respond to P intake as quickly as PiP and were more variable. FecP (and its associated ratios) provided a better indicator of diet P content (and P intake) the longer the steers had consumed their allocated treatment diets.

Activity 2. Dry season P supplementation of cows under field conditions

Bos indicus cows (n=544) and steers (n=80) were offered supplements with or without P in the wet and dry seasons under extensive conditions on a commercial cattle station. The various indicators of dietary P content/P intake measured in Activity 1 were measured in Activity 2 as well as reproductive performance of cows and LW gain of steers. An auto-drafter was used to draft animals to allocated supplement treatments in the wet and dry seasons, resulting in four treatments

1. +P (wet season)/+P (dry season)
2. +P (wet seaon)/-P (dry season)
3. -P (wet season)/+P (dry season)
4. -P (wet seaon)/-P (dry season)

The wet season LW gain and serum inorganic P concentration at the end of the growing season in the unsupplemented steers suggested that it was unlikely that a response to wet season P would occur in the experimental paddock (Stud paddock). Approximately two-thirds of Stud paddock (black soil) had a soil P concentration of approximately 2 ppm while the remaining one-third of the paddock (red soil) had a soil P concentration of approximately 7 ppm. Presumably the cattle in Stud paddock were more than able to compensate for the low P content of the black soil area by foraging in the red soil areas. In hindsight, the selection of this paddock was not appropriate to quantify the carry-over effects of dry season P supplementation on herd performance. There was no response of either cows or steers to P supplementation. Performance of the mob was excellent with weaning rates of approximately 85% across all treatments over two years and LW gain of approximately 150 kg in supplemented and unsupplemented steers over the first wet season. Liveweight of cows was maintained throughout the year for all treatments; comparison of the measured with published FecP:ME threshold values would suggest that cows were not receiving adequate P to maintain LW either during late pregnancy or lactation. FecP:ME (and serum inorganic P) indicated an increase in P intake in cows and steers in the dry season, reflecting higher supplement intakes over that period of time. Incorporation of a source of P into dry season supplements resulted in higher P intakes than were achieved by offering a P supplement in the wet season, however the carry-over effects of dry season P supplementation on breeder cattle remain unknown. A key outcome from this activity was the improvements in the remote livestock management system with a new prototype likely to be released commercially in 2014.

Project B.NBP.565

Re-alimentation of cattle of varying phosphorus status

This project was funded by MLA, September-2011 to July-2012. Simon Quigley was the Chief Investigator on the project and responsible for conduct of the pen experiment, sample analysis, analysis and interpretation of data and submission of the final report. The final report was published by MLA in July-2013.

Steers that were previously fed diets with different P content for approximately six months were fed a diet of approximately 100 g CP/kg DM, 63% dry matter digestibility (DMD) and 1 g P/kg DM with supplementary P supplied to all steers to provide a total dietary P content of approximately 2.5 g P/kg DM intake for three months. The objectives of the project were to examine the response of growing steers of variable P status to a high P diet, and to test if the relationships between dietary P and a potential diagnostic ratio derived from faecal analysis (FecP:ME) varied when steers were in a re-alimentation phase. Dry matter intake of steers from the lowest P diet (0.9 g P/kg DM) was increased to the intake of steers from the highest P diet (2.4 g P/kg DM) within one week of re-alimentation (excluding a two-week adaptation period). Steers that were previously fed the lowest P diet increased their LW gain (1.33 kg/day) and rate of hip height change (57 mm/100 days) to a rate higher than that of steers that were previously fed the highest P diet (0.70 kg/day and 34 mm/100 days, respectively) during re-alimentation. The concentration of P in the faeces and plasma of steers previously fed low P diets responded to the higher P diet within the first week of feeding, with little difference in concentration between steers regardless of previous P intake. After three months of re-alimentation on a high P diet, steers that previously had a low P intake had lighter and leaner carcasses with lower dressing percentages than steers that previously had a high P intake, with no differences in ossification score, fat colour or meat pH. This reflected that the period of re-alimentation was not long enough for previously P deficient steers to catch up to the control steers, although compensatory growth was occurring. There were no differences in carcass characteristics when data was adjusted for carcass weight. In conclusion, steers that were fed on a low P diet responded immediately to a high P diet, in terms of feed intake and LW gain, and the increased P intake will be reflected immediately in increased concentrations of P in the plasma and faeces, which reached similar concentrations regardless of the P content of the diet previously consumed by the steers. The results indicate that FecP:ME is not indicative of P status (repletion vs. non-repletion) of growing animals but indicative of P intake, regardless of previous P intake.

RNA was extracted from muscle biopsies collected from steers fed the low and high P at the start and end of this experiment and submitted for RNA-seq analysis. Differentially expressed gene pathways were identified and included focal adhesion, MAPK signalling, axon guidance, regulation of actin cytoskeleton, ECM receptor interaction, Hippo signalling pathway and endocytosis. Bone biopsies were also collected for histology and this will be done in collaboration with Dr Lisa Kidd (School of Veterinary Science, UQ).

Project B.NBP.692

Enhancing compensatory gain by increasing skeletal growth in the dry season

This project was funded by MLA, March-2012 to October-2015. Simon Quigley contributed to the development of the proposal and experiments within the proposal (particularly Activity 1) and has been involved in all aspects of each of the three activities (experiments) to be conducted. Simon Quigley is also responsible for gene expression analysis in muscle samples collected in Activities 2 and 3 below.

Activity 1. The effect of changes in feed intake on the molecular regulation of bone elongation in sheep

Fasting and re-feeding of lambs was used as a nutritional model to induce dramatic, acute changes in bone growth. Lambs were euthanased after periods of feeding and fasting and bone

samples collected for RNA-seq studies to identify the key gene pathways involved in the regulation of bone growth.

Activity 2. The effect of crude protein content or level of metabolisable energy intake on skeletal growth, subsequent compensatory growth and bone gene expression in Bos indicus crossbred and Holstein genotype steers
Bos indicus (Brahman crossbred) and *Bos taurus* (Holstein friesian) steers were offered either a high CP/high ME intake treatment (lucerne chaff *ad libitum*), a low CP/low ME intake treatment (Mitchell grass *ad libitum*) or a high CP/low ME intake treatment (lucerne chaff with intake restricted to an equivalent ME intake as that of steers fed the Mitchell grass diet) for 4 months (Phase 1). All steers were then offered a high CP/high ME intake treatment for a further 3 months. Feed intake, LW, change in skeletal dimensions were measured regularly. Bone biopsies were conducted with bone samples collected for histology and gene expression analysis. Muscle biopsies were collected from all steers at the end of Phase 1, after 4 weeks and at the conclusion of Phase 2 for analysis of candidate gene expression. Abundance of genes within the IGF, transforming growth factor and myosin heavy chain families were determined by quantitative PCR.

Activity 3. The effect of bovine somatotrophic (bST) on skeletal growth and bone gene expression in Bos indicus cross steers.
Brahman crossbred steers, of the same genotype used in Activity 2, will be fed the same three treatment diets used in Activity 2 for 100 days with n=10 steers/treatment. Half of the steers in each treatment group will receive bST and half will not. Feed intake, LW and change in skeletal dimensions will be measured regularly. Bone, muscle, fat, liver, gastro-intestinal tract and hypothalamus samples will be collected at post-mortems conducted on the steers for gene expression studies.

Project B.NBP.695
Algal ponds as a source of protein supplementation
Simon Quigley is currently listed on this project and will potentially have a role in any cattle feeding experiments that are undertaken. The project will conclude in December-2015.

Project LPS/2008/038
Improving reproductive performance of cows and performance of fattening cattle in low input systems of Indonesia and northern Australia.
This project was funded by ACIAR and included activities in Indonesia and Australia for which Simon Quigley was responsible. Simon Quigley was also involved in all aspects of project design, proposal development and submission of the proposal to ACIAR. These project activities were conducted in collaboration with DPIF, the University of Mataram, the University of Haluleo and Balai Pengkajian Teknologi Pertanian (BPTP) Sultra. The final report for this project will be submitted to ACIAR in September-2014.

Activity 1. Changes in metabolic hormones, gene expression and body composition of Bos indicus cows that either did or did not lactate during the dry season in northern Australia (Objective 3c)
In northern Australia large nutritional demands are placed on lactating cows, particularly as pasture quality declines in the dry season. Mobilisation and deposition of adipose tissue and protein may occur in the dry and wet seasons respectively, and this is influenced by the physiological status of the cow and diet quality. Understanding the changes in body composition that occur in cows over the dry and wet seasons may assist in the development of more appropriate supplementation strategies based on their physiological status. Mature, non-pregnant lactating *Bos indicus* cows (n=39) were allocated to treatment groups that either lactated (*L*) or did not lactate (*NL*) throughout the dry season. Calves were then weaned

dependent on the allocation of their dams in either June (*NL*) or October (*L*). The cows grazed *Heteropogon contortus* dominant pastures as a single mob at the Katherine Research Station, NT. Supplement was distributed weekly, with a urea based supplement offered at 120 g/head.day in the dry season and a phosphorus based supplement offered at 120 g/head.day during the wet season. Liveweight was recorded in most months over the dry season (June to October 2012; 132 days) and subsequent wet season (October 2012 to April 2013; 175 days) after a 12 hour curfew. Data were analysed using a repeated analysis of covariance. The average LW of cows across time was influenced by lactation status across the dry season ($P<0.001$). In October, at the time when calves were weaned from *L* cows, the *NL* cows were 21.1 $\pm$5.6 kg ($P<0.001$) heavier than the *L* cows. Following the wet season, the difference between treatment groups had reduced with *L* cows 11.8 $\pm$ 5.6 kg lighter than *NL* cows ($P<0.04$). The analysis of the wet season data indicated a significant difference between the LW gain of *L* to *N* cows ($Z=-2.63$, $P=0.008$). RNA extracted from skeletal muscle biopsies of cows collected at the end of the dry season and end of the subsequent wet season was analysed by RNA-seq to identify differentially expressed genes across the entire transcriptome. Differentially expressed KEGG (Kyoto Encyclepedia of Genes and Gene pathways) pathways and genes within pathways were analysed using EdgeR and GAGE software packages. The concentration of IGF1, insulin, leptin and oxytocin were analysed in the plasma of cows, with lactating cows having lower IGF1 and leptin concentration in the dry season. The concentration of IGF1 and insulin increased in the wet season in response to increased feed quality.

Activity 2. Growth, development and puberty of Bali heifers in Indonesia

Lifetime productivity of female cattle is influenced by age at first calving. Managing pre- and post-pubertal growth of heifers is important in establishing this lifetime productivity. Bali cattle (*Bos javanicus*) are indigenous to Indonesia and are most commonly reared by smallholder farmers across the eastern islands. The age at first calving in villages across eastern Indonesia is typically 36 months of age, with lighter maiden heifers having low birth weight calves (12 kg). The objective of this experiment was to investigate the influence of post-weaning diet on age and LW of Bali heifers at the detection of first oestrus and subsequent growth. Twenty-eight weaned Bali heifers of known birth dates and birth weights (16.0 ± 0.3 kg) were sourced from cooperating farmers in Central Lombok, Indonesia. At the commencement of the experiment the heifers were 258 ± 3 days of age and 93.1 ± 1.4 kg LW. Heifers were blocked on LW and randomly allocated to one of two pre-pubertal diets and to individual pens. Heifers were offered either king grass (*Pennisetum purpureum*, 136 g CP/kg DM) *ad libitum* (R) or a maize grain-soybean meal concentrate based diet (178 g CP/kg DM) *ad libitum* with R included at approximately 15% of daily concentrate DM intake (C) (Phase 1). At an average age of 19 months and LW of 160 ± 5.7 kg, heifers within each of the pre-pubertal treatment groups were ranked on LW and re-allocated to either C or R treatments (Phase 2), resulting in four post-pubertal treatments overall (C-C, C-R, R-C, R-R). Liveweight was measured at the same time each week, with body condition score (BCS), chest girth and hip height (HH) measured every month. Oestrous detection was conducted twice daily by exposing heifers to a bull equipped with a plastic harness to prevent insemination and by visual observations of signs of oestrous. Heifers fed the C diet had higher daily W gain than heifers fed the R diet in both Phase 1 and Phase 2, with no interaction between diet and Phase. Heifers fed the C diet between 8 and 19 months of age were heavier at the first detection of oestrus; heifers that received the R-R treatment were approximately 2 months older at first oestrus than heifers that received the C-R treatment. At the end of the experiment, when heifers were approximately 34 months of age, C-C heifers were 110 kg heavier than R-R heifers, and of higher BCS than all other heifers and were significantly higher at the hips than heifers that were offered the R treatment during Phase 1. Abundance of genes within the IGF, transforming growth factor and myosin heavy chain families were determined by quantitative PCR on RNA extracted from muscle biopsies collected from heifers at different stages along the growth path. The concentration of IGF1 and Leptin in the plasma was determined every 4 months from 8 to 33 months of age and at comparative LW of 100, 150 and 200 kg.

Activity 3. Nutritional management of Bali cows in Southeast Sulawesi

To increase the population and productivity of Bali cattle in Southeast Sulawesi improved feeding management and alternative feeding strategies will be required to meet the nutritional requirements for growth and reproduction of the animal. Native grasses, rice straw and rice bran are widely available throughout Southeast Sulawesi, with grass the most commonly used feedstuff. This research assessed the best feeding strategy to increase the LW and BCS of mature, non-pregnant female Bali cattle using locally available feed resources. Twenty non-pregnant, non-lactating Bali cows (192 $\pm$ 4 kg LW and 2.2 $\pm$ 0.1 BCS) were allocated to one of four treatment diets in a randomized block design. The four treatments were (1) native grass *ad libitum* (NG) (2) 5 g rice bran DM/kg LW.day + native grass *ad libitum* (5RBNG), (3) 10 g rice bran DM/kg LW.day + native grass *ad libitum* (10RBNG) and (4) 10 g rice bran DM/kg LW.day + rice straw *ad libitum* (10RBRS) and were fed to the cows in individual pens for 112 days. Bali cows offered 10RBNG gained more LW (0.34 $\pm$ 0.05 kg/day) and BCS (0.7 $\pm$ 0.2) than cows offered NG, 5RBNG and 10RBRS over the 112 day experiment. Bali cows offered NG and 10RBRS had comparable LW gain (0.14 $\pm$ 0.05 and 0.13 $\pm$ 0.05 kg/day, respectively), BCS change (0.5 $\pm$ 0.2 and 0.2 $\pm$ 0.1, respectively) and while diet digestibility was not different between the two treatments (54 $\pm$ 3 and 53 $\pm$ 3%, respectively) Bali cows offered NG had higher basal DM intake (19.3 $\pm$ 0.4 and 11.8 $\pm$ 0.4 g DM/kg LW.day, respectively) but lower total DM intake than cows offered 10RBRS (19.3 $\pm$ 0.4 and 22.4 $\pm$ 0.4 g DM/kg LW.day, respectively) over the experiment. Across all treatments within this experiment, it was estimated that every 1 unit change in BCS was associated with approximately 50 kg LW change. Therefore, it would take approximately 150 days for Bali cows fed native grass plus 10 g RB DM/kg LW.day to increase 1 BCS. In conclusion, supplementation with increasing amounts of rice bran will increase W and BCS of Bali cows undergoing re-alimentation. A combination of rice straw and rice bran will provide equivalent nutrients, and rates of re-alimentation, to that of native grass alone and therefore may be a useful feeding strategy when native grass supply declines.

Activity 4. Metabolic and reproductive hormone profiles of Bos indicus breeders in a commercial cattle herd in northern Australia

Herd reproductive performance is a key indicator of herd profitability. The reproductive efficiency of a herd is largely determined by the duration of post-partum anoestrous. The duration of post-partum anoestrous has been shown to be largely influenced by the energy balance of the animal. A mob of *Bos indicus* cows (n=241) were managed under commercial conditions at Manbulloo Station, Katherine during the years 2010 to 2011. The cows were managed as a single mob and grazed a *Heteropogon contortus* dominant pastured paddock that was 34 km^2 in area. Supplement was distributed weekly with a phosphorus based supplement offered at 120 g/head.day during the wet season. Musters were conducted in April and September each year. At each muster, LW was measured, BCS (1-5 scale), lactation status and foetal age were assessed and blood samples were collected. Differences between incidence rates across levels of BCS change were estimated and statistically compared using pairwise comparisons. The amount of BCS loss in lactating cows was significantly associated with risk of non-pregnancy within four months of calving (P<0.0001). Overall, there was a progressive increase in the risk of non-pregnancy within four months of calving as BCS loss increased in breeders that were lactating during the wet season. Those cows that were recorded as losing greater than or equal to 2.0 BCS units during the wet season were predicted as having a significantly greater risk of non-pregnancy within four months of calving than all other categories (P<0.05).

Activity 5. Implementation and monitoring of an integrated village management system for Bali cattle in Southeast Sulawesi, Indonesia

The project implemented an integrated village management system (IVMS) for cattle in various locations across Indonesia. The IVMS included weaning the calf, access to a bull, allocation of higher quality feedstuffs to weaners and lactating cows and introduced the practice of feeding rice straw to cows as a basal diet when nutrient requirements were lower (early pregnancy).The Researcher provided advice for Indonesian researchers to implement the above strategies in Lapangisi village, Kolaka district, Southeast Sulawesi from 2010 to 2013.There was no change in

calf birth weight during the project, but calf mortality decreased over the course of the project. The reduction in calf mortality was mostly due to improvements in farmer's knowledge about management of calves between birth and weaning. Body condition score of cows was high throughout the study, probably reflecting the good supply of feed available throughout the year and the small number of females that were lactating at any one time. Rice straw feeding was not well adopted by farmers in Lapangisi due to the extensive nature of the cattle management systems and the abundance of high quality feeds throughout the year. Farmers indicated that they now know that cattle could be fed rice straw and this was useful information in the event that fresh feed supplies did run low.

Project LPS/2009/036

Enhancing smallholder beef production in Timor Leste

This project is funded by ACIAR and includes activities in Timor Leste for which Simon Quigley is responsible. The project activities are conducted in collaboration with the Ministry of Agriculture and Fisheries (MAF) and the National University of Timor Lorosa'e (UNTL). The project commenced in June 2012 and will conclude in June-2015. Simon Quigley was a contributor to the initiation and development of the project proposal and is responsible for the following activities.

Activity 1. Characterise beef production systems in Timor Leste by monitoring current practices and identify opportunities to improve beef production

Simon Quigley is working with senior MAF researchers to establish a series of village based cattle monitoring sites in five districts of Timor Leste. This work involves the training of Field Researchers based at each of the sites on measurements, data collection, collation and interpretation.

Activity 2. Implement and on-farm research project to improve pre-weaned calf growth during the dry season

Simon Quigley is working with senior UNTL researchers to evaluate a cow-calf feeding and management system implemented on-farm in Timor Leste. This activity will involve supplementation and penning of the young calf during the day and supplementation of the cow during the night during the latter part of the dry season. This work will involve training students on various aspects of the projects activities.

Project SMCN/2007/023

Improving the reliability of rice/livestock systems in Northeast Thailand

This project was funded by ACIAR and included activities in Thailand for which Simon Quigley provided technical advice on for the final 12 months of the project. The project activities were conducted in collaboration with World Vision Thailand and Khon Kaen University. The involvement of Simon Quigley was from January to December 2012. During this period of involvement farmer training activities were conducted, establishment of tree legumes were undertaken and an on-farm feeding experiment/demonstration was undertaken.

Project AH/2011/054

Improving the livelihoods of smallholders in the Central Dry Zone of Myanmar through research on animal production and health

This project is funded by ACIAR and includes activities in Myanmar and Australia in which the Researcher is involved. The project activities are conducted in collaboration with The University of Melbourne, The Livestock Breeding and Veterinary Department, Myanmar and The University of Veterinary Science, Myanmar. The project commenced in September 2013 and will conclude in September 2017.

Activity 1. Establishment of cattle monitoring systems in the central dry zone of Myanmar
Simon Quigley is providing technical advice on the implementation of cattle monitoring systems in villages in Myanmar. This includes training of Junior Scientists in measurements, data collection and collation and interpretation of findings.

Activity 2. The interaction between weaning weight and post-weaning nutrition on liveweight gain and frame size of cattle
The experiment will investigate the interaction between weaning LW and post-weaning nutrition during the dry season and LW gain in the subsequent wet season. The experiment will be conducted in the NT and Simon Quigley has contributed to experimental concepts, design and methodology and will assist with conduct of the experiment. The experiment commenced in June 2014 and will conclude in April 2016.

Activity 3. Growth curves of Brahman cross-bred steers
The experiment will investigate whole of life changes in skeletal size and LW in *Bos indicus* crossbred steers fed a high quality feedlot ration. Steers will be either non-implanted, or implanted with either estradiol (E) or trenbolone acetate (TBA) based hormonal growth promotants. Simon Quigley has contributed to experimental concepts, design and methodology and will assist with conduct of the experiment and conduct gene expression and hormonal analysis of samples collected. The experiment will commence in August 2014 and will conclude in January 2016.

Project LPS/2013/017
Improving nutrition during pregnancy and lactation to achieve production targets for Bali cattle.
This project is funded by ACIAR and includes activities in Indonesia. Simon Quigley is the Chief Investigator on this project. The project activities are conducted in collaboration with The University of Mataram and BPTP Nusa Tenggara Barat. The project commenced in October-2013 and will conclude in October-2016.

The project will investigate the importance of nutrition of Bali cows during pregnancy and lactation on calf vigour, milk production and composition, progeny growth rate pre- and post-weaning. The project will determine if there are carry-over effects of maternal nutrition on age/LW at puberty of female progeny and slaughter LW and carcass composition of male progeny.

Project LPS/2014/022
Heifer-calf and fattening strategies
This recently developed project will be funded by ACIAR from June 2014 to June 2016. The role of the Simon Quigley in this project will be to contribute to work around management of heifers (through the related project LPS/2013/017) and to conduct a review of recent research on calf survival and growth within smallholder cattle production systems and across northern Australia.

Objective 4. Publish an average of two peer reviewed scientific papers per year of funding, with one of these as first author
The published refereed publications, conference proceedings, book chapters and monographs that Simon Quigley has authored or co-authored since the commencement of the project in January 2009 are listed below.

Refereed papers
Antari R, Ningrum G, Mayberry D, Marsetyo, Pamungkas D, **Quigley SP** and Poppi DP. 2014. Rice straw, cassava by-products and tree legumes provide enough energy and N for liveweight

maintenance of Brahman (*Bos indicus*) cows in Indonesia. *Animal Production Science*. **54**, 1228-1232.

Dahlanuddin, Yulianto TB, Priyanti A, Poppi DP and **Quigley, SP**. 2012. Weaning and supplementation increase liveweight gain of Bali (*Bos javanicus*) cattle of smallholder farmers in Central Lombok, Indonesia. *Indonesian Journal of Animal Production*. **14**, 173-179.

Dahlanuddin, Yanuarianto O, Poppi DP, McLennan SR and **Quigley SP**. 2014. Liveweight gain and feed intake of weaned Bali cattle fed grass and tree legumes in West Nusa Tenggara, Indonesia. *Animal Production Science.* **54**, 915-921.

Dahlanuddin, Ningisih B, Poppi DP, Anderson ST and **Quigley SP**. 2014. Long-term growth of male and female Bali cattle fed *Sesbania grandiflora*. *Animal Production Science.* **54**, 1615-1619.

Marsetyo, Damry, **Quigley SP**, McLennan SR and Poppi DP. 2012. Liveweight gain and feed intake of weaned Bali cattle fed a range of diets in Central Sulawesi, Indonesia. *Animal Production Science*. **52**, 630-635.

Martinez ED, Turnbull KE, **Quigley SP**, Streeter SJ, Swain A, Klieve AV, Ouwerkerk D and Poppi DP. 2012. Liquid phase DGGE profiles of rumen bacteria from Brahman cross steers selected into two groups on the basis of post-weaning liveweight gain on low crude protein pasture. *Animal Production Science*. **52**, 647-652.

Panjaitan T, **Quigley SP**, McLennan SR and Poppi DP. 2010. Effect of the concentration of Spirulina (*Spirulina platensis*) algae in the drinking water on water intake by cattle and the proportion of algae bypassing the rumen. *Animal Production Science*. **50**, 405-409.

Panjaitan T, **Quigley SP**, McLennan SR, Swain A and Poppi DP. 2010. The intake, retention time in the rumen and microbial protein production of *Bos indicus* steers consuming grasses varying in crude protein content. *Animal Production Science*. **50**, 444-448.

Panjaitan T, **Quigley SP**, McLennan SR, Swain A and Poppi DP. 2014. Spirulina (*Spirulina platensis*) algae supplementation increases microbial protein production and feed intake and decreases retention time of digesta in the rumen of cattle. *Animal Production Science*. *In Press*.

Panjaitan T, **Quigley SP**, McLennan SR, Swain A and Poppi DP. 2014. Digestion of forages in the rumen is increased by the amount but not the type of protein supplement. *Animal Production Science*. **54**, 1363-1367

Quigley SP, Dahlanuddin, Marsetyo, Pamungkas D, Priyanti A, Saili T, McLennan SR and Poppi DP. 2014. Metabolisable energy requirements for maintenance of liveweight of Bali (*Bos javanicus*) cattle. *Animal Production Science*. **54**, 1311-1316.

Quigley SP, Greenwood PI, Kleemann DO, Owens JA, Bawden CS and Nattress GS. 2014. Myogenesis in small and large ovine fetuses at three stages of pregnancy. *Animal Production Science*. *In Press*.

Saili T, Marsetyo, Poppi DP, Isherwood PI, Nafiu L and **Quigley SP**. 2010. Effect of treatment of cocoa-pods with *Aspergillus niger* on liveweight gain and cocoa-pod intake of Bali (*Bos sondaicus*) cattle in South-East Sulawesi. *Animal Production Science* **50**, 693-698.

Conference proceedings

Antari R, Syahnair TM, Mayberry DE, Pamungkas D, Marsetyo, **Quigley SP** and Poppi DP. 2014. Crude protein requirements for growth of Ongole (*Bos indicus*) and Bali (*Bos javanicus*) bulls. *Proceedings of the International Symposium for Nutrition of Herbivores* Canberra, ACT, September 8-12. p 393.

Campbell AJD, Hanks JH, Henning J, **Quigley SP**, Oo KN, Aung A, Stur W, Thein WM, Myint YY, Latt ZM, Win TTZ, Oo LN, Thein SM, Aung Min and Poppi DP. 2014. Ruminant production research in the Central Dry Zone of Myanmar. *Proceedings of the XXVIII World Buiatrics Congress* Cairns, Australia (Ed. Beggs DS). p 27.

Costa DFA, Isherwood P, **Quigley SP** and Poppi DP. 2012. Microbial protein production and rumen function in *Bos indicus* cattle fed algae and cottonseed meal. *Proceedings of the 29th Biennial Conference of the Australian Society of Animal Production*, Lincoln University, Canterbury, New Zealand. p 4.

Costa DFA, Isherwood PI, **Quigley SP**, McLennan SR and Poppi DP. 2010. The chemical composition and *in vitro* degradability of various algae species, protein supplements and grasses. *Proceedings of the 28th Biennial Conference of the Australian Society of Animal Production*, University of New England, Armidale. p 61.

Costa DFA, Isherwood PI, **Quigley SP**, Vieira BR and Poppi DP. 2011. Intake and digestibility of speargrass hay by steers supplemented with algae. *Proceedings of the Northern Beef Research Conference Update*. p 139.

Costa DFA, Isherwood P, **Quigley SP**, McLennan SR and De Souza J. 2013. Effects of forage type and season on rumen parameters of grazing cattle. *American Dairy Science Association – American Society of Animal Science Annual Meeting*, Indianapolis, Indiana July 8-12, 2013. p 93.

Costa DFA, Isherwood P, **Quigley SP**, McLennan SR, De Souza J, Gibbs J, Sun XQ and Poppi DP. 2013. The fatty acid profile and retention time in the rumen of cattle grazing tropical grasses. *American Dairy Science Association – American Society of Animal Science Annual Meeting*, Indianapolis, Indiana July 8-12, 2013. p 92.

Costa DFA, Isherwood P, **Quigley SP**, McLennan SR, De Souza J, Gibbs J, Sun XQ and Poppi DP. 2013. Effect of lipid source on fatty acid profile in the rumen of cattle fed a tropical hay. *American Dairy Science Association – American Society of Animal Science Annual Meeting*, Indianapolis, Indiana July 8-12, 2013. p 667.

Dalgliesh NP, Nulik J, **Quigley SP**, Poppi DP, Suek J, Darbas T and Budisantoso E. 2010. The use of forage legumes in cereal cropping systems of eastern Indonesia. In *Food Security from Sustainable Agriculture* (Ed. H. Dove). *Proceedings of the 15th Australian Society of Agronomy Conference*, Lincoln, New Zealand.

Dollemore W, **Quigley SP**, Poppi DP and McCosker K. 2013. Change in liveweight of non-pregnant, mature *Bos indicus* cows of different lactational status over the dry season. *Proceedings of the Northern Beef Research Conference Update*. p 163.

Farmer T, Cowley T, Streeter SJ, Perkins N, **Quigley SP** and Poppi DP. 2011. Liveweight gain of weaner steers selected on growth rate after weaning and fed Cavalcade (*Centrosema pascuroum*) or Mekong grass (*Brachiaria brizantha*) hay. *Proceedings of the Northern Beef Research Conference Update*. p 131.

Gonzalez-Rivas P, Isherwood P, Callaghan M, **Quigley SP**, Begg S and Poppi DP. 2013. *In vitro* phosphorus solubility of different sources of phosphorus for cattle. *Proceedings of the Northern Beef Research Conference Update*. p 166.

Harper KJ, Costa DFA, Gulino L-M, Klieve AV, McLennan SR, **Quigley SP** and Poppi DP. 2013. The association between liveweight gain and rumen microbial diversity in cattle. *Proceedings of the Northern Beef Research Conference Update*. p 169.

Harper KJ, Panjaitan T, Gulino L-M, Klieve AV, **Quigley SP** and Poppi DP. 2013. The effects of spirulina algae supplementation on the rumen microbial community of beef cattle. *Proceedings of the Northern Beef Research Conference Update*. p 170.

Hisham MN, **Quigley SP**, Anderson ST, Phillips NJ, Loor JJ and D'Occhio MJ. 2010. Liver gene expression in suckled and weaned beef cows. *Asian Reproductive Biotechnology Society* **7**. p 16.

Irawan, F, **Quigley SP**, Panjaitan T, Poppi DP and Dahlanuddin. 2014. Age and liveweight of first oestrus detection of Bali heifers fed concentrate or roughage based diets. *Proceedings of the International Symposium for Nutrition of Herbivores* Canberra, ACT, September 8-12. p 145.

Kidd LJ, Poppi DP, McNeill DM and **Quigley SP**. 2014. The use of *Tuber coxae* bone biopsy to examine bone turnover and trabecular bone structure in growing *Bos indicus* steers fed diets with different dietary phosphorus content. *Proceedings of the International Symposium for Nutrition of Herbivores* Canberra, ACT, September 8-12. p 273.

Kidd LJ, Poppi DP and **Quigley SP**. 2014. The use of tuber coxae bone biopsy to examine bone turnover and trabecular bone structure in response to different levels of phosphorus in the diet in growing *Bos indicus* steers. *Proceedings of the XXVIII World Buiatrics Congress* Cairns, Australia (Ed. Beggs DS).

Kidd LI, **Quigley SP**, McLennan SR and Poppi DP. 2013. The effect of crude protein content or level of metabolisable energy intake on skeletal growth of *Bos indicus* cross bred and Holstein steers. *Proceedings of the Northern Beef Research Conference Update*. p 173.

Martinez ED, **Quigley SP**, Streeter SJ, Poppi DP, Swain AJ, Klieve AV and Ouwerkerk D. 2011. Relationship between rumen bacterial populations and post-weaning liveweight gain in steers selected on different growth rates in the Northern Territory. *Proceedings of the Northern Beef Research Conference Update*. p 133.

McNeill DM, Anderson ST, **Quigley SP**, Kidd LJ, Gout CR, Moate PJ and Poppi DP. 2012. Can long-term differences in phosphorus nutrition affect glucose homeostasis in growing steers? *Proceedings of the 29th Biennial Conference of the Australian Society of Animal Production*, Lincoln University, Canterbury, New Zealand. p 7.

Nattrass GS, Dahlanuddin, Poppi DP and **Quigley SP**. 2009. Sexual dimorphism of genes regulating skeletal muscle growth in Bali cattle. *Proceeding of the Association for the Advancement of Animal Breeding and Genetics*. **18**, 18-21.

Pham CH, **Quigley SP**. Isherwood PI, McLennan SR and Poppi DP. 2010. Growth of Young and Mature Cattle Fed Ryegrass Haylage or Concentrate Based Diets. *Proceedings of the 28th Biennial Conference of the Australian Society of Animal Production*, University of New England, Armidale. p 9.

Quigley SP, Anderson ST, Poppi DP, Isherwood P, Costa DFA and Nattrass GS. 2012. Gene expression in the arcuate nuclei of sheep fed diets of variable protein and energy content. *Proceedings of the 29th Biennial Conference of the Australian Society of Animal Production*, Lincoln University, Canterbury, New Zealand. p 20.

Quigley SP, Dahlanuddin, Poppi DP, Susmaningsih BR, Ali M and Nattrass GS. 2012. Sexual dimorphism and coat colour in Bali cattle. *Proceedings of the 29th Biennial Conference of the Australian Society of Animal Production*, Lincoln University, Canterbury, New Zealand. p 25.

Quigley SP, Poppi DP, Anderson ST, Isherwood P, Costa DFA and Nattrass GS. 2012. Gene expression in the liver of sheep fed diets of different protein and energy content. *Proceedings of the 29th Biennial Conference of the Australian Society of Animal Production*, Lincoln University, Canterbury, New Zealand. p 40.

Saili T, Marsetyo, Poppi DP, Isherwood PI, Nafiu L and **Quigley SP**. 2010. Effect of treatment of cocoa-pods with *Aspergillus niger* on live weight gain and cocoa-pod intake of Bali (*Bos sondaicus*) cattle in South-East Sulawesi. *Proceedings of the 28th Biennial Conference of the Australian Society of Animal Production*, University of New England, Armidale. p 52.

Silva TACC, **Quigley SP**, Kidd LJ, McLennan SR and Poppi DP. 2014. Skeletal growth, liveweight gain and feed intake of *Bos indicus* and *Bos taurus* cattle undergoing compensatory liveweight gain. *Proceedings of the International Symposium for Nutrition of Herbivores* Canberra, ACT, September 8-12. p 289.

Final Reports

Poppi DP and **Quigley SP**. *Strategies to increase growth of weaned Bali calves*. Project LPS/2004/023. Final Report submitted to ACIAR, July 2009.

Poppi DP and **Quigley SP**. *Opportunities to use cocoa-pods and forage legumes to address feed gaps in the dry season in South East Sulawesi*. Project SMAR/2007/013. Final Report submitted to ACIAR, July 2009.

Poppi DP and **Quigley SP**. *Increased efficiency of microbial protein production in the rumen through manipulation of nutrient and rumen microbial populations*. Project B.NBP.0350. Final Report submitted to MLA, October 2009.

Poppi DP and **Quigley SP**. *Increased efficiency of microbial protein production in the rumen through manipulation of nutrient and rumen microbial populations*. Project B.NBP.0350. Addendum submitted to MLA, September 2012.

Quigley SP and Poppi DP. *Analysis of potential feed samples for the Indonesian feedlot industry and for inclusion in nutrition models for Indonesian cattle feeding systems*. Project W.LIV.0373. Final Report submitted to MLA, June 2010.

Quigley SP and Poppi DP. *Factors associated with divergent post-weaning liveweight gain in northern Australian beef cattle*. Project B.NBP.629. Final report submitted to MLA, December 2012.

Quigley SP and Poppi DP. *Realimentation of phosphorus deficient cattle*. Project B.NBP.565. Final Report submitted to MLA, December 2012.

Quigley SP, Poppi DP and Schatz T. *Validation and demonstration of a diagnostic tool for phosphorus status of beef cattle*. Project B.NBP.537. Final Report submitted to MLA, May 2014.

Book chapters

Poppi DP, Fordyce G, Panjaitan T, Dahlanuddin and **Quigley SP**. 2011. Case study 2: Developing an integrated production system for Bali cattle in the eastern islands of Indonesia. In *Beef production in crop-livestock systems: Complex problems – simple solutions*. ACIAR Publications, Canberra, ACT.

Monographs

Nulik J, Dalgliesh N, Cox K and Gabb S. 2013. *Integrating herbaceous legumes into crop livestock systems in eastern Indonesia*. ACIAR Monograph No. 154. Australian Centre for International Agricultural Research, Canberra. 130 pp. (contributor)

Postgraduate student supervision
Simon Quigley co-supervised (or currently co-supervises) the following post-graduate students who have conducted/are conducting their postgraduate training at The University of Queensland.

1. Tanda Panjaitan (PhD) - Strategies to enhance the efficiency of microbial protein production in cattle consuming tropical forages (awarded July 2010).
2. Cuong Pham Hung (M. Phil.) - Growth response of young and mature steers fed grain and forage diets and energy and protein-based supplements (awarded June 2011).
3. Karen Turnbull (PhD) - Increased efficiency of microbial protein production in the rumen through manipulation of nutrients and rumen microbial populations (awarded July 2012).
4. Diogo Costa (PhD) - The effect of single cell proteins and lipids on rumen function in cattle (awarded January 2013).
5. Ilyas Mumu (PhD) - Post-partum anoestrus in Bali cattle under low-input animal production systems reared by smallholder farmers in eastern island Indonesia (commenced June 2013)
6. Tiago Alves Correa Da Silva (PhD) - Feeding strategies for the early-weaned calf (commenced August 2013)
7. Risa Antari (PhD) – Skeletal elongation in cattle (commenced February 2014)

5 Discussion

The primary objective of this project was to develop capacity of a mid-career researcher to independently conduct research that is of relevance to ruminant nutrition under northern Australian production systems. This will ensure that there is capacity to continue nutrition research that is relevant to the northern Australian beef cattle industry in the future.

Simon Quigley was appointed to the position of Senior Research Officer at The University of Queensland and has successfully prepared and submitted research proposals and received funding from MLA and ACIAR either as stand-alone projects (B.NBP.629, B.NBP.537, B.NBP.565, LPS/2013/017) or within much larger projects (LPS/2008/038, LPS/2009/036) and has also contributed to other projects. The projects and activities with which the Researcher has undertaken have ranged from applied (on-farm monitoring of cattle production systems in southeast Asia, LW gain and feed intake experiments with cattle in pens) to basic biology (gene expression studies, including the use of RNAseq to determine differential gene expression across the entire transcriptome).

The Researcher has developed a good network with researchers from within (McLennan, Fordyce, Anderson, Kidd, Waldron, Van de Fliert) and outside of (DPIF, QDAFF, CSIRO, SARDI) UQ, commercial companies (Ridley Agri-products) and international scientists from Indonesia, Timor Leste, Thailand and Myanmar.

The scientific publications submitted during the course of the project met the required number of an average of two per year, however less than half of these were as first author with the majority as co-author on the work of students or international collaborators. This is an inevitable outcome of establishing collaborations and working within multidisciplinary teams. Many of these papers would not have been published without the input of Simon Quigley. The amount of work undertaken over the duration of the project has had a negative impact on the ability of Simon Quigley to publish some of his own research at this time but several publications are in preparation.

6 Conclusions

This project has delivered a researcher who can now operate independently, either on his own or as part of multidisciplinary, collaborative project teams, and has achieved recognition with funding bodies as a person who can identify and deliver high quality work. This person has initiated new work and funded his salary (from sources other than MLA) for a period greater than the original terms of his project employment. Thus he is able to deliver on future project work within the MLA program in the short-term. This is dependent on the funding situation within MLA and its willingness to continue to support such young researchers. Based on his initial success within the first three years of this project, MLA have extended this mid-career mentor program to another group of young researchers associated with other senior scientists and groups across Australia. Simon Quigley was the first successful scientist to come through this system. The significant contribution of ACIAR to project activities and salary support should be acknowledged. In financial terms this was comparable to the contribution from MLA and demonstrates that the right individual can access various funding sources and value-add significantly to the MLA contribution. Having invested so much into this particular researcher it is hoped that MLA will continue to support him for research into nutritional problems in northern Australia.

7 Acknowledgments

We acknowledge MLA for funding this project and projects that linked with this project outlined in the body of this report. We also gratefully acknowledge the ongoing support from ACIAR for funding some of the projects that Simon Quigley worked on and many of the publications arise from ACIAR funded research.

The contributions of, and collaboration with, the following people in the various experiments and other activities over the course of the project is gratefully acknowledged.

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