Considerations of Feed Demand and Supply for the Evolution and Expansion of Beef Cattle Farming in Sabah, East Malaysia

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College of Sciences
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Januarius Gobilik

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Abstract

To develop a plan for the expansion and evolution of the beef industry in Sabah, it was decided to apply relevant farming information and technology from New Zealand pastoral systems. Based on expert recommendation in New Zealand, metabolic energy budgeting (MEB) was chosen as the vehicle for technology transfer, rather than a direct translocation of elements of farm practice between these two countries of vastly different climate. In Phase 1 of the study, farm system evolution in New Zealand over the last two and half decades was evaluated by modelling past systems from historic records for the author to gain experience of New Zealand pastoral systems and to develop MEB spreadsheet tools to identify principles of system improvement; and in Phase 2, the tools developed in New Zealand were applied for evaluation of opportunities for farm system improvement in Sabah.

In Phase 1, an evaluation was carried out of cumulative changes on New Zealand lower North Island sheep and beef cattle farms from 1980–81/1985–86 to 2010–2011. Herbage harvested on the farms studied, as determined by MEB, was 7.43 t DM ha^{-1} yr^{-1} in 1980–81 and only 5.76 t DM ha^{-1} yr^{-1} in 2010–11. Also herbage supply (based on GROW model calculations using weather data) had decreased from 9.64 t DM ha^{-1} yr^{-1} to 8.70 t DM ha^{-1} yr^{-1} (partly due to an apparent climate change effect). However, with the evolution of farm system configurations over the past quarter century focusing on efficiency gain, the feed conversion efficiency (based on national data) improved from 25 kg feed consumed per kg lamb weaned in 1980–81/1985–86 to 19 kg feed consumed per kg lamb weaned in 2010/2011 and the corresponding increases in meat production from 1980–81/1985–86 to 2010/2011 were a rise from 137 kg to 147 kg total beef and lamb carcass per ha per year. Two major drivers of the higher meat production were an increase in lambing percentage, and an increase in weight of lambs and bulls at sale.

In Phase 2, a first study in Sabah using the MEB tools developed in New Zealand involved three cut-and-carry feedlots (Brahman, Bali and Droughtmaster cattle), and utilised 5,981 monthly liveweight records of 485 cattle farmed in this system for the period 2008–2013. A second study in Sabah involved five grazing units (Brahman cow-calf, Bali cow-calf, Droughtmaster cow-calf, and Heifer and Brahman bull Units), and included 30,166 monthly liveweight records for 1353 cattle farmed in this system during the same period. A third study involved three oil-palm-integrated cattle (OPIC) farms (two in 9 yr old plantations and one in a 12 yr old plantation) and 600–700 cattle farmed in this system in 2013 and 2014. In this study, animal growth rates were assumed based on records from the nearest government farm with

animals of similar breed. For the three systems, herbage-cutting experiments were carried out in August–October 2014 to estimate herbage growth and nutritive value (metabolisable energy and protein contents), and soil samples collected to describe the soil nutrient content. In the cut-and-carry feedlot and grazing cattle farming systems, the herbage harvested, as indicated by the modelling in these systems, was lower (3.74–7.16 t DM ha^{-1} yr^{-1} herbage eaten) than the potential yield of the herbage extrapolated from the cutting experiments (6.9–21.3 t DM ha^{-1} yr^{-1}). In the OPIC farming system, the modelled herbage harvested in 9 yr old plantations was 2.0–2.4 t DM ha^{-1} yr^{-1} and that of 12 yr old plantation was 1.4–1.7 t DM ha^{-1} yr^{-1}. These values are higher than values for potential herbage supply (0.4–0.8 t DM ha^{-1} yr^{-1}) reported in literature for plantations of similar ages. In all three systems, herbage nutritive value was low (7.0–8.9 MJ ME kg DM^{-1}; 9%–14% CP), calving percentage was low (33%–47%); soil was acidic and soil nutrient content was low; while invasion of non-sown species (native grass) was high. The best average feed conversion efficiencies (FCE) for these systems were 21.3 kg DM kg LWG^{-1} (cut-and-carry feedlot), 40.2 kg DM kg LWG^{-1} (grazing), and 32.2 kg DM kg LWG^{-1} (OPIC). FCE was found to improve with application of N fertiliser and was not necessarily high when feed consumption was intensified (or at high system feed demand). A key statistic defining the stock-configuration in an efficient system for the cut-and-carry feedlot cattle farming system was 994 kg animal LWT ha^{-1}, or a comparative stocking rate (CSR) of 96 kg animal liveweight per tonne feed consumed. For the grazing cattle farming system, the observed optimum was 506 kg animal LWT ha^{-1}, or a CSR of 94 kg LWT t DM^{-1}. The identification of an optimal CSR for the OPIC farming system was limited (by the data supplied by the farms), but the available data indicated that for 9OP1 the CSR was 89 kg LWT t DM^{-1}, or approximately 231 kg animal LWT ha^{-1}.

From the series of studies in Sabah, it is concluded that the future focus of the beef industry to expand and improve the productivity should be first to adjust the farm system configuration especially the stocking rate for optimal FCE under the present forage supply regime (and for that purpose a-CSR type of statistics would be useful to determine the appropriate stocking rate), and only then, to develop a pasture husbandry and fertiliser recommendations aimed at improving herbage dry matter harvested towards a target of 14–20 t DM ha^{-1} yr^{-1}, with ME of 9–10 MJ kg DM^{-1}, and CP of 14%–16% at harvesting or grazing. The herbage production target for the OPIC farming system, however, cannot be determined until the time trajectory of the decreasing system herbage productivity with decreasing oil palm age is fully understood. The use of supplement in the three systems is optional, but if it is used, it should be targeted tactically to reduce liveweight loss and enhance cow reproductive performance.

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List of Abbreviations

Abbreviations	Descriptions	Units
ADG	Average Daily Gain	g hd^{-1} d^{-1}
AFRC	Agriculture and Food Research Council	
AFZ	Association Française de Zootechnie	
ARC	Agriculture Research Council	
Ca	Calcium	
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement	
cm	Centimetre	cm
CP	Crude protein	% of kg DM
CSIRO	Commonwealth Scientific and Industrial Research Organisation	
CSR	Comparative Stocking Rate	
CV	Coefficient of Variation	%
d	Day	
DM	Dry matter	
DOA	Department of Agriculture (Sabah)	
DSM	Department of Statistics (Malaysia)	
DSSM	Department of Statistics of Sabah Malaysia	
DVS	Department of Veterinary Services (West Malaysia)	
DVSAI	Department of Veterinary Services and Animal Industries (Sabah)	
ENSO	El ñino-Southern Oscillation	
FAO	Food and Agriculture Organisation	
FCE	Feed conversion efficiency	kg DM kg LWG^{-1}
g	Gram	g
ha	Hectare	ha
hd	Head	
H_{km}	Horizontal distance walked a day	
INRA	Institut National de la Recherche Agronomique	
K	Pottasium	
kg	Kilogram	kg
k_g	Coefficient of use of ME for liveweight gain	
k_l	Coefficient of use of ME for lactation	
km	Kilometre	
k_m	Coefficient of use of ME for body maintenance	
k_p	Coefficient of use of ME for pregnancy	
LWG	Liveweight gain	kg d^{-1}
LWL	Liveweight loss	kg d^{-1}
LWT	Liveweight	kg
m^2	Square metre	
MAFF	Ministry of Agriculture, Fisheries and Food	
ME or M/D	Metabolisable energy	MJ ME kg DM^{-1}
MEB	Metabolic energy budgeting	
ME_{LWL}	Mobilised body energy from liveweight loss	MJ ME d^{-1}
meq	Mili-equivalent	
Mg	Magnesium	
MJ	Megajoules	
mm	Millimetre	mm
mo	Month	
MPOB	Malaysian Palm Oil Board	
NASEM	National Academies of Sciences, Engineering, and Medicine	
N	Nitrogen	
NEM	North East Monsoon	
NEMI	National Enteric Methane Inventory	
NZ	New Zealand	
ºC	Degree Celsius	

OP	Oil palm
OPIC	Oil Palm Integrated Cattle
P	Phosphorus
P	Statistical probability
PKC	Palm Kernel Cake
PMLD	Pusat Menternak Lembu Dara (Centre for Heifer Rearing)
ppm	Parts per million
PPT	Pusat Pembanyakan Ternakan (Centre for Livestock Production)
R	Pearson's correlation coefficienct
RM	Ringgit Malaysia
SCA	Standing Committee on Agriculture
SKSB	Sawit Kinabalu Sendirian Berhad
SOA	Sulphate of Ammonia
SPT	Stesen Pembiakan Ternakan (Station for Livestock Breeding)
SRW	Standard Reference Weight
SU	Stock Unit
SWM	South West Monsoon
t	Tonne
V_{km}	Vertical distance distance walked per day
yr	Year

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Chapter 1

Introduction

1.1 Background

The research reported in this thesis arose from an interest in developing the local beef industry in Sabah, East Malaysia. The industry is in need of improvement to meet the domestic beef demand, to reduce the cost to the domestic economy of importing beef, and to maintain the status of beef farming as a means to improve the financial standing of the rural population (Awang Salleh, 1991; Chew and Ibrahim, 1992; Department of Veterinary Services and Animal Industry, DVSAI, 2008; DVSAI, 2009). The average production of beef in Sabah between 2002 and 2013 was only 4.6% of the domestic demand. Over that period beef has had to be imported notably from India, Australia and New Zealand (DVSAI, 2008, 2014). The cost to import beef, however, has increased from just RM35 million in 2003, to RM127 million in 2012 (DVSAI, 2014). This cost increase is exacerbated partly by a decline in the foreign exchange rate for the Malaysian Ringgit from 2003 to 2012. During the same period, a number of local beef cattle farmers ceased farming or were disqualified from participation in the government beef farming projects because of non-compliance with scheme policies (DVSAI, 2008, 2009). The pattern of farmers leaving the industry has in turn contributed to the decrease in local production of beef.

The low beef production of the pastoral systems in Sabah has been a point of concern for more than two decades (Awang Salleh, 1991; DVSAI, 2008, 2014). Despite the concerns raised, there has been little research carried out to improve the performance of the systems. Most of the studies are also not recent. The few studies carried out have related to limited assessment of breeding performance and growth (Bacon, 1974; Copland, 1974; Punimin, 1989; Nooraisyah, 2010) and effect of particular types of feed, mainly palm kernel cake (PKC) and cocoa waste on growth of a few breeds (Chew, 1991; Ibrahim et al., 1987; Damshik, 2007). Fewer than 20 studies in the 1970s and 1980s have related to pasture development (17 studies cited in Chew, 1991). Of those studies, none has focussed on understanding the fundamental performance of the systems as a basis for future development. This problem is further compounded by a lack of analytical tools to capture the system details.

As there is little information about the pastoral systems in Sabah and a lack of analytical tools to capture system details, to develop a plan for the future expansion of the beef industry the author decided to review relevant farming information and technology from New Zealand to gain insights into methodology for describing and quantifying beef production systems there, so as to identify the steps for lifting the performance of the pastoral systems in Sabah. In New Zealand, a discussion with several experts led to the recommendation to use data on animal weights, growth rates, and reproductive performance, together with metabolic energy budgeting (MEB) to document the feed demand and supply patterns over an annual cycle, for current beef production systems in Sabah. This recommendation was based on extension industry experience in New Zealand over the past 25 years where MEB has been an important farm management tool for the evolution of system configuration and improvement of system productivity. In New Zealand, the equations to calculate metabolic energy budgets and feed demand are now used (e.g., in the proprietary software packages, Farmax and Overseer), both to assist scientists and regulatory bodies to develop environmentally sustainable farming practices and to help farmers refine farm system configurations over time. New Zealand farmers and farm consultants frequently run metabolic energy budgets for alternative farm system configurations before each farming season to identify optimal scenarios and plan their farming operations, or develop contingency plans for events such as drought. It was further suggested to the author that the strategy of analysing current production systems in Sabah with a view to identifying appropriate developmental change, was more likely to be successful than direct translocation of elements of farm practice from New Zealand to Sabah. Preston and Leng (1987) highlighted that a direct transfer of farming practice between animal production systems with vastly different ecological background is rarely successful.

It was decided to begin this research with an analysis of selected farm systems in New Zealand where MEB is a well-established analytical tool for farm systems optimisation and evolution of the system over time. In this way it was envisaged that a methodology would be established that could be used in Sabah. Hence, the study was planned in two phases with the first carried out in New Zealand for the author to have exposure to beef production practice in New Zealand and to the use of spreadsheet methodologies for creating an animal metabolic energy budget to assess farm performance. The second phase, would be the adaptation of a metabolic energy budget spreadsheet or spreadsheets developed in

New Zealand (after some coefficients were adapted for the tropical climate in Sabah) to capture the current feed demand and supply patterns and performance of beef cattle production systems in Sabah and the identification of the opportunities for effecting change in current practices to improve performance of systems in Sabah.

1.2 Research goals and specific objectives

To carry out this study the author needed to first acquire a knowledge of feed budgeting methodology which is largely unknown in Sabah, and research objectives were structured to accommodate this knowledge acquisition. Therefore, the first goal of this study was to learn feed budgeting methodology by setting up a series of metabolic energy budgets to describe New Zealand farm systems from 25 to 30 years ago to the present. The specific objective for this first goal was:

- To review key farm data for New Zealand North Island Hill Country sheep and beef cattle farm system for the period from 1980–81/1985–86 to 2010–11 obtained from annual surveys by Beef + Lamb New Zealand and to model the system feed demand and supply of an average farm as represented by the annual farm survey data and 3 case farms representative of the selected farm category using a metabolic energy budget spreadsheet to identify the cumulative change in farm performance of the selected farm category and to discuss the factors that made the greatest contribution to the cumulative change.

The second and main goal was to transpose the metabolic energy budgets learnt in New Zealand to describe current beef cattle production systems in Sabah and provide a benchmark description of the more important systems as a basis for future development of those systems. Despite the small size of the beef industry in Sabah, a number of systems and breeds are used. Hence, the MEB from the New Zealand study was applied to three important beef cattle farming systems of different cattle breeds (Brahman, Bali, and Droughtmaster) in Sabah. Specific objectives for this second goal were:

- (i) To use animal MEB developed from the New Zealand systems to capture the current status of feed demand and supply of cut-and-carry feedlot, grazing, and oil palm integrated (where beef is effectively a by-product of the non-chemical understorey vegetation control in the plantation) beef cattle farming systems in Sabah; (ii) to use summary statistics such as feed conversion efficiency to assess configuration of the systems that provide the best outcome, and some general characteristics of the efficient configurations; (iii) to collect additional farm data to support application of insight from metabolic energy calculations, such as information on nutritive value of herbage being consumed, and typical herbage accumulation rates in these systems; and (iv) to develop practical recommendations from the research that could be implemented by farm managers in Sabah.

1.3 Thesis structure

This thesis is divided into 7 chapters. Following this introduction in Chapter 1, a literature review is presented in Chapter 2. Chapter 3 presents the study in New Zealand. Chapters 4 (feedlot), 5 (grazing) and 6 (oil palm integrated) present the studies of the various systems in Sabah. Chapter 7 provides a general discussion and draws on insight from the studies in New Zealand and Sabah to provide a synthesis of understanding and recommendations for future development of the beef industry in Sabah.

Chapter 2

Literature Review

2.1 Sabah beef cattle production

Sabah, East Malaysia, is located in the north east of the Island of Borneo, and lies approximately 6º north of the Equator. Sabah has a land area of 73,631 square km of which approximately 30% can be used for agriculture. Approximately 175,000 ha of the land area suitable for agriculture could be used for grazing (Thomas et al., 1976a–d; Appendix 2.1). To date 127 blocks of land located in different regions of the state with a total area of 21,698 ha have been reserved by the government for use as grazing land (Awang Salleh, 1991) and close to 8,128 ha of the area was previously described as improved pasture (Chew and Ibrahim, 1992). Sabah also has land areas identified as capable of supporting some beef production in conjunction with other land uses. For example, in 2014, there were just over 1.511 million ha of oil palm in Sabah (Malaysia Palm Oil Board (MPOB), 2014; Department of Statistics Malaysia, Sabah, DSSM, 2015), of which 155,969 ha were immature and 1,355,541 ha were mature plantations (MPOB, 2014). The land area currently used for production of other commercial crops is 131,241 ha for rubber, 41,019 ha for rice and 16,785 ha for coconut (DSSM, 2015). All of these land uses could potentially provide some feed for an associated livestock enterprise.

2.1.1 Production systems

Reliable statistics on the number of beef cattle farmers and farm sizes in Sabah are not available. There are believed to be 1800 farmers contributing to local beef production in Sabah with many of these farmers having farms of only 4 to 5 ha in area. Similarly, the types of pastoral systems used in Sabah have never been formally described. In West Malaysia, the beef production systems have been classified into traditional, draught, crop integrated, and feedlot systems (Liang, 1996). For the most part, the types of beef production systems in Sabah have many similarities with those in West Malaysia, although in Sabah grazing system is also used quite extensively.

In planning this study, the only source of information available to the author about cattle production systems in Sabah was conversation with the staff of the Department of Veterinary Services and Animal Industry (DVSAI), which is reported here. The traditional system and draught system in Sabah can be regarded as the same system. In this system, the animals are allowed to free graze on open areas such as crop stubble and grassland surrounding villages (e.g., Figure 2.1) or tethered and fed using a cut-and-carry system. The animals are used as draught animals and to store wealth (e.g., an animal may be sold to pay for school fees or a wedding, or slaughtered during a cultural festival or religious ceremony). Villagers and smallholder oil palm owners typically use this system.

Figure 2.1 Traditional cattle farming along Kota Belud – Kota Marudu road (Kota Belud District).

The feedlot system is a cut-and-carry system. The animals are kept in a shelter with a concrete floor (e.g., Figure 2.2) and fed herbage from purpose-planted forage grasses, and concentrate (either palm kernel cake (PKC) or a mixture of PKC and grains). This is also called a green forage feedlot system. The number of beef farms using cut-and-carry feedlot system and their area is unknown, but 13 of the 14 dual-purpose dairy-beef farms in Sabah use this system and their total area is 2,321 ha (DVSAI, 2008).

Figure 2.2 Cut-and-carry feedlot cattle farming system with Bali cattle at Stesen Pembiakan Ternakan (SPT) Tawau (Tawau District).

The grazing system is commonly found on government demonstration farms and on community farms established under government initiatives (e.g., Figure 2.3). In this system, the farms are divided into paddocks and the cattle are let to graze by rotation from paddock to paddock. The grazing cycle has been reported to be 28 days. Mating occurs all year round or twice a year with the mating and off-matting seasons alternating every 3 months.

The crop-integrated system is found mainly in conjunction with edible oil production from oil palms (*Elaeis guineensis* Jacquin) and are designated here as 'oil palm integrated' cattle (OPIC) farming system (e.g., Figure 2.4). As stated earlier, there are 1.54 million ha of oil palm plantation in Sabah, with some of this area used for cattle farming. Little is known about the extent of plantation use for cattle farming. However, Sawit Kinabalu Sendirian Berhad (SKSB) (2010) reported that 22,949 ha of its oil palm plantation is used to farm 8,018 cattle.

Figure 2.3 **A grazing cattle farming system with Bali cattle at Pusat Pembanyakan Ternakan (PPT) Timbang Menggaris, Kota Belud (Kota Belud District).**

Figure 2.4 **Oil palm integrated cattle farming system with Brahman cattle at km 25 Lahad Datu – Tungku road (Lahad Datu District).**

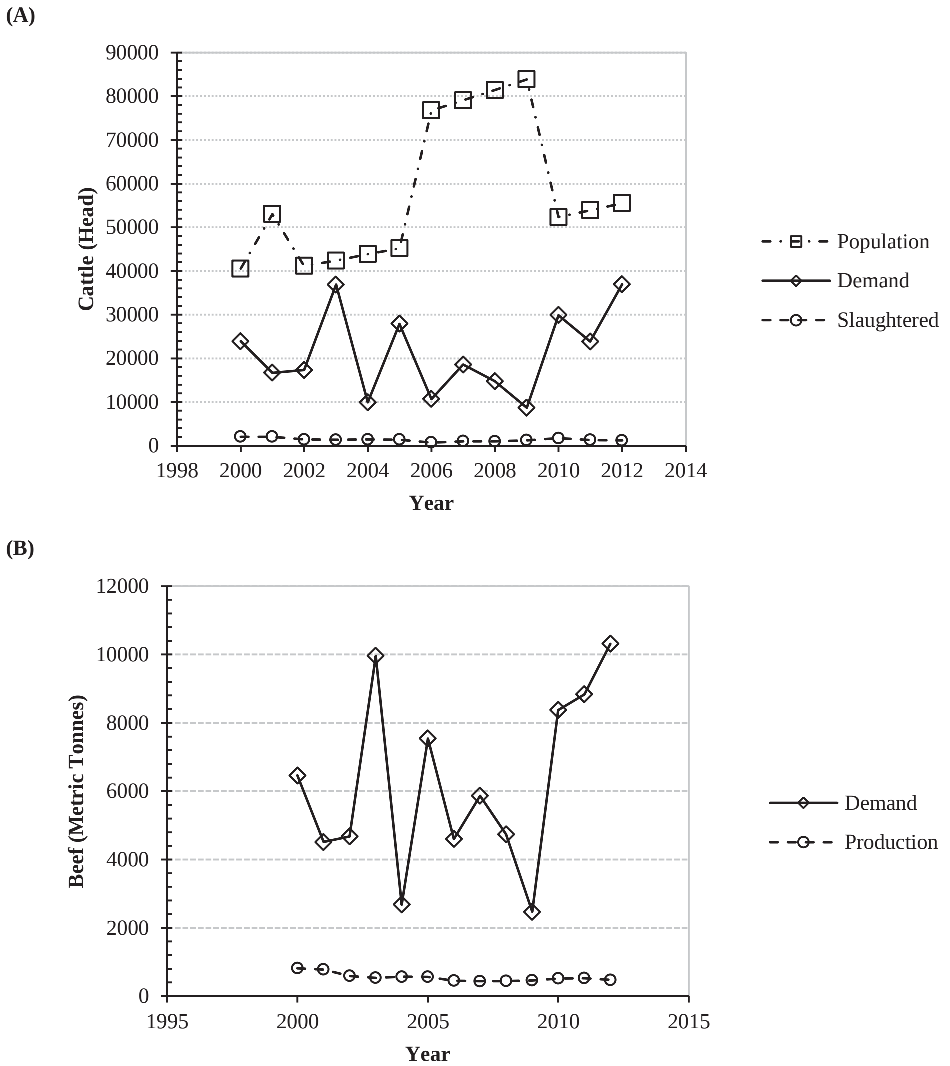
2.1.2 Industry Performance

Beef production in Sabah is low (Figure 2.5) with the average production only 500 t a year. The production in 2012 was 479 t compared to 537 t in 2003 (DVSAI, 2014). To meet the annual domestic beef demand with local product for a year, almost half of the cattle population in Sabah would need to be slaughtered, extrapolating from the average carcass weight of the cattle sold in 2003 and 2012. There were reported to be 42,380 cattle in Sabah in 2003, the carcass weight of slaughtered animals ranged from 193 to 270 kg hd^{-1}, and the beef demand was 9,959 t (DVSAI, 2014). The reported cattle population in 2012 was 55,530 hd, the carcass weight ranged from 201 to 279 kg hd^{-1} and the beef demand was 10,314 t. A report by the DVSAI (2008) suggested that the future of the beef industry would depend on intensive (feedlot) as well as crop-integrated cattle farming systems.

The beef import cost has escalated in recent years and this highlights the socio-economic potential of the local beef industry. In 2003, the beef import cost was Ringgit Malaysia (RM) 35.19 million, and in 2012 this had increased to RM112.9 million (DVSAI, 2014). (In 2012, 1USD = RM3.08; 1NZD = RM2.54). This increase was partly due to a decline in the foreign exchange rate of the Malaysian Ringgit in recent years. Foreign exchange rate variations also partly explain the large year-to-year variation in beef demand (Figure 2.5) in Sabah. A survey in Kota Kinabalu revealed that consumers buy more beef when they deem that the price is sufficiently low (Assis et al., 2015). As most of the beef is imported, the price fluctuates with the foreign exchange rate. Other reasons for the fluctuation in beef demand from year to year are unknown because of lack of study.

In keeping with the increase in cattle population from 2003 to 2012 noted above, the domestic earnings of the industry have increased, while by contrast, the export earnings have decreased. In 2003, the reported domestic beef sales were RM8.06 million and the export earning was RM1.78 million (DVSAI, 2014). In 2012, the domestic and export earnings were RM11.2 and RM1.5 million, respectively. The exported beef is mainly water buffalo meat. A factor in increase in domestic earnings has been a high local retail price of beef in recent years. Between 2003 and 2012, the local retail price for beef increased from RM14.7 kg^{-1} to RM24 kg^{-1} (DVSAI, 2014).

There are several potential benefits of improving the local beef production in order to meet a greater part of the local beef demand. If domestic beef demand had been met from local production, at the retail price in 2012, the earnings would have been RM236 million, with a corresponding saving in import costs. Hence, both the external balance of trade and the domestic rural economy would be boosted by expansion of the local beef industry. This earning power would have a great impact on financial status of farmers, especially those participating in an initiative referred to as the government poverty mitigation project. Expansion of beef cattle production has been one of the policies used by the Sabah government to improve the financial standard of rural people over the past few decades (DVSAI, 2009).



Source: DVSAI (2014)

Figure 2.5 (A) Cattle population in Sabah, domestic demand (assuming 270 kg carcass weight) and numbers slaughtered (head); and (B) domestic beef demand and local production (tonnes).

(The population of cattle for 2006 to 2009 reported by this source shows an unexplained anomaly. The production (head slaughtered in (A) or tonnes beef in (B)) refers only to those animals produced locally, and excludes imported cattled and beef; imports account for the difference between local production and demand.)

2.1.3. Constraints and industry extension initiatives

Apart from the government demonstration farms where some information can be obtained from the annual reports, little is known about the performance statistics of the production systems on most farms in Sabah. Data of interest include, among others information on farm biophysical data (calving percentage, weaning rate, farm size, cattle growth and demography, and feed type) and economic performance. Generally, there is a lack of farm extension information to provide a foundation to decide the strategy for development of the production systems. This information vacuum is one of the problems impeding attempts to improve beef production systems in Sabah. Other problems are a lack of farming skills, lack of marketing opportunities, lack of financial capital to undertake development initiatives, a low calving rate, slow development of grazing land, limited transport infrastructure for access to supplies such as fertiliser or feed supplements, and transport of product to market, and limited support in remote areas (Awang Salleh, 1991). As stated earlier (Section 2.1.1), many of the farmers also have only 4–5 ha of land.

To mitigate those problems, the government has developed a number of projects aimed at assisting expansion of ruminant farming including a project known as the Pawah Scheme, another known as the Livestock Smallholder Project, and a third named the Buffalo Assistance Scheme (Awang Salleh, 1991). These initiatives are based on the principle that the government supplies animals (10 to 50 cattle or buffalo heifers) to qualified farmers and provides them with technical advice relating to animal husbandry and pasture improvement. The farmers then have to reimburse the government for the animals loaned to them, with an agreed repayment period. There is no direct monetary support to the farmers in those projects. The farmers must either obtain a loan from a bank or use their personal savings to finance the establishment of their farms. The poverty mitigation project uses those initiatives as a delivery mechanism and is managed as a group project for villagers who have been granted a community land reserve for community livestock farming. In contrast with private local cattle farming, the community livestock farming is funded and implemented through a local government authority. The main goal is to train the participating villagers within a particular period to be able to handle the project independently. The community projects help them to gain cattle farming skills, and they are then expected to use the skills gained to increase income and to reimburse the government for the cattle supplied. The members of the community projects share the responsibility to look after the cattle, but the quality of the work may be below the standard because they have also had other occupations (e.g., rice farming, rubber tapping, etc.). The government has also developed various livestock farming facilities and support centres in Sabah to improve the industry (Appendix 2.2). Despite the influence of these schemes (and some success) over past decades, the constraints to beef industry expansion as stated above and in Appendix 2.3 still persist (DVSAI, 2008, 2009).

The Pawah Scheme and the Livestock Smallholder Project in Sabah (and also in other states in Malaysia) were implemented decades ago. These initiatives can be traced back to the 1970s. Generally, the technical approaches to animal husbandry and pasture improvement in those initiatives have similarities with government livestock projects in neighbouring countries such as Indonesia and Philippines. For example, one goal of the initiatives in Sabah: to increase cattle productivity through genetic selection and improvement of farmers' skills, was also listed as a target for a pastoral development scheme in Indonesia in the 1980s (Packard, 1983). To date, however, the local beef production in Indonesia and Philippines is also still markedly lower than the demand (Nitis, 2006; Moog, 2006; Waldron et al., 2015; Philippine Statistics Authority (PSA), 2016) similar to the situation in Malaysia (Ariff et al., 2015), meaning the need for technical improvement of beef production systems is likely similar in those countries to that in Sabah. Thus, the methodology for development of beef cattle production systems in Sabah is still undefined, with one option being transfer of relevant farming technology from major beef producers such as Australia and New Zealand.

2.1.4 Annual herbage production and nutritive value

2.1.4.1 Cut-and-carry feedlot and grazing cattle farming systems

A pasture development program was initiated in Sabah in the 1960s to establish and develop ruminant production (Chew, 1991). Over 90 native and introduced plant species were studied and evaluated for suitability as forage. Of the species tested, 10 improved grass species were recommended (Chew, 1991). Seven of the species are still recommended for livestock feeds (DVSAI, 2007a). Those species are *Digitaria milanjiana* (Rendle) Stapf, also known as 'Jarra' grass; *Brachiaria decumbens* Stapf, also known as Signal grass (Figure 2.6), *Panicum maximum* Jacquin, or known as 'Guinea' grass; *Brachiaria humidicola* (Rendle) Schweick; *Setaria sphacelata* (Schumacher) Stapf & C.E. Hubb. var. *anceps* (Stapf) Veldkamp, also known as 'Kazungula' (Figure 2.7); *Setaria sphacelata* (Schumacher) Stapf & C.E. Hubb. var. *splendida* (Stapf) Clayton; and *Tripsacum andersonii* J.R. Gray, also known as

Guatemala grass. Three of the species, *B. humidicola*, *S. sphacelata* var. *splendida* and *T. andersonii* (and livestock-feed legumes in Sabah), however, are not used for beef cattle production. The common non-sown grass on cattle farms in Sabah is *Axonopus compressus* (Swartz) P. Beauvois.

Figure 2.6 *B. decumbens* pasture at SPT Tawau.

From the limited studies carried out in Sabah (and also in West Malaysia), previously published yields for those species range from 7 to 30 t DM ha^{-1} yr^{-1} (Table 2.1). In other cases, the interpretation of the reported yields of pasture grass in Malaysia is difficult. For example, in an experiment in West Malaysia, Chen and Devendra (1990) reported that with addition of 150 kg N ha^{-1} yr^{-1} and a stocking rate of 20 goats ha^{-1} (7 to 12 kg liveweight), the *D. milanjiana* 'Jarra' (syn. *D. setivalva* or Mardi Digit) could produce 4.4 t DM ha^{-1} yr^{-1}, which is problematic to interpret since the liveweight of the goats reported is unusually low. Metabolisable energy (ME) contents of these grasses are reported to range from 6 to 9.3 MJ kg DM^{-1} (Table 2.1). Reported crude protein contents (% CP on a DM basis) range from 11% to 19% (Table 2.1).

Table 2.1 Dry matter production, ME content, and CP content of grasses commonly used as feed for beef cattle in Sabah and Peninsular Malaysia.

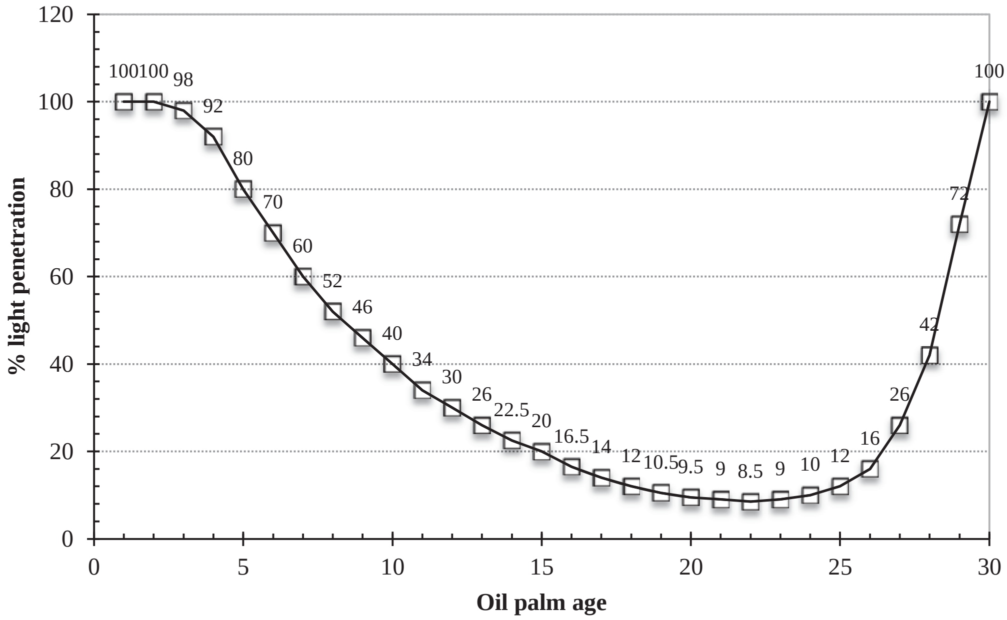
Species	Dry matter production (t DM ha^{-1} yr^{-1})	ME (MJ kg DM^{-1}) at 2 or 3–4 week regrowth	% CP on a DM basis at 2 or 3–4 week regrowth	References
B. decumbens	14–26	8.1–8.5	12–19*	Chen and Devendra (1990), Cook et al. (2005), DVS (undated), DVSAI (2007a), DVS (2005), Feedipedia – INRA, CIRAD, AFZ and FAO (undated), Roberts (1970a,b) as cited in FAO (undated), and Wong et al. (1985).
P. maximum	15–18 or 30	7.1–7.8* or 8.3	12–14*	
S. sphacelata	10–15 (or 26 elsewhere)	7.4–9.2*	14–15*	
A. compressus	7–8 (or 10 elsewhere)	Data unavailable (6.4 elsewhere)	Data unavailable (9 or 18–22 at 100 kg N ha^{-1} application elsewhere)	
D. milanjiana	4–5 (or 7, 10–20 or 34 elsewhere)	8.2–8.6*	16	

*Value at week 4 is lower than those in weeks 2 and 3.

Figure 2.7 *S. sphacelata* 'Kazungula' pasture at SPT Tawau.

2.1.4.2 Oil palm integrated cattle farming systems

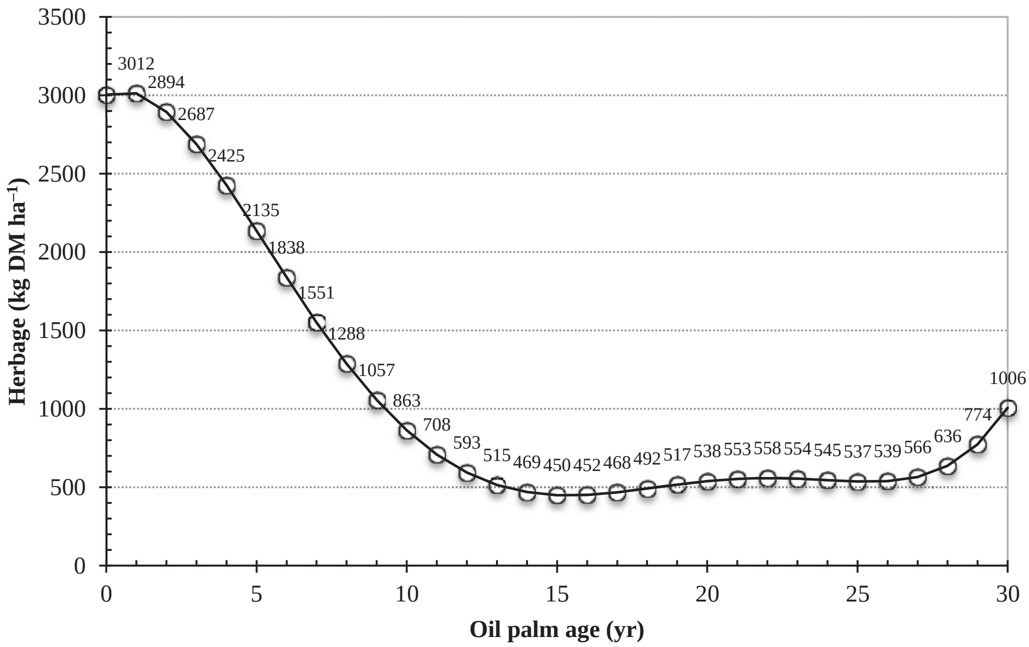
Little information is available on botanical composition, production and nutritive value of herbage in OPIC farms in Sabah. Elsewhere, studies indicate that production and nutritive value decrease when the palms get older because canopy expansion of the palms reduces the understorey light (Norton et al., 1990; Dahlan et al., 1993) and limits the photosynthetic activity of the understorey herbage. Generally, understorey light penetration (%) in oil palm plantations declines rapidly after 5 years to less than 10% in mature stands but may increase again at the end of the plantation life (Figure 2.8), when old and unproductive palms are felled to pave a way for the planting of young palms. A classification of oil palms by age given by Ling (2014) is immature (0 to 3 yr old), young (4 to 8 yr old), prime (9 to 18 yr old; e.g., Figures 2.4 and 2.10), ageing (19 to 23 yr old) and old (24 to 28 yr old).



Source: redrawn from Dahlan et al. (1993)

Figure 2.8 An example of a light penetration trajectory with palm age in an oil palm plantation.

The dry matter yield off understorey herbage decreases with palm age. In a 3 to 4 yr non-weeded oil palm plantation in West Malaysia, Chen (1990) reported that 5.5 to 9.5 t DM ha^{-1} yr^{-1} of herbage could be harvested by animals grazing the understorey vegetation. When the palms were 6 to 7 years old, understorey herbage production was only 0.4 to 0.8 t DM ha^{-1} yr^{-1}. For the next 20 years, the harvestable understorey herbage remains at 0.4 to 0.8 t DM ha^{-1} yr^{-1} (Jalaludin and Halim, 1998). When the palms are 15 years old and beyond, the opportunity for cattle grazing in the plantation is minimal. Although the declining production trajectory reported by Chen (1990) and described above would indicate that understorey herbage dry matter yield in a 5 to 6 yr old oil palm plantation would be less than 1.0 t DM ha^{-1} yr^{-1}, there is evidently some variability. For example, understorey herbage production was in the vicinity of 3 t DM ha^{-1} yr^{-1} when the plantation was 1 to 2 years old (Chen et al., 1991 as cited in Hassan, 2001; Figure 2.9). In another case, production of 1.69 t DM ha^{-1} yr^{-1} was reported for 5 yr old OPIC farms in the north eastern region of West Malaysia (Hassan et al., 2004).



Source: redrawn from Chen et al. (1991, as cited in Hassan, 2001)

Figure 2.9 An example of an understorey herbage dry matter production trajectory with palm age of in an oil palm plantation.

It can be inferred from the different curve shapes for years 25 to 30 in Figures 2.8 and 2.9 that the two plantations from which the data were collected may have differed in the age at which palms were felled for replanting, with this occurring after year 30 in Figure 2.9. Alternatively, other factors such as low soil fertility in older plantations might account for low herbage growth, even if light penetration is increased, since older, less productive palms typically receive less fertiliser, to lower operating costs and to protect profit margin.

Figure 2.10 A view of oil palms in a 9 yr old plantation.
Note the shady conditions under the oil palm canopy.

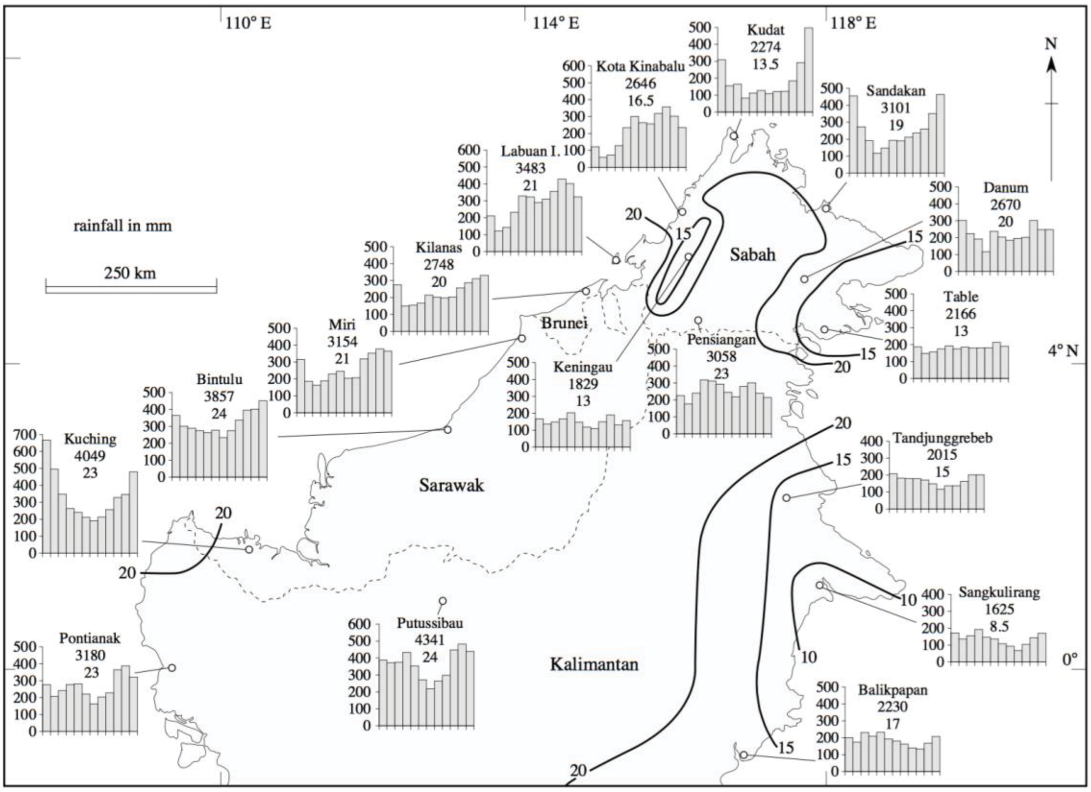
In terms of species composition, the understorey vegetation of an oil palm plantation may comprise as many as 298 species (Subtropen, 2003), but only 60 (20%) of the species are important as livestock feed (Chen, 1990). Species diversity decreases when the palms get older (Chen, 1990; Dahlan et al., 1993). Dahlan et al. (1993) reported that broadleaved plants are dominant when the palms are less than 4–5 years old. This pattern arises partly because of the use of leguminous species as a ground cover in young plantations. The important broadleaved plants are the *Mucuna* group and *Asystasia intrusa*. Grasses replace these plants when the palms are 5–6 years old and beyond. The important grasses in oil palm plantations in West Malaysia are *A. compressus*, *Ottochloa nodosa* (Kunth) Dandy and *Paspalum conjugatum* Bergius (Dahlan et al., 1993), and the same species could also be expected in oil palm plantations in Sabah.

A. compressus (the common volunteer or unsown grass on grazing farms in Sabah) has been reported to produce 929 kg DM ha^{-1} yr^{-1} in 5 to 7 yr old oil palm plantation (Chen and Bong, 1983). *A. compressus* survives better in semi-shade conditions; its performance in moderately shaded areas is better than that in open areas (Wong et al., 1985). In other words, it is unadvisable to grow this species as a feed source for cattle in a grazing system where the land is directly exposed to sunlight. As noted above, in ideal conditions in a tropical climate in North Sulawesi, Indonesia, *B. decumbens* may produce as much as 67 kg DM ha^{-1} d^{-1}, even as an understorey crop in a coconut plantation (Kaligis and Sumolang, 1991). However, under 5 to 7 yr old oil palms, reported yield of *B. decumbens* was only 1727 kg DM ha^{-1} yr^{-1} (Chen and Bong, 1983) or roughly 5 kg DM ha^{-1} d^{-1}, indicating that this species has a low potential productivity as a feed source for cattle in OPIC farming systems, where light levels under the palm canopy are much lower than those under the canopy of a coconut plantation.

2.1.5 Seasonal herbage production and nutritive value

Little is reported on weather-related variation in herbage accumulation rate and nutritive value for grazing systems in Sabah. The average temperature generally varies little throughout Sabah. In the west coast region, the annual temperature from 2000 to 2009 was reported to be 26ºC to 29ºC (Puah and Madihah, 2011). In the eastern region, it was reported to be 24ºC to 29ºC, with a monthly minimum averaging 22ºC and maximum averaging 31ºC (Walsh and Newbery, 1999). However rainfall distribution in Sabah is regionally heterogeneous, with some areas much drier than others; for example, rainfall in Keningau (131 km from Kota Kinabalu) is reported to range from 543 to 1929 mm yr^{-1}, while in Penampang (8 to 9 km from Kota Kinabalu), reported rainfall ranges from 3356 to 6923 mm yr^{-1} (Department of Agriculture Sabah, DOA, 2015; Figure 2.11). Thus, there may be regional differences in herbage dry matter yield related to regional differences in rainfall pattern.

On the other hand, the typical climate of Sabah is aseasonal with warm and humid conditions throughout the year (Thomas et al., 1976a–d) with the majority of the interior region (e.g., Pensiangan and Keningau) and sub-coastal area (e.g., Danum) showing little variation between months in average rainfall. Some coastal centres, however, such as Kota Kinabalu, Kudat and Sandakan have a marked pattern of low and high rainfall periods (Figure 2.11).



Source: Walsh and Newberry (1999)

Figure 2.11 **Monthly rainfall distribution, with total rainfall and perhumidity index below each site name for selected locations in Sabah and elsewhere in Borneo.**

It is stated that there is no satisfactory definition for a dry period of areas under tropical rainforest climate (e.g., Sabah), but for general classification, 100 mm rainfall would be the threshold to define 'wet' and 'dry' months for such areas (Walsh and Newberry, 1992). Between 2007 and 2013, an extract from the statistics reported by DOA (2015) showed that only 17% (247 months) of the 1,440 months observed at 24 agriculture weather stations representing 24 districts in Sabah had 5 to 95 mm rainfall. Most of the months (60%) of lower than 100 mm rainfall were reported for areas in the districts of Kudat and Pitas (northwestern coast), Keningau, Sook and Tambunan (interior region), and some in Tawau (southeastern coast). Hence, seasonal variation of herbage dry matter yield between dry and wet seasons would not be expected at most localities in Sabah.

In Sabah, the North East (NEM) and South West (SWM) monsoons determine the within-year weather variation and the El niño–Southern oscillation (ENSO), and its interaction with the NEM or SWM, determine the between-year weather variation. The ENSO has a cycle of 2–7 years and phases within the cycle will persist for a few months to more than a year, which means during the ENSO-neutral or -mild year, the within-year weather follows the regular NEM and SWM. During a regular year, there is a mild within-year fluctuation of precipitation. The NEM (October to February) brings relatively more rain and the SWM (March to September) brings relatively less rain, but there is no pronounced, "within-year dry or wet season", except for some localities in the coastal areas of the districts mentioned above. Depending on its interaction with the NEM or SWM and its strength, the ENSO can result in noticeable dry and wet periods, and during these periods, the herbage dry matter yield is expected to vary markedly in the same year or between years. This prediction is rationalised based on the effect of ENSO on trees. Extensive tree defoliation and small-branch shedding was observed at Danum, Sabah during the ENSO-associated drought in 1998 (Walsh and Newbery, 1999). Over the past four decades, however, there were only two severe ENSO events in Sabah, in 1982/83 and in 1997/98 (Curativo et al., 2012), meaning in most years, the weather follows the patterns determined by the NEM and SWM.

In Malaysia, a year-long observation of monthly herbage DM yield and nutritive value is seldom reported. Of the published >1 yr-long pasture yield records in West Malaysia (e.g., Chen and Devendra, 1990; Chen et al., 1982), where there were not reported marked dry and wet periods, herbage production was also not reported to be seasonal. In one of the studies (i.e., Chen et al., 1982), the annual productivity of the pasture was reported to have declined after 2 years of grazing even at low stocking rate, which suggests that besides the question of whether there is seasonality of herbage production, there may be situations where a gradual decrease of herbage productivity from year to year occurs, although the reason why this might occur is unclear.

In contrast to the situation in Sabah, seasonality of herbage production is not unusual in tropical areas elsewhere, even in some regions of Malaysia. For example, in the north eastern region of West Malaysia, where the weather is markedly affected by the NEM and SWM, on the 5 yr old OPIC farm mentioned above (i.e., Hassan et al., 2004, Section 2.1.4.2), herbage production was 1991 kg DM ha^{-1} during the 4-month wet season (October to January) and 1463 kg DM ha^{-1} during the 8-month dry season (February to September). In Bali, Indonesia, Rika et al. (1991) reported that *B. decumbens* performed well at a comparatively shaded site under coconuts with lower rainfall, and exhibited a marked seasonality of yield, with 35.7 and 14.8 kg ha^{-1} d^{-1} growth during the rainy and dry seasons, respectively. In West Sumatra, Indonesia nutritive value of some grass species was also reported to change with (dry and wet) seasons (Evitayani et al., 2004).

2.1.6 Supplements and nutritive value

The available information indicates that local beef cattle farmers in Sabah do not use a wide variety of feed supplements. PKC and a mixture of PKC and grains (Figure 2.12), however, are commonly used on cut-and-carry feedlot and grazing systems on government demonstration farms. The PKC mixture is usually a mixture comprising PKC, milled corn, milled soybean, and fishmeal (DVSAI, 2007b). Silage made from banana waste has also been tested and reported to be useful as a beef cattle feed (Garai and Jalani, 1992). However, little is known about the feeding of banana silage apart from that research. Also little information is available about the use of non-conventional forages or other agricultural wastes as beef cattle feeds. Rice straw was reported to have been used in the traditional systems in the past (Thomas et al., 1976a–d), but there is no recent information on the extent to which rice straw is still used by village beef cattle farmers as a feed source for cattle.

The production of PKC in Sabah is high considering the limited land area, but most of this material is exported. The production was 663,621 t in 2008, 629,911 t in 2012, and 665,985 t in 2015 (MPOB, 2009, 2013, 2016). Export of PKC was 654,347 t in 2008 and 602,238 t in 2012 (DOA, 2008, 2012a), meaning more than 90% of the PKC produced was exported. In contrast to PKC production, the average production of maize in Sabah was low and static with only 3,351 t in 2004, 4,018 t in 2010 and 4,056 t in 2012 (DOA, 2004, 2010, 2012b). The area planted with maize was also small (1,008 to 1,272 ha), and yields would also be low, compared to the potential yield of maize. The production of banana waste in Sabah is unknown, but the estimated production in the whole of Malaysia has been reported to be 12,677 t yr^{-1} with 5% annual increase in production (DSM, 2012).

Figure 2.12 Feed concentrate (comprising 65% PKC, mixed with 21% milled corn, 11% milled soybean, and 3% fishmeal) as cattle feed at SPT Tawau.

The annual production of oil palm fruit (in Sabah and Malaysia) is affected by El niño and La niña (MPOB, 2010), but has not been reported to be seasonal. Hence, PKC production is also expected to be aseasonal. Little is known about seasonality of production of maize and banana in Sabah. El niño and La niña weather patterns are also expected to affect the production of these crops, however.

In Malaysia, the energy content of supplementary feeds such as PKC, maize, banana and other similar feeds varies from 7 to 14 MJ ME kg DM^{-1}, but there has been little systematic collation of information about feed energy values or about the cost of these materials for ruminant consumption. For PKC, in terms of price, the manager of the government farm at SPT Tawau reported it to be RM700 to 800 per tonne, or sometimes RM500–600 per tonne. PKC typically has 10.5 to 11.5 MJ ME kg DM^{-1}

(Alimon, 2004). However, the variation is high. For example, PKC of 9 to 10 MJ ME kg DM^{-1} has also been reported (DVS, 2005). It is presumed that lower values result from inclusion of a greater proportion of ground shell or husk in the product. Oil palm leaves contain less than 6 MJ ME kg DM^{-1}, but the value improves slightly (1 to 2 MJ ME kg DM^{-1}) when treated with 6% sodium hydroxide (NaOH). The energy content of young leaves and stems of maize is approximately 7.7 to 8.2 MJ ME kg DM^{-1} (DVS, 2005). Levels as high as 12.2 to 13.4 MJ ME kg DM^{-1} have been reported for corn kernel and ground kernel. Corn stover has a higher energy yield than oil palm leaves and is cited by DVS (2005) as 9.1 MJ ME kg DM^{-1}. Maize stems were reported to have only 8.4 MJ ME kg DM^{-1} or lower than this for older maize. The energy content of banana fruit is approximately 9.9 to 10.2 MJ ME kg DM^{-1}, while the fruit skin has 7.5 to 8.7 MJ ME kg DM^{-1} (DVS, 2005). Banana leaves and stems have less than 7 MJ ME kg DM^{-1}.

The CP content of PKC, maize and banana ranges 7% to 20%. PKC is reported to have 18% CP (DVS, 2005), but like the ME of PKC, the CP content would be subject to variation between batches. Young leaf and stems of maize are reported to have 12% to 20% CP (DVS, 2005), while corn stover is reported to have only 5% CP. For much older maize, the CP is lower than 12%. Banana, irrespective of the plant part, has less than 7% CP.

There are other agricultural wastes in Malaysia (DSM, 2012) that may potentially be important as non-conventional livestock feedstuffs or feed supplements in Sabah (Table 2.2). It is noted here that many of those wastes rot quickly in a tropical climate, but pomace or bran from the wastes may be useful as ruminant feed. Mohd. Sukri (1982) reported that an addition of 30% to 55% of pelleted pineapple bran in a ration improved the liveweight gain of cattle from 390 g d^{-1} to 430 g d^{-1}. The positive effect of pineapple bran on growth of cattle may have been due to this material having a higher energy content than other ration components (Table 2.2). Besides pineapple byproducts, wastes from jackfruit and durian (thorny fruit) are also reported to have >10 MJ ME kg DM^{-1} (Table 2.2), i.e., more than the energy content of herbage reported in earlier paragraphs.

Table 2.2 Availability and feed value of potentially useful non-conventional livestock feedstuffs in Malaysia.

	Fresh waste (t yr^{-1})	Change (% yr^{-1})	% DM	MJ ME kg DM^{-1}	% CP
Pineapple	15,570	6.7	9.1–14.7	10.8–11.5	5.3–8.3
Coconut*	13,027	5.6	19.0–87.9	7.5–10.3	6.4–19.1
Watermelon	9,410	24.7	5.3–14.0	4.74–8.24	12.2–30.6
Durian	8,889	4.7	47.8	10.8	7.6
Cabbage	6,479	57.8	6.9	9.2	22.3
Jackfruit	3,603	–1.9	15.1–17.9	10.6–10.8	10.8–14.4
Tomato	3,341	437.8	–	–	–
Mango	3,079	10.7	–	–	–
Mustard	2,546	17.1	–	–	–
Rambutan	2,209	–3.2	–	–	–
Okra	1,707	7.1	–	–	–
Mangosteen	1,705	–7.1	–	–	–
Cucumber	1,309	12.1	–	–	–
Spinach	975	1.6	7.0	3.04	24.9
Long bean	931	0.9	19.1–20.6	7.4–8.1	20.7–25.2
Egg plant	533	20.2	–	–	–

DM, ME and CP from DVS (2005). *Some of the wastes could be shell and husk.

2.1.7 Cattle breeds, growth, reproduction, and feed demand

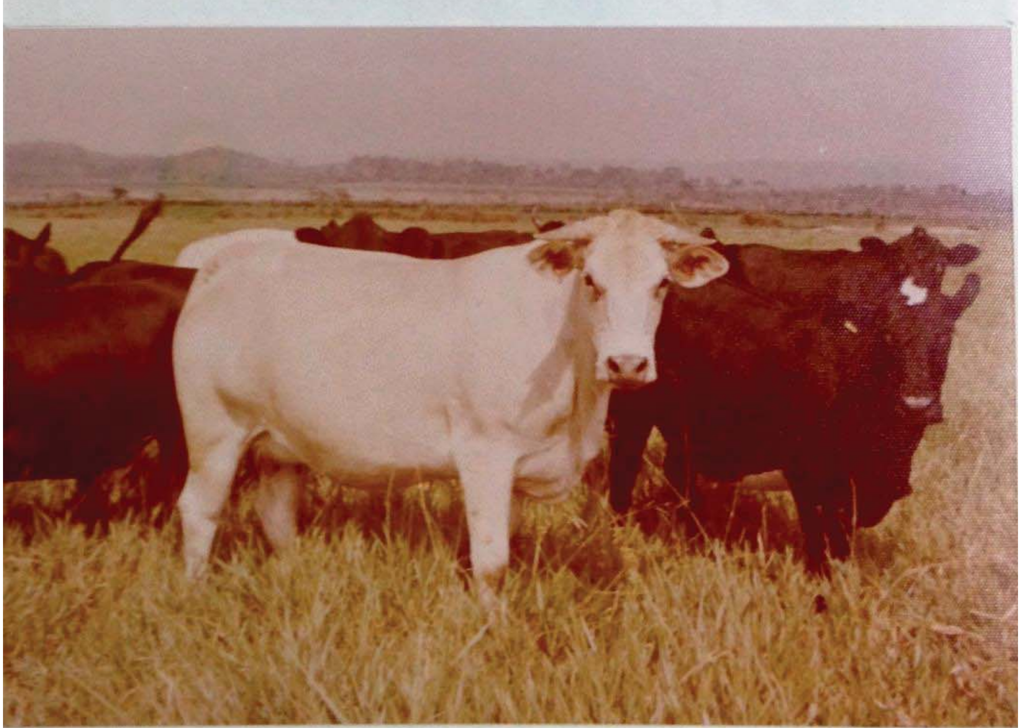
Little information is published about beef cattle breeds used in Sabah. Four breeds commonly reported as being farmed are: Brahman, Bali, Bali crossbred, and Droughtmaster. In the past, other breeds such as Aberdeen Angus, Charolais (Figure 2.13), Simmental, Santa Gertrudis and Friesian × Brahman were introduced for breeding experiments (Bacon, 1974; Awang Salleh, 1981), but there have been no further reports of the use of these breeds since those breeding experiments.

Generally, the origin of the cattle in Sabah has not been well documented and little information is available. Some of the Brahman cattle were imported from Australia and the United States. The first group of Droughtmaster cattle in Sabah were animals of certified breed (bulls and cows) imported from Australia. In Australia, this breed has been developed in North Queensland from crossing between Brahman and a British breed, the Beef Shorthorn (Porter, 2005). The “Bali cattle” in Sabah were imported from a plantation in West Malaysia in 1956 (Punimin, 1988). The purity of the Javan banteng (*Bos javanicus javanicus*) ancestry is uncertain because many (65%) of the Bali cattle in West Malaysia have been reported to have zebu ancestry (Nijman et al., 2003) and perhaps this is also true for the so-called Bali cattle in Sabah. The wild banteng in Sabah are not an introduced *B. j. javanicus* either, but purebred cattle closely related to *Bos gaurus* (Matsubayashi et al., 2014). There is speculation, however, that the wild banteng in Sabah originated from the Bali cattle brought in from West Malaysia, because a group of the cattle were released to the forest when one of the early Bali cattle farms was closed (Punimin, 1988). The Bali crossbreed arises from a cross between the Brahman (sire) and Bali cows.

As with the knowledge about breeds, little information is published on cattle growth rates. Only some growth data, including data for breeds that are no longer farmed (e.g., Aberdeen Angus, Charolais, Simmental, and Santa Gertrudis) were reported (e.g., Bacon (1974). Generally, most of the cattle including the so called ‘kampung breed’ (village cattle of mixed ancestry) were reported to have not been fed to their genetic potential (Bacon, 1974). Interestingly, more than 30 years later, the problem of cattle being fed below their genetic potential is still reported to be a factor impeding the beef production in Sabah (DVSAI, 2008). With reference to growth data, the author, however, found later during the fieldwork stage of this study that the government farms have a substantial accumulation of unpublished liveweight data of the currently used beef cattle breeds. In other words, the scarcity of information about growth data of cattle in Sabah arises partly because available data have not been disseminated.

For Brahman cattle, the birth weight was reported to be 56.8 kg, with an ADG of 1160 g hd^{-1} d^{-1} during the first 6 mo and 760 g hd^{-1} d^{-1} in the second 6 mo (Bacon, 1974). In another more recent study (i.e., Nooraisyah, 2010), the liveweights of locally born stud male calves of the breed were reported to be 23 kg at birth, 99 kg at 3 months old, and 224 kg at 9 months old. In the same study, the reported liveweights for female stud calves of the same breed were 22 kg at birth and 99 kg at 3 months old. The pre-weaning average-daily-gain (ADG) of the male and female stud calves was reported as 710 g hd^{-1} d^{-1}. The weaning weights were reported as 186 kg for males at a weaning age of 229 days and 184 kg for females at a weaning age of 227 days. As a brief summary, Bacon (1974) reported a much higher birth weight and ADG during the first and second 6 mo for the Brahman cattle, than that reported by Nooraisyah (2010). Although comparability of the previous study and recent data in terms of genetics of the cattle and feed used are uncertain, it appears that the experiments indicate that the Brahman breed in recent years has a lower growth rate than in the earlier research.

8. F_1 Angus Cow.



9. F_1 Charolais Cow.

Source: Bacon (1974)

Figure 2.13 Historical pictures of Angus and Charolais cattle used for breeding experiments in Sabah.

For Droughtmaster cattle, previously published growth observations are not available. For Bali cattle, the reported average birth weight ranges from 12 to 18 kg for males and 12 to 16 kg for females (Punimin, 1989). At six months of age, Bali cattle were reported to be 73 kg for males and 68 kg for females, and at 2 years, 225 kg for males and 200 kg for females. Copland (1974) reported a closely similar growth rate for Bali cattle: 300 g d^{-1} (females) to 330 g d^{-1} (males) from birth to 6 months old and 280 to 290 g d^{-1} during the second six months. The previous studies, however, did not specifically report the types and the nutritive values of the feeds eaten by the cattle, meaning these growth rates are less useful for comparison with present data.

Information on breeding performance is also scarce for most breeds, although there is some information reported for Bali cattle. Punimin (1989) reported that Bali heifers first calve at 33 months old and the cattle have a calving interval of 36±8 mo and a calving-to-conception interval of 163±89 days. Under an all year round mating system, the cattle calve mostly in October and November. Under research conditions, the calving percentage has been reported as 71%, and the herd mortality rate as 13%, with two thirds of the total deaths being calves younger than 3 months old. Copland (1974) reported a similar observation of age at first calving, but reported that the calving interval was shorter (13±2 mo) and calving rate was higher (>93%). Andrews (1972) noted that in northern Australia, Bali cattle exhibit no nutritional anoestrus, but published breeding data of this breed in Sabah are insufficient to draw a conclusion on this point. Generally, the calving rate of beef cattle in Sabah is reported to be <50% (DVSAI, 2008).

There is also no information published on quantifying the feed demand of beef production systems in Sabah. Of the limited studies published in the past (i.e., Chew, 1991; Ibrahim et al., 1987; Damshik, 2007), most studied the effect of particular types of feed (mainly PKC and cocoa waste) on growth of beef cattle. Ibrahim et al. (1987), for example, reviewed the importance of PKC as a cattle feed and concluded that addition of PKC beyond 60% of the total dry matter allowance fed to cattle did not result in significant further improvement in growth, and noted that addition of grain to the ration as well as PKC, is necessary to achieve 720 to 810 g hd^{-1} d^{-1} gain. However, these authors also did not report the nutritive value of the feeds used in the trial, raising the same issue mentioned above when using these data to evaluate performance of present day systems.

2.2. Animal metabolic energy budgeting for New Zealand farms

Metabolic energy budgeting (MEB) to match the seasonal feed supply to the animal feed demand is a pastoral practice widely understood in New Zealand and Australia (Corbett and Freer, 2003; Webby and Bywater, 2007) that has received little attention in the international literature. Selected New Zealand farmers and farm consultants frequently run metabolic energy budgets for alternative farm system configurations before each farming season to identify optimal scenarios and plan their farming operations, or develop contingency plans for events such as drought (e.g., Tayler et al., 2016). This is one of the methodologies used by New Zealand farmers with good effect in recent decades to achieve high animal production per head and per hectare (Parker, 2010).

According to Kooijman (2010) an energy budget is "the specification of the uptake of energy from the environment by an organism (feeding and digestion) and of the use of this energy for various purposes including: maintenance, development, growth and reproduction". Historically, research on energy budget involving animal calorimetry or equivalent field techniques was widespread internationally in the post-war period (see e.g. Blaxter, 1952; Langlands et al., 1963; Blaxter and Wainman, 1966), and such research formed a foundation for application of MEB to farm systems optimisation. An early collation of animal energy requirements from those studies is found in publications such as those by MAFF (1977, 1984) and the interest in collating such information continues to the present, with the latest publication of the standard on nutrient requirements of beef cattle in the United States by NASEM (2016). Corbett and Freer (2003) provide an expanded account on the development of energy feeding systems especially those currently used in Australasian region (i.e., CSIRO, 2007).

The use of energy budgets to determine feeding requirements of sheep and cattle was widely explored in New Zealand (e.g., Jagusch and Coop, 1971; Joyce, 1971). More recently, the most widely used MEB methodology for sheep and beef cattle in New Zealand was described by Nicol and Brookes (2007), who in turn have adapted equations from SCA (1990) and CSIRO (2007), after a review by Yan et al. (2003). The latter compared several animal nutrient requirement standards to predict the energy demand of dairy cows and found that the Australian and French systems provided the most accurate prediction. Bown et al. (2013) also recommended this methodology for the use in the New Zealand National Enteric Methane Inventory (NEMI). The methodology is now widely used in extension circles in Australasia with a number of commercial software packages available (e.g. Udder, Farmax, GrazPlan, and Overseer®) (Webby and Bywater 2007; Freer et al. 2012; Wheeler, 2015; Tayler et al., 2016). Many researchers and consultants simply use the relevant equations in Microsoft®Excel spreadsheets for customized projects (e.g. Matthew et al. 2010).

The equations used by Nicol and Brookes (in Microsoft®Excel format) are outlined in the following paragraphs and compared to those of SCA (1990) and CSIRO (2007). Some comments relevant to the use specifically in Sabah are provided where necessary. Overall, the animal MEB recommended by CSIRO (2007) or its older version, SCA (1990) are suited for tropical livestock systems as well as temperate environments (CSIRO, 2007).

2.2.1 Total energy requirements (ME_{TOTAL})

The calculation of total energy requirements (MJ ME d^{-1}) of beef cattle can be derived from Nicol and Brookes (2007) as:

(Eq. 1) $$\mathbf{ME_{TOTAL} = ME_{BASALMETABOLISM} + ME_{GAIN} + ME_{GRAZE} + ME_{PREGNANCY} + ME_{LACTATION}}$$

Where ME_{TOTAL} is the total energy requirements of the animal. $ME_{BASALMETABOLISM}$ represents the energy requirements for basal metabolism and ME_{GAIN} represents the energy requirement for liveweight gain. ME_{GRAZE} represents the energy requirement for grazing. $ME_{PREGNANCY}$ represents the energy requirement for pregnancy and $ME_{LACTATION}$ represents the energy requirement for lactation.

CSIRO (2007) uses ME_{TOTAL} (MJ ME d^{-1}) = $ME_{BASALMETABOLISM}+0.1*ME_{PRODUCTION}+ME_{GRAZE}+E_{COLD}$. Where $ME_{BASALMETABOLISM}$ represents the energy requirement for basal metabolism. $ME_{PRODUCTION}$ represents the energy requirement for liveweight gain, pregnancy and lactation. ME_{GRAZE} represents the energy requirement for grazing. E_{COLD} represents the energy requirement for body heat maintenance. Nicol and Brookes' (2007) and CSIRO's (2007) equations are similar, except the former made minor adjustments as follows. First, Nicol and Brookes (2007) increased the inflation scalar for ME_{GAIN} and $ME_{LACTATION}$ by adding 0.1 (10%) to make a coefficient of 1.1. They rationalized this 10% increment from the suggestion by SCA (1990) and Moe et al. (1970, as cited by Nicol and Brookes, 2007). The 10% increment is incorporated to cover the extra energy spent by muscle and fat cells to grow and by the udder cells to produce milk. However, they did not multiply $ME_{PREGNANCY}$ by 1.1, stating that any extra energy required for pregnancy has already been accounted in the calculation of total ME requirement for pregnancy (see “Physiological State” in their paper). Second, they dropped E_{COLD}, considering this requirement to be negligible in the New Zealand farm environment. Although the environmental temperatures in New Zealand can at times drop below –5ºC (average $T_{LOWERCRITICAL}$ temperature across cattle of different ages set by CSIRO, 2007) where E_{COLD} would be required. Such a situation, however, is temporary in most cases (Nicol and Brookes, 2007).

2.2.2 ME requirements for basal metabolism ($ME_{BASALMETABOLISM}$)

The calculation of energy requirement for basal metabolism (MJ ME d^{-1}) of cattle, devised by CSIRO (2007) and used by Nicol and Brooks (2007) after a slight modification, is:

(Eq. 2) $$ME_{BASALMETABOLISM} = (Species*Sex*0.28*EXP(-0.03*Age)*LWT\hat{}0.75)/k_m$$

Where Species is 1.2 for *Bos indicus*, 1.4 for *Bos taurus*, or intermediate values for crosses between these cattle types; Sex is 1.0 for females and castrates and 1.15 for entire males; age is in years; LWT is live weight (kg); and k_m (i.e., efficiency of use of ME for maintenance) is M/D*0.02+0.5. M/D is feed ME content (MJ ME kg DM^{-1}).

The structure of the equation is similar to that of CSIRO (2007) (= (Species*Sex*M*0.28*EXP(–0.03*Age)*LWT^0.75)/k_m), except that Nicol and Brookes (2007) fixed M to 1.0 (M is 1+0.23*the fraction of the DE intake provided by milk and takes a minimum value of 1.0: CSIRO, 2007), and thus, they omitted it from the respective equation in their paper. The equation used to calculate energy requirement for basal metabolism given by SCA’s (1990) and then by CSIRO’s (2007) documents was adopted from the approach by Graham et al. 1974 (Corbett and Freer, 2003). However, several of the scalars were adopted from other resources. Bown et al. (2013) reported that the ‘Species’ scalar was rationalised from the studies by Frisch and Vercoe (1977, 1984). By comparing the metabolic data of cattle from these authors and that of sheep, the coefficient of metabolic live weight for *Bos taurus* is 1.4 × that of sheep and for *Bos indicus* is 1.2 × that of sheep. The gender scalar was obtained from ARC (1980). ARC (1980) proposed (in page 98) that, “until further information is available the 15% higher fasting metabolism adopted for intact male sheep has been taken to apply to intake male cattle”. This proposal was rationalized from the study by Webster et al. (1976), which indicated that maintenance energy requirements of bulls were 20% greater than those of castrates, and from the study by Graham (1968) and Joshi (1973, as cited in ARC, 1980), which indicated that rams had a higher (12% to 18%) metabolic rate than ewes and wethers, while metabolic rate of the latter animals showed no significant difference. The conclusion was adopted by AFRC (1993) and again by CSIRO (2007) and Nicol and Brookes (2007).

2.2.3 ME requirements for liveweight gain (ME_{GAIN})

The calculation of energy requirement for liveweight gain (MJ ME d^{-1}) of cattle, devised by SCA (1990) and CSIRO (2007) and used by Nicol and Brooks (2007) after a slight modification, is:

(Eq. 3.1) $$ME_{GAIN} = 1.1*((0.92*LWG)*((6.7+(((920*LWG)/(4*(SRW^{\wedge}0.75)))–1))+(20.3–(((920*LWG)/(4*(SRW^{\wedge}0.75)))–1))/(1+EXP(–6*((LWT/SRW)-0.4)))))/k_g$$

Where LWG is live weight gain (kg d^{-1}); SRW is standard reference weight in kg (as defined below); LWT is current live weight (kg); and k_g (i.e., efficiency of use of ME for weight gain) is M/D*0.042+0.006 for a non-lactating animal consuming herbage, M/D*0.043 for a non-lactating animal consuming concentrate (CSIRO, 2007), and 0.095* k_l for a lactating animal. k_l (i.e., efficiency of use of ME for lactation) is M/D*0.02+0.4. M/D is feed ME content (MJ ME kg DM^{-1}).

The structure of the equation is similar to that of SCA (1990) and CSIRO (2007), except that as stated earlier (Section 2.2.1), Nicol and Brookes (2007) multiplied ME_{LWG} by 1.1 to take account of the extra energy needed by muscle and fat cells to grow. CSIRO (2007) stated that SRW is the maximum live weight achievable by the animal at its current genetic potential, with the proviso that at that weight, the animal has a moderate condition score, that is, 3 for beef cattle. The SRW of Brahman animals is 770 kg for males and 550 kg for females (Table 1.12 in CSIRO, 2007). The SRW of Bali animals is 450 to 500 kg for males, or rarely 550 kg (Porter, 2007). However, a maximum live weight of 600 to 800 kg for male and 500 to 650 kg for female Bali has also been reported (e.g., Martojo, 2012). Brahman and Droughtmaster are both medium sized breeds (MacDonald and Katherine, 2011). Hence, the SRW of Droughtmaster can be assumed similar to Brahman. Little information is available on maximum live weight of beef cattle breeds in Sabah. For application of the equation in Sabah, the SRWs of the Brahman, Droughtmaster and Bali cattle will be based on the heaviest weights recorded for these breeds in Sabah; this is not ideal, but it is the best available option until a thorough study to estimate the SRW of the cattle in Sabah is carried out. As stated earlier (Section 2.1.7), relevant data on growth of these cattle are available from the government farms.

In a farming system, it is also of interest to estimate the energy from animal liveweight loss ($ME_{LWL,}$ MJ ME d^{-1}) to assess the performance of the system. CSIRO (2007) stated that "the energy value of 1 kg liveweight loss by non-lactating animals of any particular live weight should be taken to be the same as the energy content 1 kg liveweight gain made at the same live weight by animals of the same breed and sex" and "the energy provided to animals from catabolism of their tissues may be calculated by means similar to those used to calculate the energy content of gains".

Therefore, the equation to calculate ME_{LWL} (MJ ME d^{-1}) can be derived from CSIRO (2007) as:

(Eq. 3.2) $$\mathbf{ME_{LWL} = 1.1*((0.92*LWL)*((6.7+(((920*LWL)/(4*(SRW\wedge 0.75)))-1))+(20.3-(((920*LWL)/(4*(SRW\wedge 0.75)))-1))/(1+EXP(-6*((LWT/SRW)-0.4)))))/k_g}$$

Where LWL is live weight loss (absolute value, kg d^{-1}); SRW is standard reference weight in kg (as defined earlier); LWT is the current live weight (kg); and k_g is M/D*0.042+0.006 for a non-lactating animal consuming herbage, 0.043*M/D for a non-lactating animal consuming concentrate, and 0.095*k_l for a lactating animal. k_l is M/D*0.02+0.4. M/D is feed ME content (MJ ME kg DM^{-1}).

However, the efficiency, if the energy is used for body maintenance, is lower, that is, 0.80 (CSIRO, 2007). Hence, the energy recovered from body energy mobilisation by a non-lactating animal (ME_{LWLRNL}) can be derived as:

(Eq. 3.2.1) $$\mathbf{ME_{LWLRNL} = ME_{LWL}*0.80}$$

Where LWL is described in Eq. 3.2.

Nicol and Brookes (2007) used the 0.8 scalar for ME_{LWLRNL} of a non-lactating animal and added that for a lactating animal, the efficiency if the energy is used for lactation is 0.84, and thus, the energy recovered from body energy mobilisation by a lactating animal (ME_{LWLRL}) can be derived as:

(Eq. 3.2.2) $$\mathbf{ME_{LWLRL} = ME_{LWL}*0.84}$$

Where ME_{LWL} is described in Eq. 3.2.

Nicol and Brookes (2007) also devised a pasture equivalent for the energy of tissue mobilisation, to denote the energy that would originally need to be obtained from feed where that energy is first stored as body tissue and then mobilised to provide metabolic energy. In this case, the energy of feed saved is divided by k_m for non-lactating animals and k_l for lactating animals. The equations they proposed are:

(Eq. 3.2.1.1) **ME_{LWL} as dietary ME spared = ME_{LWLRNL}/k_m**

(Eq. 3.2.2.1) **ME_{LWL} as dietary ME spared = ME_{LWLRL}/k_l**

Where ME_{LWLRNL} is described in Eq. 3.2.1; k_m is M/D*0.02+0.5; ME_{LWLRL} is described in Eq. 3.2.2; and k_l is M/D*0.02+0.4. M/D is feed ME content (MJ ME kg DM^{-1}).

2.2.4 ME requirements for grazing (ME_{GRAZE})

The calculation of energy requirement for grazing (MJ ME d^{-1}) of cattle can be derived from Nicol and Brooks (2007) as:

(Eq. 4) **$ME_{GRAZE} = ME_{CHEW+RUMINATE}+ME_{MOVE}+ME_{ACTIVITY}$**

Where $ME_{CHEW+RUMINATE}$ is the energy requirement for chewing and ruminating the feed ingested; ME_{MOVE} is the energy requirement for moving while grazing; and $ME_{ACTIVITY}$ is energy requirement for activities other than grazing, such as walking.

Nicol and Brookes (2007) adopted ME_{GRAZE} of CSIRO (2007), but separated the calculation into smaller components (see Eq. 4.1 to 4.3 below). CSIRO (2007) uses ME_{GRAZE} = [C*DMI*(0.9–DMD)+0.0026*H]*W/k_m. Where C is 0.0025 for cattle; DMI is dry matter intake from pasture, excluding supplementary dry matter; DMD is digestibility of the dry matter (decimal); H is horizontal equivalent of distance walked in kilometres per day; W is live weight (kg); and k_m is M/D*0.02+0.5. M/D is feed ME content (MJ ME kg DM^{-1}).

H = T*[min(1,SR/SD)/(0.057GF+0.16)+M, where T takes a value of 1.0 to 2.0 for a terrain varying from level to steep; SR is current grazing density as animal per ha; SD is a threshold for grazing density as animals per ha, which takes 5 for cattle, and the minimum value of SR/SD is 1.0; GF is green forage availability, that is, t DM ha^{-1} when cut to ground level; and M is total distance walked in kilometre a day. ME_{GRAZE} is not applicable for stall fed (feedlot) animals because for these animals, the energy has been accounted for during the formulation of energy requirements for body maintenance of animals in confinement (CSIRO, 2007).

The calculation of the energy requirement of cattle for chewing and ruminating the feed ingested, devised by CSIRO (2007) and used by Nicol and Brooks (2007), is:

(Eq. 4.1) **$ME_{CHEW+RUMINATE}$ = LWT*((Species*DM intake*(0.9–Digestibility))/k_m**

Where LWT is liveweight (kg); species is 0.0025 (for cattle); DM intake is the dry matter intake; Digestibility represents digestibility (as a proportion) of the feed consumed and is calculated as (M/D)÷15.088; and k_m is M/D*0.02+0.5. M/D is feed ME content (MJ ME kg DM^{-1}).

Nicol and Brookes (2007) did not specify the method to calculate the dry matter intake. CSIRO (2007) proposed that the total dry matter intake is estimated as potential dry matter intake (**I**) × relative dry matter intake. The relative dry matter intake is estimated as relative ingestibility (**RQ**) × relative availability (**F**).

The calculation of potential dry matter intake (**I**) is given by CSIRO (2007) as:

(Eq. 4.1.1) **I = j*SRW*Z*(1.7–Z)*CF**

Where j is 0.025 (for cattle); SRW is standard reference liveweight (kg); Z is relative size of the cattle; and CF is a correction factor for the energy requirement of the cattle during lactation (cows eat more feed to support the calf) or when non-lactating. Z is calculated as N/SRW, where N is equal to SRW–(SRW–BirthWT)*EXP(–k*Age*SRW^–0.27), Age is in months, and k is 0.35 for cattle. CF is equal to RC*(1.5–RC)/0.5 if RC >1.0 (non-lactating), or otherwise CF is equal to 1.0; and RC is the relative condition, which is calculated as LWT/N, where LWT is the current live weight (kg).

The calculations of relative ingestibility (**RQ**) and relative availability (**F**) of herbage dry matter are given by CSIRO (2007) as:

(Eq. 4.1.2) **RQ = 1–1.7*(max((0.8–(1–P_{legume})*g)–D,0.0))**

Where P_{legume} is the proportion of legume in the pasture; g is 0.16 for C4 (tropical) grass; and D is the digestible dry matter (DMD in decimal) of the diet and is calculated as M/D÷15.088. RQ and D have a linear relationship and when D is 0.8, RQ will be 1.0 (Freer, 2002); M/D is feed ME content (MJ ME kg DM^{-1}).

(Eq. 4.1.3) **F = E*T = (1.0–EXP(–b*B))*(1.0+c*EXP(–d*B^2))**

Where E is the relative rate of ingestion; T is the relative time spent eating (E and T takes a default value of 1.0 when pasture is abundant: CSIRO, 2007); b is 1+0.35; B is the weight of herbage available (kg DM ha^{-1}); c is 0.6; and d is 1+0.35. Freer (2002) states that E = 1–EXP(–(1+0.35)*0.0012*H*B) and T = 1+0.6*EXP(–(1+0.35)*(0.0012*H*B)^2), that is, b and d are both 1+0.35, and c is 0.6. H is mean current herbage height ÷ standard herbage height at the B herbage weight.

There is no previous research in Sabah quantifying the feed intake (kg DM) of cattle in the field by cutting experiments following the method explained by Freer (2002). Hence, the default value of E and T (i.e. 1.0) has to be used for a study using F in Sabah.

The calculation of energy requirement of cattle for moving specifically for grazing, devised by CISRO (2007) and used by Nicol and Brooks (2007), is:

(Eq. 4.2) $$ME_{MOVE} = (0.0026*LWT*S*(TSR/SD)/((0.057*GF)+0.16))/k_m$$

Where LWT is liveweight (kg); S is slope, which takes a value of 1.0, 1.5 or 2.0 for flat land, easy hill and steep hill farms, respectively; TSR/SD is the relative stocking rate, which takes a default value of 1.0 for beef cattle; SR is the current grazing density (animal ha^{-1}); SD is the threshold for grazing density (animal ha^{-1}), which takes a value of 5 for cattle; GF is the green forage in t DM ha^{-1} (when cut at ground level); and k_m is M/D*0.02+0.5. M/D is feed ME content (MJ ME kg DM^{-1}).

CSIRO (2007) did not specify the selection of slope index, but suggests a range from 1 to 2. Nicol and Brookes (2007) used 1, 1.5 and 2 to relate the slope index to the general classification of topography of farms in New Zealand: i.e. classified as flat (usually dairy farms), easy hill country and hard hill country farms. New Zealand hill country is generally steeper than 10º/15º (Lambert and Roberts, 1976) and hard hill is perhaps >20º slope (Joblin, 1983). In Sabah, agricultural activity is limited to slopes <25º (Sabah Agricultural Policy 1999–2010, 2000) and anecdotally, most beef cattle farms are known to be on areas of <15º slope for accessibility reasons (i.e., the cost to build and maintain roads on steep slopes is high due to erosion associated with high rainfall). Slope is a farm specific attribute, and thus the selection of the index for the case in Sabah will depend on the topography of the farm studied. The approximate ranking method would be that used by Nicol and Brookes (2007). The green forage (GF) can be determined by herbage cutting.

Calculation of the energy requirement of cattle for other activity during grazing, devised by CSIRO (2007) and used by Nicol and Brooks (2007), is:

(Eq. 4.3) $$ME_{ACTIVITY} = LWT*((0.0026*H_{km})+(0.028*V_{km}))/k_m$$

Where LWT is liveweight (kg); H_{km} is the horizontal distance walked (kilometre); V_{km} is the vertical distance (kilometres) walked by the cattle; and k_m is M/D*0.02+0.5. M/D is feed ME content (MJ ME kg DM^{-1}).

The maximum horizontal distance that cattle will walk a day to graze was stated by CSIRO (2007) to be 6.3 km, depending on the herbage availability; the cattle would walk a lesser distance to graze when herbage is abundant and would walk a greater distance when herbage is becoming scarce, but may simply walk less when herbage abundance is very low. (Of course other resources such as water and shade would also affect the movement of the cattle). Slope length is farm specific and thus, V_{km} a day will depend on the topography of the farm; length of vertical slope on the farm will need to be estimated for the calculation of $ME_{ACTIVITY}$. V_{km} would be zero on flat land.

2.2.5 ME requirements for pregnancy ($ME_{PREGNANCY}$)

The calculation of total energy requirement for pregnancy (MJ ME d^{-1}) of cattle, devised by CSIRO (2007) and used by Nicol and Brooks (2007), is:

(Eq. 5) $$ME_{PREGNANCY} = (BirthWT/40)*EXP(349.222–349.164*EXP(–0.0000576*Days))*0.0201*EXP(–0.0000576*Days)/k_p$$

Where BirthWT is the birth weight of offspring (kg); Days are days since conception; and k_p is 0.133 (i.e., efficiency of use of ME for pregnancy).

The equation was similar to CSIRO (2007), except that as stated earlier (Section 2.2.1), Nicol and Brookes (2007) did not multiply $ME_{PREGNANCY}$ by 1.1, stating that any extra energy requirement for pregnancy has already been accounted in the calculation of total ME requirement for pregnancy.

2.2.6 ME requirements for lactation ($ME_{LACTATION}$)

The calculation of energy requirement for lactation of cattle is given here based on the alternative method used at Massey University, New Zealand:

(Eq. 6) $$ME_{LACTATION} = (Eq. 2)+(Eq. 3.1)+(Eq. 4)$$

Where Eq. 2, Eq. 3.1, and Eq. 4 are as described earlier (Sections 2.2.2, 2.2.3, and 2.2.4).

Eq. 6 is an alternative method used in Massey University to calculate the energy requirements of calf, that is, based on the calf liveweight. The calculation involves ME_{BM}, ME_{LWG} and ME_{GRAZE} of the calf. The conventional method recommended for estimating the lactation energy cost requires data on milk production and fat and protein contents of the milk. These data are difficult to obtain for grazing beef cattle (Nicol and Brookes, 2007). By 4 weeks of age calves will start to graze and by 6 wk of age they will graze actively, which means during the first and second months the calf uses energy from the cow's milk. However, whether the calf receives energy from cow's milk or from pasture, both energy sources come from the system and thus, calculating the energy requirements of the calf based on its liveweight is generally representative of the energy harvested by the calf from the system. Since $ME_{LACTATION}$ is calculated based on the calf liveweight, dietary feed saving when the calf loses weight can be calculated using Eq. 3.2.1.1 and Eq. 3.2.2.1 as described earlier.

2.2.7 ME requirements for thermoregulation ($ME_{THERMOREGULATION}$)

An effect of cold or heat on metabolic energy requirements of animals in Sabah is unlikely because the ambient temperature is higher than the lower critical temperature but lower than the optimum body temperature of the animals where energy for body thermoregulation would be required. The optimum body temperature of a ruminant is reported to be close to 39ºC (CSIRO, 2007). The lower critical temperatures ($T_{LOWERCRITICAL}$) of cattle are reported to be 12ºC to 31ºC for a 2 day old calf, –2ºC to 22ºC for a calf 28 days of age or older, and –15ºC to 19ºC for an adult animal under various wind, rainfall and coat depth conditions (CSIRO, 2007). The ambient temperature of the lowland areas in Sabah is reported to be 22ºC to 32ºC. Although temperature can drop to 15ºC to 18ºC on agricultural land of >1000 m (a.s.l.) elevation, this land is usually used for cultivation of vegetables and in fact, there is only one cattle (dairy) farm at such elevation in Sabah. The 31ºC $T_{LOWERCRITICAL}$ for a young calf is under conditions of 20 km h^{-1} wind speed and 30 mm d^{-1} rainfall. While that rainfall rate does sometimes occur in Sabah, high wind speed is rare. Even in New Zealand (Nicol and Brookes, 2007, as stated earlier) E_{COLD} is negligible. CSIRO (2007) stated that the upper critical temperature ($T_{UPPERCRITICAL}$), or the upper limit temperature where energy would be required to regulate body temperature around the optimum body temperature of a ruminant, has never been well established. Hence, until new information on $T_{UPPERCRITICAL}$ is available, it is assumed not to be an issue for Sabah.

2.3 Summary

Based on the above review, little information is available on the operation and information of the beef cattle pastoral systems in Sabah. Information on feed demand and supply is particularly lacking, with which to provide a basis for (i) describing and quantifying the existing systems and (ii) evaluation of possible approaches to improving the productivity of the systems. Hence, the methodology adopted in this study in the first instance to fill the knowledge gap was to search for farming technology insight from a successful pastoral system. However, as noted by Preston and Leng (1987) attempts at development of farming systems that focus on 'transplanting in' foreign technology often do not work well. Therefore, following discussion with experts in New Zealand an alternative approach to exploring development options of pasture-based beef production systems in Sabah was developed. Specifically, this thesis will explore the application of MEB developed and used in New Zealand sheep and beef cattle systems over recent decades as a tool to assess systems performance and to draw from the resulting analysis, opportunities to improve systems performance in Sabah. A key part of the initial analysis was to capture the feed profile of the various beef cattle production systems in Sabah with a spreadsheet MEB tool that emulated software like Stockpol (Marshall et al., 1991; McCall and Tither, 1993) and its successor Farmax (Bryant et al., 2010; Farmax, 2013; Tayler et al., 2016). For that purpose, the first step was to develop the relevant spreadsheet based on how MEB is used on New Zealand farms. As the proprietary models that exist (Section 2.2) are generally tailored to specific systems and the equations and coefficients used are generally subject to intellectual property protection, there is no flexibility for adjustment to specific conditions. By developing a model from first principles, the author has full control of the model configuration and output. The approach used in this study was to formulate the model first for New Zealand sheep and beef cattle farms (as the New Zealand system best suited to formulating a model for later adaptation for use in Sabah) and this work was reported in Chapter 3; followed by an evaluation of 3 major categories of cattle farming system in Sabah (Chapters 4 to 6).

Chapter 3

Changes over 25–30 years in New Zealand North Island sheep and beef cattle farm performance evaluated by metabolic energy budgeting as a first step towards transfer of New Zealand farming systems technology to a tropical system

Abstract. In order to apply insight from New Zealand farm system technology to development of the beef industry in Sabah, Malaysia, a two-phase study was carried out in which metabolic energy budgeting (MEB) was used as the vehicle for technology transfer. The two phases of the study were: 1) evaluation of farm systems evolution in New Zealand over the last 2.5–3 decades by modelling past systems from historic records to develop spreadsheet tools to identify principles of system improvement; and 2) application of the tools developed in New Zealand to evaluation of opportunities for farm system improvement in Sabah. Here phase 1 is reported. Farm average data for North Island Hill Country sheep and beef cattle farm systems in New Zealand for the period 1980–81 or 1985–86 to 2010–11 were obtained from annual surveys by a farmer organisation and reviewed for patterns of change over time. System performance for a hypothetical farm based on the average data and 3 commercial case farms (Farms A, B, and C) representative of the selected farm category and for which records spanning 25 years were available were then modelled using MEB. This work therefore provided a retrospective appraisal of cumulative changes for North Island hill country sheep and beef cattle farm systems in New Zealand over the study period, giving insight beneficial for the industry in New Zealand as well as tools for use in Sabah. Modelled pasture productivity of New Zealand farms was 12% lower, and herbage harvested 13% lower in 2010/2011 than in 1980–81/1985–86. This productivity decline is attributable to increased incidence of warmer and drier summer weather. However, through changes in farm system configuration and associated gains in performance, the feed conversion efficiency improved over the 25-year study period from 25 to 19 kg feed consumed per kg lamb weaned, and the corresponding increases in meat production were a rise from 137 to 147 kg total beef and lamb carcass per ha per year based on national data. Similar or slightly better improvements were observed for sheep or cattle feed conversion efficiency on case farms A, B, and C during the same period. The experience gained using MEB to evaluate New Zealand hill farm systems will be adapted to capture insight about system performance and opportunities for system improvement in Sabah.

3.1 Introduction

New Zealand is unique in that it is a developed country yet still economically dependent on primary production. Pastoral agriculture in New Zealand underpins the economy of the country as a source of overseas earnings (MPI, 2012). New Zealand farmers carry the primary risk of the business and face growing regulatory requirements to adopt environmentally sustainable practices. They continually apply new technology and new ideas to maintain and improve farm productivity to be an economically viable land use and to meet changing customer demands and the needs of society. In this operating context, pastoral systems in New Zealand have become highly evolved, and there is international interest in knowing more about them with a view to transferring systems expertise and technology to different farming systems in other countries. The present study is an attempt to use information, farmers' experience, and technology from New Zealand farming systems to improve the beef cattle farming industry in Sabah, East Malaysia.

In attempting to transfer farming systems expertise and technology between vastly different climatic regions, it was realised in this study that no literature or established methodology is available. As noted in Chapter 1, a previous evaluation reported that the direct transfer of ruminant livestock production technology is rarely successful (Preston and Leng, 1987). After considering what elements of farm system technology in New Zealand might be both transferable to and of benefit in Sabah it was recognised that MEB might be an appropriate means of technology transfer through identification of fundamental principles applicable to both temperate and tropical pastoral systems. MEB to match the seasonal feed supply to the animal feed demand is a pastoral practice widely understood in New Zealand and Australia (Corbett and Freer, 2003; CSIRO, 2007; Webby and Bywater, 2007) that has received little attention in the international literature. Metabolic energy budgets and feed demand estimates can be calculated using commercial software or purpose-built spreadsheets. The equations to calculate metabolic energy budgets and feed demand are now available in New Zealand (e.g., Farmax), both to assist scientists and regulatory bodies to develop environmentally sustainable farming practices and to help farmers to develop and refine farm system configurations over time. Some New Zealand farmers and farm consultants frequently run metabolic energy budgets for alternative farm system configurations before each farming season to identify optimal scenarios and plan their farming operations, or develop contingency plans for events such as drought. One side effect of this practice is that farm system configuration research tends to be heavily focussed on incremental benefits moving forwards, and a retrospective review of cumulative changes is seldom undertaken.

After considering the available options, it was decided in this study to develop the spreadsheet model to describe the evolution of farming on New Zealand hill country (Class IV) sheep and beef cattle farms (*sensu* Beef + Lamb New Zealand, www.beeflambnz.com), the most common and widespread type of sheep and beef cattle farm in New Zealand’s southern North Island. The research aim was to use the MEB spreadsheet to assess the performance of an average farm and specific case-study farms in this category in 2010–11 and back in time in 5-yearly steps to the period 1980–81/1985–86. It was envisaged this study would produce several outputs: (i) a spreadsheet for an animal metabolic energy budget that could be adapted in the future for use in Sabah by adjusting some of the coefficients for the tropical climate; (ii) an understanding of pastoral systems in New Zealand as a step towards international technology transfer; (iii) an assessment of cumulative changes in performance as a result of system configuration evolution over time of the selected farm category in New Zealand; and (iii) insights into which factors have made the greatest contribution to the cumulative performance changes over time. Here, the outcomes of the work in New Zealand are presented in two parts: first, a review of key farm information from annual surveys by a farmer organisation, Beef+Lamb New Zealand, and from three case-study farms representative of the studied farm category, and second, a system performance analysis of an average farm and the three selected case-study farms.

3.2 Methods

3.2.1 Survey of key farm data

3.2.1.1 Average farm

Descriptive statistical information for the selected farm category in New Zealand was collated every 5 years from 1980 to 2011. The data used were obtained from Beef + Lamb New Zealand by email correspondence (www.beeflambnz.com) and from a publication *Supplement to the New Zealand Sheep and Beef Farm Survey* (SNZSBFS, 1983, 1984, 1988). The data collated were mainly for factors related to feed demand and supply of the farming system. The data included farm size (total and effective area), hay or silage area, animal number (sheep and cattle), reproductive performance (lambing and calving percentages), and chemical inputs (lime and fertiliser application).

3.2.1.2 Case farms

To evaluate data at the farm level, similar types of data were collated for the 1980–81/1985–86 and 2010–11 production periods, for the three case-study farms (A, B, and C), also hill country farms belonging to the same farm category (e.g., Figure 3.1, Farm A), located at –40.3462 (latitude)/175.6178 (longitude), –40.6527/176.128 and –40.8422/175.618, southeast North Island, New Zealand, respectively. The information was obtained from farm diaries for Farms A and B and from the annual feed budget prepared by the farm manager in 2009–2011, Parker and Lowe (1980/1981), and Parker (1986) for Farm C. All farms practiced rotational grazing, except during lambing (spring) where the ewes and lambs were set stocked, had detailed records spanning the 25–30-year study period suitable for this study, and (at the time of this study) were performing above the national average in terms of effective farm area and animal stock units per hectare. Farms A and B have been operated by the current farmers over the past 25 and 30 years, respectively. Farm C (Riverside Farm) has been operated by Massey University since 1979 (Parker and Lowe, 1980/81).

Figure 3.1 A view of Farm A, illustrating slope and pasture type typical of the farm and the region generally.

3.2.2 Farm system performance analyses

3.2.2.1 Feed demand and consumption modelling

The initial plan was to model the feed demand and consumption of the system every 5 years since 1980. However, since data were not available for some years, the time intervals studied were re-selected based on the years for which data were available. For the average farm, the periods studied were 1980–81, 1985–86, 1992–93, 1999–00, 2003–04, and 2010–11. For Farm A, the periods studied were 1985–86, 1999–00, 2003–04, and 2010–11. The periods studied for Farm B were the same as those studied for Farm A, with the addition of 1980–81, 1992–93, and 2011–12. The latter were included to verify the trends in 2010–11. For Farm C, the periods were 1980–81, 1985–86, and 2010–11.

(a) Acquisition of animal data

For the average farm, the numbers of animals by type and age class were obtained from the Supplement to the New Zealand Sheep and Beef Farm Survey (SNZSBFS, 1983, 1984, 1988) and the New Zealand Sheep and Beef Farm Survey (NZSBFS, 1988–2003) for the production periods 1980–81, 1985–86, 1992–93, and 1999–2000. Since that information was no longer published after 2002, the data were obtained for 2003–04 and 2010–11, the numbers of animals by type and age class in 2002–03, 2003–04, 2009–10, and 2010–11 were calculated from the annual animal "stock units" reported by Beef + Lamb New Zealand (2012) for these periods, taking data for the previous year as "opening stock", and data for the subsequent year as "closing stock". For Farms A and B, the data were obtained from farm diaries. For Farm C, the data were obtained from Parker and Lowe (1980/81), Parker (1986), and from the annual feed budgets prepared by the farm manager in 2009–2011.

(b) Modelling of animal metabolic energy requirements

The animal metabolic energy requirements were calculated on a monthly basis from the animal monthly liveweight data, which were obtained from previous reports on New Zealand farming (Appendix 3.1) and from the farm diaries of Farms A, B, and C. The calculation utilised equations published by Nicol and Brookes (2007) (Appendix 3.2); the methodology was reviewed in Chapter 2 (Section 2.2). The requirements were calculated using a standard Microsoft®Excel template adapted from one used by Massey University over the last 15 years (e.g., Matthew et al., 2010) and that indicated by Webby and Bywater (2007). The calculation was slightly adjusted in two respects. First, Nicol and Brookes (2007) propose that if the metabolisable energy (ME) content of the diet is above (or below) 10.5 MJ per kg dry matter (DM) (11 MJ ME kg DM^{-1} for lactating ewes), a flat rate of 7% (or 10% for lactating ewes) of body maintenance energy should be deducted from (or added to) the total energy requirements. In this study, the deduction (or addition) in body maintenance energy requirement with increasing (or decreasing) herbage ME from the herbage ME threshold (10.5 or 11 MJ ME kg DM^{-1}) was not applied as a sudden increment at a threshold value of ME as proposed by Nicol and Brookes (2007), but the rate (%) was instead calculated as a gradual transition using the formula: (|Monthly herbage ME – Herbage ME threshold|) ÷ herbage ME threshold × 100. Second, the energy cost of weight gain for adult steers and bulls was taken to be 70 MJ ME per kg liveweight gain rather than 55 MJ ME per kg liveweight gain, used by Nicol and Brookes (2007), and energy recovered during weight loss of sheep was decreased by 5 MJ ME per kg liveweight to 20 MJ ME per kg liveweight. These adjustments were made to take account of anecdotal comments from New Zealand farmers suggesting that modification to published coefficients would better reflect farmer experience of feed consumption during paddock grazing events.

(c) Energy values assumed for pasture when converting energy requirements to feed demand

The conversion of energy requirements to feed demands was based on the ME content of browntop/ ryegrass-clover (*Agrostis capillaris* L./*Lolium perenne* L.-*Trifolium* spp.) pasture grown on New Zealand farms. For periods before 2005–06, the ME of herbage on Tuapaka Farm reported by McRae (1987) was used (Appendix 3.3). For periods after 2005–06, the ME of herbage reported by Machado et al. (2005) on the same farm was used (Appendix 3.3). These data were used because (a) the ME of herbage was historically rarely measured on New Zealand farms and thus, using known information from a farm of similar pasture type the nearest farm is an option for forecasting feed demand (Waghorn, 2007; Webby and Bywater, 2007) and (b) the farmers of Farms A and B believed that the nutritive value of herbage on their farms had improved since 1980–81/1985–86. For calculations for the average farm, the ME of herbage for finishing cattle was lowered, compared to the value used for herbage eaten by sheep. As cattle typically follow the sheep mob in the rotation, the herbage grazed by the cattle will tend to have lower ME content than that grazed by the sheep (Morris and Smeaton, 2009). The reduction in the ME of herbage grazed by cattle compared with that grazed by sheep was based on percentages extracted from Figure 1.2 in Morris and Smeaton (2009). For Farm A, the ME of herbage for finishing cattle was assumed to be the same as that for sheep, because this farm did not operate a rotation that prioritised sheep. For Farms B and C, the ME of herbage consumed by cattle and sheep was assumed to be the same as that of the average farm.

(d) Comparison of model output with commercial software Farmax®Lite

For benchmarking purposes, the feed demand estimates for Farm C in 1980–81 and in 2010–11 were calculated using Farmax®Lite (www.farmax.co.nz), a commercial feed budgeting software package widely used in New Zealand, and compared with those obtained from the Microsoft®Excel spreadsheet model developed in this study. The calculations using Farmax®Lite incorporated farm system details, seasonal change in stock numbers (sold stock was set to random in terms of liveweight following the practice on the farm) and animal liveweight, hay and crop area, and farm size of Farm C.

3.2.2.2 Herbage accumulation modelling

The herbage accumulation on the respective farms was modelled using a software package named GROW, for the same periods as those used in the feed demand modelling described above. GROW was specifically designed for the New Zealand farm environment. A description and limited validation of the GROW model has been reported by Butler et al. (1990). The model uses rainfall, temperature, and soil fertility data as the main inputs, and other parameters relevant to soil water storage as minor inputs. In this study, the default set-up of the model was used, except for herbage composition (ryegrass-white-clover-browntop), soil fertility (Olsen P = 10), soil type (moderate clay loam), and cutting rotation (28 days). For the national farm average, mean temperature and rainfall data for central and southern parts of North Island were obtained from NIWA (2013) (www.niwa.co.nz). For Farms A and B, the data were obtained from farm diaries. For Farm C, the data were obtained from Radcliffe (1975), Parker and Lowe (1980/81), Thompson (1982), Parker (1986) and from NIWA (2013) for 2010–11 data.

3.2.2.3 Feed conversion efficiency

The FCEs of the systems were estimated for the average and case farms during 1980–81 and 2010–11 production periods. FCE was expressed as amount of feed required (kg DM) per product (kg carcass of sheep + cattle, kg sheep carcass, lamb weight and number of lambs weaned, kg cattle carcass, and calf weight and number of calves weaned). Feed demand information was obtained as described in Section 3.2.2.1. The annual carcass weight data were obtained from the Supplement to the New Zealand Sheep and Beef Farm Survey (SNZSBFS, 1983, 1984) and from Beef + Lamb New Zealand (2013). Additional carcass weight data were obtained from farm diaries, Parker and Lowe (1980/81), and Parker (1986). The liveweight to carcass weight conversion rates were 40% and 51% for sheep and cattle, respectively (Farmer A, *pers. comm.*).

3.3 Results

3.3.1 Cumulative changes over time on an average farm

The various statistics for an average North Island hill country sheep and beef farm almost all showed change trends for the period from 1980 to 2010 (Table 3.1). Reviewing these selectively in the order presented in Table 3.1; (i) farm size increased by 25%, and farm effective ha by 21%; sheep numbers and sheep SU ha^{-1} decreased by just under 20% and over 30%, respectively; cattle numbers increased by over 30% and cattle SU ha^{-1} by 11% (The ratio of sheep to cattle SU changed from >70:30 to <60:40,); lambing % increased by around 20% (though calving % declined), and fertiliser applications were increased, especially nitrogen fertiliser.

Table 3.1 Changes in average farm area, effective area, sheep, cattle, animal stock units (SU), lambing and calving percentages, and nutrient inputs on North Island hill country sheep and beef cattle farms in New Zealand from 1980 to 2011.

Farm information	1980–81	1985–86	1990–91	1995–96	2000–01	2005–06	2010–11	Change (%)
Farm area (ha)	398	396	408	433	469	493	498	25
Effective area (ha)	361	363	376	397	421	437	436	21
Effective area (%)	91	92	92	92	90	89	88	–3
Hay and silage (ha)	6	7	5	10	8	8	9	50
Sheep (head)	3,118	3,139	2,817	2,542	2,569	2,798	2,532	–19
Sheep SU	2,837	2,874	2,569	2,315	2,331	2,538	2,300	–19
Sheep SU ha^{-1}	7.86	7.92	6.83	5.83	5.54	5.81	5.28	–33
Sheep:Cattle (SU)	70:30	72:28	65:35	56:44	58:42	59:41	58:42	–17
Cattle (head)	254	233	290	370	348	372	347	37
Cattle SU	1,236	1,129	1,394	1,788	1,675	1,784	1,658	34
Cattle SU ha^{-1}	3.42	3.11	3.71	4.5	3.98	4.08	3.8	11
Lambing (%)	101	100	101	107	110	126	116	15
Calving (%)	85	83	86	84	83	82	80	–6
Nitrogen (T)	-	0.2	0.5	1.2	2.4	5.5	2.7	1250
Phosphorus (T)	-	2.1	3.7	6.2	9.4	8.4	6.7	219
Sulphur (T)	-	2.7	3.9	7.1	11.2	8.5	8.4	211
Potassium (T)	-	0.7	0.7	1.8	2.2	1.9	1.4	100
N+P+S+K (T)*	62.4	26.0	39.6	64.6	103.6	91.1	82.5	32

Source: Beef + Lamb New Zealand (www.beeflambnz.com). All values are per farm basis. *Total as actual quantity (e.g., urea, superphosphate), not elemental nutrient (e.g., the quantity of N, P, S, and K in the table).

3.3.2 Cumulative changes over time on case farms

Changes over time on the case farms were largely consistent with industry trends described above but also showed unique features reflecting polices of the individual farmers concerned. On Farm A, notably large changes included the rate of fertiliser application (particularly nitrogen), the number of cattle (>200% increase, compared to <40% on an average farm), the farm size, and the lambing percentage (Table 3.2). Nitrogen application was from none to 63 kg ha^{-1} yr^{-1}. More phosphorus and sulphur were also used in 2010–11, than historically. This farm did not produce hay or silage, however. With these changes, the sheep to cattle ratio on a SU (feed demand) basis was 34:66 in 2010–11, compared with 57:43 in 1985–86. The effective area was 138% larger in 2010–11 compared to than that in 1985–86, meaning the total sheep stock units per ha had actually decreased by 47% (Table 3.2) and the overall stocking rate (animal stock units per ha) was 12% lower than that 25 years ago. The lambing percentage was 43% higher in 2010–11 than in 1985–86, and 6% higher than the national average in 2010–11. On this farm, breeding cattle were not farmed, but weaned steers and bulls were purchased and farmed. Beef cattle were the main product of this farm long before the 1980s and the number of cattle has further increased in recent years. Hence, although there was a higher sheep than cattle stocking rate on the farm in 1985–86, beef was the main commercial product rather than wool and lamb. Copper dosing of cattle was practiced on this farm in recent years to improve the health and growth of the cattle.

The trends in farm statistics on Farm B differed from those on Farm A, and also from those of the average farm. In this case, the farm had made changes before 1980 that other farms did not make until later (as evidenced by the lambing percentage of 123% and P fertiliser application of 22 kg P ha^{-1} yr^{-1} in 1980–1981) and expansion of farm area between 1980 and 2010 came from development of steeper land at the margins of the property, that would be expected to have lower natural productivity, rather than aggregation of neighbouring farmland of similar topography. Notable features in the development statistics on this farm over time included a reduction in cattle stock units and increase in sheep numbers which was a different pattern from that of average farm mainly in the increment of sheep (Table 3.2). The application of phosphorus and sulphur, being already above average in 1980–1981, did not increase further, but there was a marked increase in the application of lime. As on Farm A, the application of nitrogen on Farm B was also higher in 2010–11 (from none to 7.2 kg ha^{-1} yr^{-1}), the effective area was larger (+61%), and the total animal stock units per ha were lower (–6%), compared with that in 1980–81 (Table 3.2). This farm also did not produce hay or silage. This farm focussed on its sheep enterprise, maintaining sheep to cattle ratio (SU) at around 80:20 in 2010–11, compared with 69:31 in 1980–81. The lambing percentage was 123% in 1980–81, the same in 2010–11, but 137% in 2011–12, or 14% higher than the national average. The calving percentage in 2011 was 5% higher than that in 1981. In 1980–81, wool was the main product while lamb and beef were the secondary products. More recently, lamb has become the main product while wool and beef were the secondary products. In the current farm system, 800–900 dry ewe hoggets are transported off the farm from August to December to allocate more feed to ewes and lambs.

Table 3.2 Changes in effective farm area, number of sheep and cattle, animal stock units (SU), lambing and calving percentages, and nutrient inputs on case farms from 1980–81/1985–86 to 2010–11.

Farm information	Farm A		Farm B			Farm C	
	1985–86	2010–11	1980–81	2010–11	2011–12[A]	1980–81	2010–11
Effective area (ha)	345	821(138)	670	1081(61)	1081(61)	670	677(1)
Hay or silage (ha)	0	0	0	0	0	63	33(–48)
Rainfall (mm)	1094	1287(18)	1602	1348(–16)	1391(–13)	1560	927(–41)
Temperature (ºC)	12.8	13.4(5)	12.8	13(2)	11.7(–9)	12.6	13.2(5)
Sheep (head)	3,080	4,100(33)	6,531	12,364(89)	13,144(101)	11,574	6,750(–42)
Sheep SU	2,359	3,004(27)	4,815	8,620(79)	8,765(82)	8,830	4,829(–45)
Sheep SU ha^{-1}	6.8	3.6(–47)	7.2	8.0(11)	8.1(13)	13.1	7.1(–46)
Sheep:Cattle (SU)	57:43	34:66	69:31	80:20	79:21	90:10	81:19
Cattle (head)	403	1,288(220)	453	441(–3)	507(12)	221	238(8)
Cattle SU	1,815	5,808(220)	2,192	2,089(–5)	2,396(9)	1,024	1,169(14)
Cattle SU ha^{-1}	5.3	7.1(34)	3.3	1.9(–42)	2.2(–33)	1.5	1.7(13)
Lambing (%)	79	122(54)	123	123(0)	137(11)	105	131(25)
Calving (%)	NB	NB	89	94(6)	99(11)	95	100(5)
Nitrogen (kg $ha^{-1}yr^{-1}$)	0	63	0	7.2	4	0	40
Phosphorus (kg $ha^{-1}yr^{-1}$)	18	21(17)	22	21(–5)	22(0)	26	16(–38)
Potassium (kg $ha^{-1}yr^{-1}$)	0	0	0	0	0	0	0.0[B]
Sulphur (kg $ha^{-1}yr^{-1}$)	22	25(14)	27	25(–7)	27(0)	32	20[B](–38)
N+P+S+K (kg $ha^{-1}yr^{-1}$)*	203	367(81)	250	246(–2)	255(2)	292	269(–8)
Lime (kg $ha^{-1}yr^{-1}$)	0	0	0	454	290	1034	1.5[B](–100)
Olsen P	16–19	19–29(37)	12	18(50)	18(50)	14	25[B](79)
Copper	0	4[C]	0	0	0	0	0

*Total as actual quantity (e.g., urea, superphosphate). NB = No breeding cattle. [A] Results for Farm B in 2011–2012 as for comparison. [B] Riverside Farm leaflet (www.massey.ac.nz). [C] Four treatments a year. Numbers in parenthesis are the percentage change between 1980–81 or 1985–86 and 2010–11 or 2011–12. Note: N content in urea is 46%; and P and S content in superphosphate are 9% and 11%, respectively.

The trends in farm statistics on Farm C were similar to those of the average farm, except for effective area, fertiliser use, and hay and silage area (Table 3.2). On this farm, which is a Trust Property and not a family farm, the effective area changed only slightly. The total application of phosphorus and sulphur and stocking rate was markedly higher than that on Farms A and B in 1980–81 (Table 3.2), but had dropped back to be approximately in line with those farms by 2010–2011. In common with other farms, the application of nitrogen increased in recent years to 40 kg ha^{-1} yr^{-1}. The higher use of nitrogen started in the late 1980s. On this farm, the number of sheep decreased by 42%, and the total animal stock units per area decreased by 40% during the period studied (Table 3.2), so the picture for this farm over the past 30 years is one of de-intensification. Even so, the number of cattle increased by 8%, and the lambing and calving percentages increased by 26% and 5%, respectively. In 1980–81, wool was the main product while lamb and beef were the secondary products. In 2010–11, lamb was the main product while wool and beef cattle were the secondary products. Cattle farming ceased for a time on this farm in the mid-1980s. Dairy heifers have also been farmed in recent years; the heifers are purchased and reared before being sold at around 2 years of age to dairy farmers. With the farming of both beef and dairy cattle and the reduction of sheep on this farm, the sheep to cattle ratio (SU) was 81:19 in 2010–11, compared with 90:10 in 1980–81.

3.3.3 Feed demand, herbage supply, and feed balance

The feed demand modelling revealed that annual herbage harvested was 13% lower in 2010/2011 than that in 1980–81 or 1985–86. Less herbage was harvested on Farms A and C and on the 'average' farm in 2010 than in 1980, though no decline was observed on Farm B (Table 3.3, Figure 3.2). On Farm B, the effective import of feed by running ewe hoggets off-farm for part of the year coupled with a modest increase in herbage harvested resulted in increased overall herbage consumption by 0.57–0.66 t DM ha^{-1} yr^{-1}. This practice also saved 0.33 t DM ha^{-1} yr^{-1} herbage for the on-farm lambs on Farm B. A large portion of the herbage was consumed by the animals intended for sale, that is, cattle on Farm A and sheep on Farm B (Table 3.4, Section 3.3.4). The variation in feed demand among the case farms decreased from around 1.70 t DM ha^{-1} yr^{-1} in 1980–81 to around 0.99 t DM ha^{-1} yr^{-1} in 2010–11. Herbage harvested per kg fertiliser application was also lower in 2010–11 for an average farm and for Farms A and C but was maintained on Farm B (Table 3.3).

Table 3.3 Change in herbage supply and feed demand on case farms and on average for North Island hill country farms in New Zealand between 1980–81/1985–86 and 2010–11.

	Farm A		Farm B			Farm C		NZ average	
	1985–86	2010–11	1980–81	2010–11	2011–12[A]	1980–81	2010–11	1980–81	2010–11
Herbage supply[B]									
Total, t DM $ha^{-1}yr^{-1}$	8.87	7.79	7.27	7.41	8.44	8.61	6.34	9.64	8.70
kg DM ha^{-1}/kg fertiliser ha^{-1}	43.7	21.2	29.1	30.1	33.1	29.5	23.6	46.2	46.0
Feed demand									
Total, t DM $ha^{-1}yr^{-1}$	7.94	7.04	6.01	6.25	6.34	8.21	5.64[C]	7.43	5.76[C]
kg DM ha^{-1}/kg fertiliser ha^{-1}	39.1	19.2	24.0	25.4	24.9	28.1	21.0	35.6	30.4
Off farm, t DM $ha^{-1}yr^{-1}$	0	0	0	0.33	0.33	0	0	ND	ND
Estimate of utilisation (%)	89	90	83	84	75	95	89	77	66

NZ average = national average for North Island hill country farm in New Zealand calculated in this study. Fertiliser refers to N+P+S+K as actual quantity. ND = not determined. [A] Results for Farm B in 2011–12 as an additional comparison. [B] Herbage production based on GROW model. [C] Including feed demand of grazing-in dairy cattle.

The modelled annual pasture productivity was 12% lower in 2010/2011 than that in 1980–81 or 1985–86. The GROW model indicated that herbage supply on Farms A and C was expected to be lower in 2010 than in 1980 based on local weather records, while supply was expected to be slightly increased on Farm B (Table 3.3, Figure 3.2). The trends in herbage production on the average farm were similar to those of Farms A and C (Table 3.3, Figure 3.2). Farm C reported that herbage supply in 2010–11 based on regular pasture herbage mass scoring and calculation of increments in ungrazed paddocks was 5.41 t DM ha^{-1} yr^{-1}, slightly lower than the 6.34 t DM ha^{-1} yr^{-1} projected by the GROW model. The variation in herbage supply among the case farms decreased from around 1.21 t DM ha^{-1} yr^{-1} in 1980–81 to around 1.06 t DM ha^{-1} yr^{-1} in 2010–11. Herbage supply per fertiliser application was also lower in 2010–11 or 2011–12 (additional data for Farm B) for average farm and Farm A, B and C (Table. 3.3).

When herbage supply from the GROW model and feed demand from feed demand modelling was compared, the estimates of annual feed non-utilisation (supply minus demand) on Farms A, B, and C were 0.93, 1.26, and 0.40 t DM ha^{-1} yr^{-1}, respectively, in 1980–81/1985–86, and 0.75, 1.16, and 0.70 t DM ha^{-1} yr^{-1}, respectively, in 2010–11. The annual feed non-utilisation on the average farm was 2.21 t DM ha^{-1} yr^{-1} in 1980–81/1985–86 and 2.94 t DM ha^{-1} yr^{-1} in 2010–11. The estimate of herbage utilisation for average farm was 77% in 1980–81 and 66% in 2010–11 (Table 3.3). The corresponding values for the case-study farms were 95% and 90%, respectively. The variation in annual feed non-utilisation among the case farms decreased from around 0.61 t DM ha^{-1} yr^{-1} in 1980–81 to around 0.36 t DM ha^{-1} yr^{-1} in 2010–11.

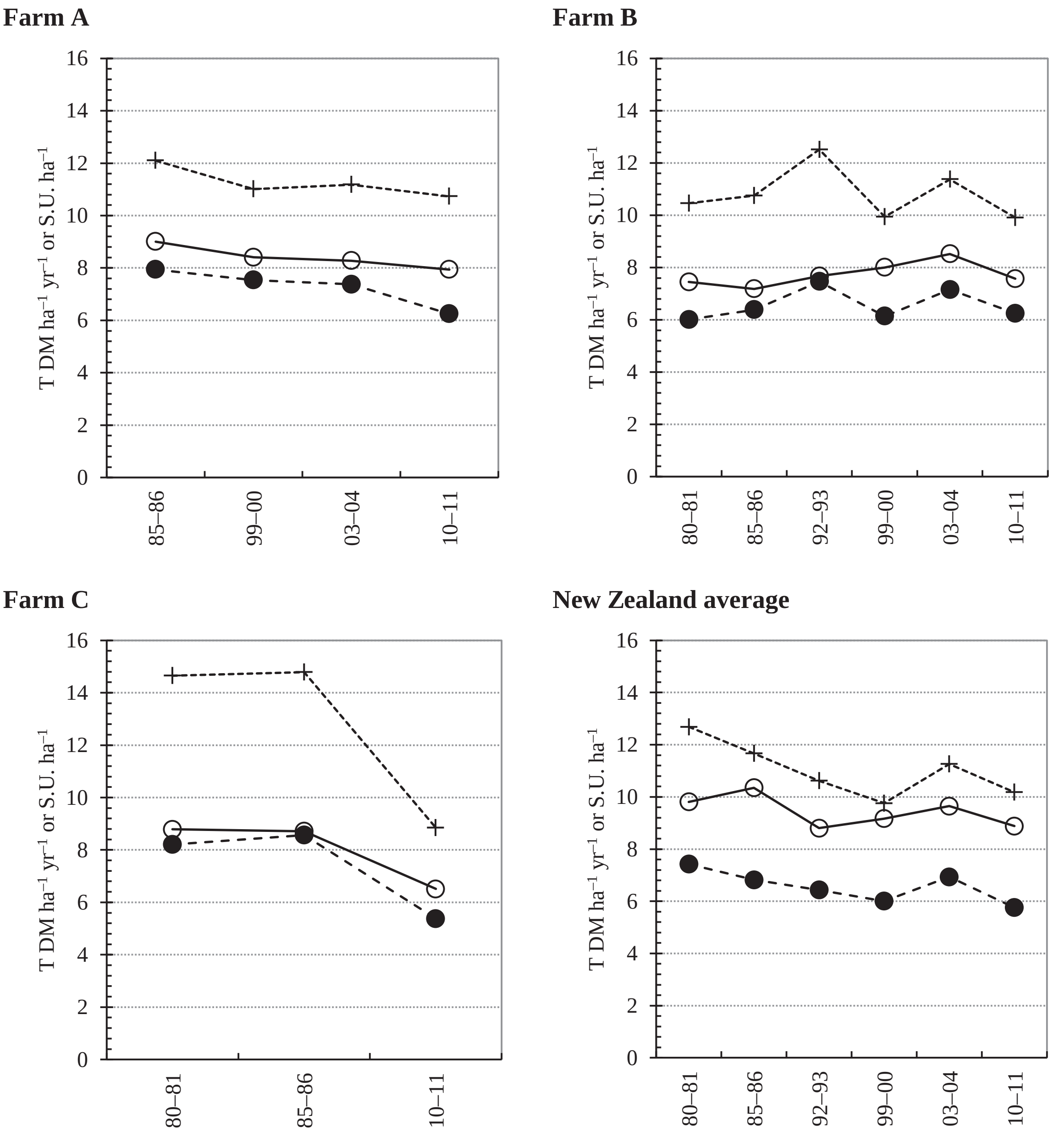


Figure 3.2 **Annual herbage supply determined using GROW (○), feed demand determined by MEB (●), and animal stock units (SU) per hectare (+) on case farms and averages for North Island hill country sheep and beef cattle farms in New Zealand from 1980–81/1985–86 to 2010–11.**

In addition to the annual totals discussed above, the modelling is able to provide insight into seasonal demand and supply in the farming systems studied. Although not a focus of this study, it is of interest to compare the GROW prediction for years with contrasting growth pattern, and the monthly feed demand and supply balance of a particular growth pattern when coupled with the system configuration in a given year. In a drier summer (2010–11) feed supply is greatly reduced in contrast to a wet summer (1980–81) (Appendix 3.4). The impact of the drought-reduced summer feed supply in a system with increased lamb production emphasis (2010–11) is a large negative late-spring/early-summer feed balance deficit, larger than the well-known winter feed deficit (July) (Appendix 3.5).

3.3.4 Feed conversion efficiency

All of the case farms showed improvements in feed conversion efficiency from 1980 to 2010 (i.e., less feed consumed to produce a kg of product) (Table 3.4). On Farm A, the changes were 27% less feed (kg DM) to produce a kg of sheep+cattle carcass, 37% less feed to produce a kg of sheep carcass, 13% less feed to produce a kg of cattle carcass, and 36% less feed to produce a kg of lamb weaned. On Farm B, the decreases were 2% to 7% less feed to produce a kg of sheep+cattle carcass, 11% to 15% less feed to produce a kg of sheep carcass, 33% more feed to produce a kg of cattle carcass (this was an exception), 22% to 33% less feed to produce a kg of lamb weaned and 3% to 8% less feed to produce a kg of calf weaned. On Farm C, the corresponding feed reductions per kg product (categories in the same order as for Farm B) were –55%, –54%, –33%, –22% and –16%, respectively; and on the average farm, the feed reductions per kg product were –28%, –28%, –23%, –24% and –21%, respectively.

Table 3.4 Changes in feed conversion efficiency on case farms and on average for North Island hill country sheep and beef cattle farms in New Zealand between 1980–81/1985–86 and 2010–11.

	Farm A		Farm B			Farm C		NZ average	
	1985–86	2010–11	1980–81	2010–11	2011–12[A]	1980–81	2010–11	1980–81	2010–11
Feed conversion per animal class									
*Sheep, kg DM ha^{-1}	3753	2250	4214	5091	5155	7284	4741	4983	3299
*Beef cattle, kg DM ha^{-1}	4184	4791	1794	1049	1194	908	888	2444	2430
Dairy cattle, kg DM ha^{-1}	0	0	0	0	0	0	15	0	36
Feed conversion per product									
kg DM kg sheep+cattle carcasses^{-1}	44	32	44	43	41	56	25	54	39
kg DM kg sheep carcass^{-1}	76	48	46	41	39	100	46	65	47
kg DM kg cattle carcass^{-1}	32	28	39	52	52	12	8	40	31
kg DM kg lamb^{-1} weaned	28	18	18	14	12	23	18	25	19
kg DM per lamb weaned	672	661	417	450	392	649	490	574	611
kg DM kg calf^{-1} weaned	NB	NB	38	37	35	19	16	28	22
kg DM per calf weaned	NB	NB	3305	3498	3333	2852	2653	4182	3239

NZ average = national average for North Island hill country farm in New Zealand calculated in this study. ND = Not determined because average run-off animal is not reported from the annual farm survey. NB = No breeding cattle. [A] Results for Farm B in 2011–12 as additional comparison. *Note: (i) that sheep and beef cattle on New Zealand farms are heavier in recent years, meaning meat production per kg DM ha^{-1} is also higher; (ii) that the feed demand per animal class such as lambs is specifically calculated for that class.

One factor in the higher feed conversion efficiency in recent years has been sale of offspring at higher weights, which is reflected in the statistics as more meat produced per lamb, steer, or bull on the case farms in 2010–11 than in 1980–81, except for slightly less meat per bull on Farm A (Table 3.5). On Farm B, sheep weight increased by 3% to 5%, lamb weight by 36%, and steer weight by 8% to 11% in recent years. The increase in lamb weight coupled with higher lambing percentage resulted in higher kg lamb weaned per ewe. Similar trends were observed for Farm A. More meat was produced per ha on all farms (kg sheep+cattle carcass ha^{-1}) in 2010 than in 1980. The increased meat production on Farms A and C was from increased beef production, while on Farm B the increase was from lamb production. Similar trends were observed on average farm for meat produced per lamb, steer, or bull and meat produced per hectare (kg sheep+cattle carcass ha^{-1}; Table 3.5).

Table 3.5 Changes in productivity on case farms and on average for North Island hill country sheep and beef cattle farms in New Zealand between 1980–81/1985–86 and 2010–11.

	Farm A		Farm B			Farm C		NZ average	
	1985–86	2010–11	1980–81	2010–11	2011–12[A]	1980–81	2010–11	1980–81	2010–11
kg sheep+cattle carcass ha^{-1}	181	219	137	148	154	146	222	137	147
kg sheep carcass ha^{-1}	49	47	91	128	131	73	104	76	70
kg cattle carcass ha^{-1}	132	172	46	20	23	74	188	61	77
kg lamb weaned per ewe	18	43	28	38	43	30	35	23	39
kg calf weaned per cow	0	0	140	159	169	140	171	125	137
Lamb carcass weight, kg	14.7	16.3	11	17	17	7.8	12.0	13.9[B]	18.2[C]
Steer carcass weight, kg	0	NA	277	308	308	188	240	277[D]	316[D]
Bull carcass weight, kg	262	260	296	329	329	NR	NR	252[D]	306[D]

NZ average = national average for North Island hill country farm in New Zealand calculated in this study. NA = Not applicable; Farm A did not rear steers in 1980–85. NR = No record. [A] Results for Farm B in 2011–12 as an additional comparison. [B] 1990 and [C] 2010: from Beef + Lamb New Zealand (www.beeflambnz.com). [D] From Morris (2013a, b). See Table 3.1 and 3.2 for lambing and calving percentages.

3.3.5 Comparison of feed demand estimates between model and Farmax®Lite

The Microsoft®Excel spreadsheet model and Farmax®Lite estimates for annual feed demand on case farm C were similar. The feed demand totals estimated by the Microsoft®Excel model for Farm C were 8.21 and 5.64 t DM ha^{-1} yr^{-1} in 1980–81 and 2010–11, respectively. The corresponding estimates by Farmax®Lite were 8.14 and 5.58 t DM ha^{-1} yr^{-1}. The difference between the Microsoft®Excel model and Farmax®Lite software amounted to just 0.21 kg DM ha^{-1} day^{-1} in 2010–11. Compared with Farmax®Lite, the model gave higher feed demand estimates for winter (0.51 kg DM ha^{-1} day^{-1}) and spring, (3.48 kg DM ha^{-1} day^{-1}) and lower estimates for summer (−1.11 kg DM ha^{-1} day^{-1}) and autumn (−2.04 kg DM ha^{-1} day^{-1}).

3.4 Discussion

3.4.1 Factors contributing to cumulative change in farm systems

A farm system has complex behaviour determined by the interactions among system factors such as the levels of inputs and outputs that mutually affect each other and affect animal performance. A particular set of system factors chosen by a farmer can be referred to as the farm systems configuration. The configuration of farm system on hill country sheep and beef cattle farms in New Zealand has evolved over time as a dynamic response to a range of factors. Historically, the balance in livestock numbers on New Zealand farms has reflected changing land use patterns and the relative returns from milk, sheep meat and wool, and beef cattle (Matthews et al., 2011). The economic realities of milk, sheep meat and wool, and beef cattle farming determine their prioritisation for production, which classes of animals are farmed, and the prioritisation of particular farm system configurations. Currently, lamb is the main product of sheep and beef cattle farms (Beef + Lamb New Zealand, 2013), with New Zealand being the largest lamb exporter in the world, producing 47% of the traded volume (Morris, 2009, 2013a) from approximately 10,000 farms. It follows that the current farm system configurations would include ewes in the stock classes on farm and be developed in a way that facilitates production of lambs.

The key factors contributing to cumulative change in farm systems recognised in the present study were improvement of reproductive performance, change in animal stock classes on farm to facilitate lifting of sale weight of animals sold for meat, or addition of weight to purchased stock for resale. An ingredient in achieving this greater weight gain in stock for sale was a decrease in stocking rate, although a general fall in pasture productivity related to climate change was also detected. However, the climate change effect was offset by an increase in fertiliser application. Another major change has been expansion of effective farm area, as discussed further below. It has to be noted that the percentage values of changes in Tables 3.1 and 3.2 for each of the statistics do not indicate which factor is more important, as contributions of some of the factors to farm performance are difficult to quantify and have complex causes such as farmer response to feed surplus or deficit, for example, changes in effective farm area and hay or silage area. The discussion that follows will focus on elucidating those trends in the data that represent the evolution of system configuration towards greater feed conversion efficiency.

The higher number of lambs produced per ewe mated and lamb weight weaned per ewe in 2010 compared to 1980 (Table 3.5) is because of improved genetic merit of ewes and ewe hogget mating. Increased fecundity has been an industry target extension in recent decades, because it was recognised as the single most attainable way of lifting productivity. The Farmer A has identified breeds that perform well on his property (Romney sheep and Friesian steers and bulls), and used those same breeds of sheep since 1985. Farmer B has used the same types of sheep (Romney) and cattle (Hereford or Angus) since 1980, but has exploited hybrid vigour in recent years through cross breeding to improve fertility of the sheep (Romney × Coopworth) and slaughter weight of the cattle (via crossing with a Charolais terminal sire). Mating of ewe hoggets has become a common practice in New Zealand since 1990 (MacKay et al., 2012) to increase the number of lambs for sale.

Associated with the higher number of offspring produced per ewe in recent years is a decrease in stocking rate (Tables 3.1 and 3.2). It is generally understood that this drop in stocking rate reflects the growing recognition of the higher feed demands of ewes carrying multiple lambs and the link between higher lambing percentages, lamb weaning weights and post weaning growth rates in lambs (and calves) and profitability, but declining pasture productivity indicated by GROW may also be a factor (see below) as farmers adjust stocking rate for the coming year, in part according to perception of feed surplus or deficit in the previous year. In the 1950s, most New Zealand farms had the capacity to increase output per ha through increased pasture utilisation (by increasing the stocking rate), albeit with a corresponding reduction in per animal performance statistics (McMeekan, 1958). By the 1980s, partly encouraged by government incentives in the 1970s aimed at increasing livestock numbers (Griffith and Grundy 1988), many farms were stocked to the point that the animal body maintenance component of the system became a limiting factor to animal production. Farming so many animals per unit area in the 1980s appears to have been an overcorrection of a lower-than-optimum stocking rate in earlier decades. From the end of the 1980s, New Zealand farmers, however, have recognised that fewer animals per area resulted in higher production per head. Therefore, the shift to per head performance in the sheep and beef sector, through improved genetics and better feeding of priority stock, have been the key factors driving the changes in the farm performance. The data indicated that for the average farm and both for Farms A and B stocking rate was reduced, and the effective farm area increased, while management of Farm C, with a different context for decision making, decreased the animal stocking rate markedly without changing the farm area. Other strategies to improve productivity were also employed. For example, over the study period Farm A implemented a winter rotation which controls animal intake and allows more animals to be wintered, so providing more lambs for sale, and moved from set stocking to seasonal switch between set stocking and rotational grazing to improve feed harvesting and manage winter or summer feed deficit (such as during the dry summer in 2010–11). A second example is the policy adopted on Farm B of "grazing replacement stock off farm in late spring/early summer" in recent years, a policy which the modelling shows to be an intelligent reaction to changing seasonality of feed deficits when the effects on feed demand and supply of increased lambing percentage and drier summer conditions are superimposed. Previously, grazing stock off farm has been a farming practice mainly seen on dairy farms. Farmer B has practiced the policy for the last several years and financially benefited from it, which means the costs incurred implementing the policy are less than the production loss that would be incurred if the early summer feed deficit were met by reducing breeding ewe numbers is secondary issue.

The stocking rate of cattle on sheep farms increased from 1983 to 2000, but has remained static over the past decade (Table 3.1; Morris, 2013a,b). The number fluctuates depending on the number of calves that are transferred from dairy farms and reared for beef production and the number of cattle sold for slaughter (Morris and Smeaton, 2009; Morris, 2013a,b). The contribution of beef cattle to the cumulative change on sheep and beef cattle farms can be summarised as follows. The cattle are important for controlling pasture quality and generating additional revenue for sheep farms, as there are no capital overheads tied up in a beef-breeding herd, although the business is less profitable if the farms use only high-quality herbage (Morris and Smeaton, 2009). Where cattle are purchased as weaners rather than bred as calves as in traditional practice, the associated elimination of the mother's body maintenance also increases overall meat output per unit of feed consumed.

The use of fertiliser in New Zealand has increased over the past decades (Tables 3.1 and 3.2). Since in the 1950s, New Zealand farmers have recognised the important impact of fertiliser on productivity of herbage (Matthews et al., 2011). Both Suckling (1959) and Lambert et al. (1983) reported that unfertilised pastures in the lower North Island produced around 6 t DM ha^{-1} yr^{-1}, while addition of 30 kg P yr^{-1} as superphosphate fertiliser increased the yield to 9–10 t DM ha^{-1} yr^{-1} within a few years. This type of fertiliser application is an inexpensive way to generate additional feed, if turned into additional product. Phosphorous application encourages legumes in the sward, which in turn supply additional N to the system. In recent years, N application (national average 10 kg N ha^{-1}) has become more common on sheep and beef cattle farms (Parfit et al., 2012), although at the national level, little is known about the quantity of pasture generated from the extra application of N. The application of N also tends to be strategically timed to ease seasonal feed deficits, especially late winter and early spring.

The average farm size in New Zealand has also increased (Tables 3.1 and 3.2), and the number of farms and farmers has decreased since the 1950s (Matthews et al., 2011). This trend largely reflects economic trends in farmer terms of trade and concerns to control production costs that are beyond the scope of this study. Whether trends of increasing farm size contribute to improved farm performance has not been studied, and would be difficult to quantify if a study were undertaken. The data, however, indicated that Farm A and B, which were considered efficient in the 1980s and had an above average profit both purchased more land in the late 1990s, in keeping with the trend in average farm data. New Zealand land-use patterns have also changed over time especially after the deregulation of agriculture and removal of incentive payments to farmers in 1984. Some farmers sold their farms, shifted to dairy, horticulture, viticulture, or forestry businesses, or used a portion of their farms for those enterprises (Matthews et al., 2011; Smith and Montgomery, 2004; Forney and Stock, 2013). Some farmers allocated more area to conservation (Smith et al., 2007), or expanded their farms to include larger non-farmable areas.

Where available, supplementary feeds are used to overcome winter and summer drought herbage deficits (Morris, 2007). The reported areas of hay and silage at national level (Table 3.1) are small compared to the total farm area in these farming systems. In fact, Farms A and B did not use hay or silage and Farm C reduced the hay or silage area from 1980 to 2010.

3.4.2 Feed supply factors

There has been little or no discussion in the literature about the trend to reduced stocking rates on New Zealand farms over recent decades and as noted above anecdotal assumption has been that this is part of the focus on improving animal weight gains in growing animals, and measures to enhance feed supply such as rotational grazing to restrict animal intake seasonally when pasture growth is low, higher fertiliser inputs, and other measures (e.g., use of pasture growth stimulants like gibberellic acid in recent years), and grazing animals off farm, also facilitate improvement of animal performance.

However, this study has uncovered another dimension to the time trend in feed supply, namely reducing pasture productivity (Table 3.3, Figure 3.2) attributable to climate change. Hence any factor enhancing feed supply will mitigate declining productivity and result in a better match of the supply and demand curves, which is important to the performance of the sheep and beef cattle farms in New Zealand over the past 25–30 years. Consistent with this result, Matthew et al. (2010) modelling New Zealand dairy farm system evolution from the 1980s to 2007 noted that pasture productivity had not changed substantively in that period despite use of 150 kg ha^{-1} yr^{-1} N fertiliser (which should have increased productivity by 1.5 t DM ha^{-1} yr^{-1}) becoming standard practice. However, those authors did not consider climate change as a possible explanation for the lower than expected herbage productivity in recent years. It was also found that the results of herbage supply estimates using the Microsoft®Excel and GROW models in the present study align with the long-term climate-based pasture growth index trend reported by NIWA (NZXAGRI, 2012). The index indicated that pasture growth on New Zealand farms had decreased by a factor of 0.05 from 1980 to 2010 (Appendix 3.6). In other words, the conclusion from both the farm system models (Microsoft®Excel and Farmax®Lite) and the pasture growth model (GROW) that pasture growth has declined over the study period is supported by independent NIWA assessment. The NIWA assessment also indicated that the decline was associated with warmer climate in recent years tending to exacerbate summer soil moisture deficit conditions.

This finding of a negative effect of climate change on annual herbage production in New Zealand needs to be studied further. Checking that the apparent climate change effect is not an artefact of model inputs and assumptions (mentioned in Appendix 3.1) would be prudent. Then, even if confirmed, the effect may also be geographically variable throughout the country. For example, the estimates of herbage supply on Farm B did not indicate a marked decrease in annual production over the period studied. From a seasonal perspective of herbage production, however, there were marked feed deficits on all of the case farms during summer, even on Farm B, and these summer deficits were larger in 2010 than in 1980 (Section 3.3.3; Appendix 3.5).

3.4.3 Effects on feed conversion efficiency

An insight to emerge from this study is that the FCE of the sheep and beef cattle farm systems would not have been improved to the extent that they have without, for example, contribution from the increased reproductive performance of the ewe, higher lamb weaning weights and earlier slaughter dates for lambs and cattle (which can be achieved through, e.g., change in stocking rate, grazing animals off farm, and rotational grazing to restrict animal intake seasonally when pasture growth is low), and higher fertiliser inputs. The farm system configuration has evolved from the 1980s to the present time to put a greater emphasis on conversion efficiency especially focusing on more of the feed generated being consumed by animals that are gaining weight to be sold and not by breeding stock that are retained. Farmers on Farm A and Farm B were early adopters, as indicated by their having achieved certain gains before those same gains were seen in average farm statistics. The evolution in farm system configuration during that period has improved the feed conversion efficiency by around 20%–30% on New Zealand North Island hill country farms based on the analysis in the present study (Table 3.4). While the primary drivers of the focus on efficiency gain have been economic, a perspective that emerges from this study is that efficiency gain has also allowed sheep and beef cattle farmers to mitigate the adverse effect of the decreasing herbage production on New Zealand farms. The findings of improved feed conversion efficiency in this study are also supported by comparison with other previous studies:

i. New Zealand sheep and beef cattle farm systems were reported to use 29–38 kg DM feed per kg carcass, with the once-bred heifer/cow system less-used and the traditional/conventional system more-used (Morris et al., 1994). The case farms in this study had a conversion ratio of more than 38 kg DM feed per kg carcass in 1980–81. However, in 2010–11, much less feed per kg carcass was used on Farms A and C (25–32 kg DM feed per kg carcass), and only slightly more feed per kg carcass on Farm B (Table 3.4). In the case of Farm B, the expansion of area in the late 1990s was onto land of steeper average slope and therefore has lower productivity than the original farm, so that to maintain performance statistics could actually be seen as an improvement.

ii. Brookes et al. (1998) reported that Romney sheep (the type farmed on Farms A–C), required 27.1 kg feed per kg lamb weaned. The case farms used less or only slightly more (Farm A in 1985–86) than this amount per kg lamb weaned in 1980–81 and used much less than this in 2010–11. Brookes et al. (1998) also reported that Texel × Dorset, East Friesian, and East Friesian-sired ewes mated as hoggets require 25.3, 20.2 and 17.8 kg feed per kg lamb weaned, respectively. In 2010–11, the case farms used close to 17.8 kg DM feed or slightly less per kg lamb weaned.

Several factors, however, should be considered in interpreting the results of the feed conversion efficiency analysis in this study, since efficiency calculations can give different indications depending on how they are formulated or specific farm details. Firstly, where a farm is destocked in a particular year and the efficiency expressed as kg DM consumed per kg meat sold off farm, the conversion ratio will be smaller, falsely indicating greater efficiency. This was a factor for Farm C in the 2010–11 statistics as the farm had been destocked in that year because of drought. Secondly, factors such as lambing % are very important to a farm financial performance, but could be strongly influenced by factors such as breed change, independently of feed demand and supply considerations evaluated in this chapter. Similarly, where the production goals focused on a different product such as wool rather than meat production, which was the basis for the efficiency calculations above, then different statistics would be compiled. Thirdly, practices such as hogget mating, when introduced will likely decrease lambs born:sheep mated, while increasing the number of lambs born. Hence, in interpreting the conversion efficiency statistics in this chapter care has been taken to understand wider factors influencing them.

3.4.4 Feed demand model performance

Matthew et al. (2010) reported that estimates of herbage demand and supply by modelling technique similar to that used here were within 5% of those obtained using other models. In this study, the annual herbage demand and supply estimates produced using the model and Farmax®Lite showed <5% difference. The small differences in annual feed demand estimates between the model and Farmax®Lite were attributable to the decision in this study to use a higher metabolic coefficient for energy of gain in adult steers and bulls and the assumption that the herbage quality was lower for finishing cattle than for sheep. Both decisions increased cattle feed demand, which matched with anecdotal farmers' reports that adult steers and bulls required more feed than model predictions indicated. Another reason is that the effect of shearing on feed demand was not considered in the model, following the suggestion by Nicol and Brookes (2007). Omitting the shearing effect could be one reason why the model slightly over- or underestimated the seasonal feed demand compared with that estimated by Farmax®Lite. Overall, the trends and variations in feed demand estimates of the model have resulted from the biological differences among farms, rather than from the equations used in the model (as the same equations were used). The differences among farms in terms of the data inputs in the model are the number of animals farmed and ME content of herbage. The differences among production cycles in terms of data inputs are the number of animals farmed, the ME content of herbage, and animal liveweight. These biological variations are expected on any farm in New Zealand.

3.4.5 Potential for farming technology transfer and future study

As discussed earlier, the outcomes of the feed demand modelling created in this study were in line with the results of the GROW model, NIWA research (NZXAGRI, 2012), and Farmax®Lite (<5% difference). This gives confidence that the model can be used on a trial basis to capture a quantitative description of farming system (after the relevant coefficients are modified) in a tropical climate, e.g., Sabah. An advantage of using the model is it eliminates the need for herbage intake measurements, which are difficult to carry out to obtain seasonal herbage demand and supply. The data analysis method is highly repeatable, and the model offers flexibility for modification to suit with the available data and farming condition on a farm. Example of the spreadsheets used in this study is copied into a CD and enclosed (Appendix 3.7). Chapters 4, 5 and 6 below report use of the model to analyse three different categories of cattle farming system in Sabah.

3.5 Conclusions

The modelling indicated that the average herbage harvested in North Island hill country sheep and beef cattle farming systems in New Zealand between 1980 and 2011 has decreased (7.43 to 5.76 t DM ha^{-1} yr^{-1}). One of the reasons is that herbage supply in these systems (as indicated by the GROW model) has decreased (9.64 to 8.70 t DM ha^{-1} yr^{-1}); this trend is also consistent with a decrease in the national herbage growth index in New Zealand during the same period, reported by NIWA. The reduced herbage production on the case farms may be attributable to a trend towards warmer and drier summers, as the feed deficit during summer months on the farms had increased (–5.3 to –17 kg DM ha^{-1} day^{-1}).

The modelling also indicated that over the same period, farmers have improved feed conversion efficiency in addition to achieving economic gains. This has maybe unwittingly mitigated the adverse effects of changing climate on herbage production. The feed conversion efficiency (in kg feed per kg lamb weaned) improved from 25 to 19 on average (or from 18 to 14 or 12 kg DM per kg meat produced on Farm B) from 1980 to 2010. A similar trend in feed conversion efficiency was observed for cattle (in kg feed per kg calf weaned; from 28 to 22 on average, and 19 to 16 on Farm C from 1980 to 2010). The increase in meat production from 1980 to 2010 was 137 to 147 kg sheep+beef carcass ha^{-1} yr^{-1} (or 146 to 222 on Farm C).

The most important changes in configuration of the systems (based on average farm) during 1980–2011 are the increased reproductive performance of sheep (from an average of <105% in 1980s, with exception of >120% on Farm B, to >120% lambing percentage at the present time) and the change in production strategy of the systems from more animals per unit area to higher productivity per animal. (In particular, more feed was consumed by animals for sale.). On average, animal stock units per ha decreased from 11.3 to 9.1 from 1980 to 2011, but feed conversion efficiency (in kg DM per kg sheep+cattle carcass) improved from 54 to 39 during the same period, while fertiliser application slightly increased (172.9 kg ha^{-1} to 189.2 kg ha^{-1}). Other changes included increase in effective farm area (361 ha to 436 ha), and carcass weight (13.9 to 18.2 kg hd^{-1} for lambs, 277 to 316 kg hd^{-1} for steers, and 252 to 306 kg hd^{-1} bulls. Also, dairy heifer farming (as a source of young animals to eliminate body maintenance cost of the mother when rearing a calf) and hogget grazing-off (as a tactical feed import to support greater weight gain and conversion efficiency in young frowning animals) became part of the farming practice.

This study demonstrates that MEB is effective as a tool to capture the cumulative impacts of changes in farm configuration on productivity of the New Zealand systems. MEB has allowed evaluation of farm factors contributing most to improved systems performance. This has provided the author the analytical tools and expertise to carry out a similar study to capture the feed supply and demand status of beef production systems in Sabah to facilitate farming technology transfer from advanced temperate pastoral systems to less advanced tropical pastoral systems without direct transfer of the advanced system as such. The farm information used in the present study provides the basis for information to be collected in Sabah to carry out an analysis similar to that reported in this study.

Chapter 4

Feed Profile Analysis of Cut-and-Carry Feedlot Cattle Farming Systems by Metabolic Energy Budgeting and Implications for Beef Production and Future System Design in Sabah

Abstract. A metabolic energy budgeting (MEB) model was used to estimate the feed demand of cut-and-carry feedlot cattle farming system at SPT Tawau, Sabah, to understand and investigate options to improve the system. The data used comprised 5,981 monthly live weight records for 485 Brahman, Bali and Droughtmaster cattle, and key farm information kept by the case farm for operation from January 2008 to December 2013. The analysis also included determination of system feed conversion efficiency (FCE) and its correlation with inputs like rainfall and N application. For further insight, measurements were also carried out on nutritive value of herbage being consumed, pre-cut-and-carry herbage mass (separated in time to estimate herbage accumulation), and actual feed intake of cattle in pen condition (through a limited feeding experiment). The difference in energy intake of cattle estimated by the MEB model and feeding experiment (4%) is within of the acceptable range for metabolic energy modelling, signifying that the model used was adequate to capture the system. The MEB indicated that (i) operational herbage supply in the system (6.22 t DM ha^{-1} yr^{-1} relative to the 22.26 ha cut-and-carry paddocks) is lower than potential local herbage DM production estimated by cutting (21.3 t DM ha^{-1} yr^{-1}), which could have been due to soil acidity, low soil fertility as a result of low nutrient inputs, invasion of non-sown herbage, poor nutritive value of herbage and at times a 'substitution effect' of feed concentrate, weaning weight loss effects, and perhaps feed wastage; (ii) feed concentrate use as herbage equivalent is not high (1.80 t DM ha^{-1} yr^{-1}); (iii) there is a feed cost related to liveweight loss (0.58 t DM ha^{-1} yr^{-1} as herbage equivalent) especially during weaning; and (iv) the best FCE was 20.4 kg DM kg LWG^{-1} in year 2010; and FCE was affected by N application to the cut-and-carry paddocks and rainfall on the farm. Based on this study, the recommended first step to evolve the system is to optimise it based on existing efficient farm configurations (e.g., 994 kg animal LWT ha^{-1}); the second is improvement of pasture husbandry to improve herbage ME (e.g., >9.5 MJ ME kg DM^{-1}) and CP (e.g., >13%) and revision of feed concentrate use either to eliminate it or to use it tactically to prevent marked animal liveweight loss and to stimulate compensatory growth; and the third is to increase herbage production to achieve higher yield, closer to the local potential (e.g., 14–26 t DM ha^{-1} yr^{-1}).

4.1 Introduction

The number and size of beef cattle farms in Sabah is largely unknown. Anecdotally, there are believed to be 1800 beef cattle farmers contributing to the local beef production, with a variety of farming systems including cut-and-carry feedlot system (13 of the 14 dairy cattle farms and involving 2321 ha), grazing system (government-initiated community farms and government demonstration farms to promote beef industry development and improve the financial situation of rural landholders), traditional system (with village herds typically around 5–10 animals in number) and oil palm integrated cattle farming system.

The beef production systems in Sabah can be described as having low productivity. As noted in Chapter 2 (Section 2.1.2), the local beef production is approximately 537 t per year against a demand of approximately 10,314 t per year (DVSAI, 2014). One suggestion to ease the problem is to use intensive farming systems, such as the feedlot system (Chew and Ibrahim, 1992; DVSAI, 2008). In Sabah, this system has been practiced as cut-and-carry feedlot system, where the cattle are fed with freshly cut improved herbage and with feed concentrate daily. This system has been used alongside grazing system on government demonstration farms or some community farms under government initiatives and (as stated above) on dairy farms to produce beef as a secondary product to increase profit. To date this intensive farming approach has not been effective in increasing the local beef production. One of the problems is a lack of information about the operation of the system, especially feed demand and supply, on which an analysis can be carried out to identify the possible improvement of the system. One factor contributing to this problem is a lack of analytical tools to capture the system details.

A suggestion to fill the gap of knowledge and analytical tools is to search for farming technology insights and methods from a successful pastoral system. As noted in Chapter 2 and 3 (Sections 2.3 and 3.1), attempts at development of farming systems that focus on ‘transplanting in’ foreign technology, as such, often do not work well (Preston and Leng, 1987). Therefore, an approach explored in Sabah to examine the steps to improve the pasture-based beef production systems is the application of methodologies developed in New Zealand over recent decades as described in Chapter 3.

To explore how system evolution methodologies used in New Zealand might be applied to pastoral systems in Sabah, a project was carried out to analyse the feed demand and supply of the current beef cattle production systems on a leading government demonstration farm, such as, the cut-and-carry feedlot cattle farming system described below (and the grazing and oil palm integrated cattle farming systems in the next two chapters). A key part of this analysis was to capture the feed profile of the production systems with a spreadsheet tool developed in the New Zealand phase of the project (Chapter 3) that emulated tools like Stockpol (Marshall et al., 1991; McCall and Tither, 1993) and its successor Farmax (Bryant et al., 2010; Farmax, 2013; Tayler et al., 2016). The analysis is based on MEB that allows determination of feed demand, but also uses summary statistics like feed conversion efficiency (FCE) and its correlation with rainfall and N application, to assess which system configurations provide the best outcomes. For further insight of the MEB results, some nutritive value analyses of herbage being consumed, and some pre-harvesting (pre-cut and carry) herbage mass measurements (separated in time to estimate herbage accumulation) were also carried out on the government demonstration farm studied.

4.2 Materials and methods

4.2.1 Case farm: SPT Tawau

The case farm was identified following contact and discussion with the Department of Veterinary Services and Animal Industry (DVSAI) and smallholder beef cattle farmers in Sabah. Except for the government beef cattle farms, many of the farms in Sabah were found to have limited animal data. Of the government farms, the Stesen Pembiakan Ternakan Batu 16 Tawau (SPT Tawau), Sabah was suggested to be the focus. The farm is situated in the southeastern part of Sabah, in the coastal area of the Tawau District (Lat. 4.2892; Long. 118.0347). This farm has been operating since the 1970s. The farm operates two production systems, cut-and-carry feedlot cattle farming system and grazing cattle farming system (the evaluation of the grazing system will be presented in Chapter 5).

The average annual rainfall on the farm from 2008 to 2013 was 1837±200 mm. The average monthly rainfall is 154 mm, and generally, there is no marked seasonality of rainfall, except August is wetter and February is on average drier than other months (Figure 4.1). Over 2008 to 2013, lower than average rainfall (i.e. <154 mm) was more likely to occur in January, February, July and October (71%–86% probability). The temperature in the area was almost constant throughout the year at 28.0±2.6ºC.

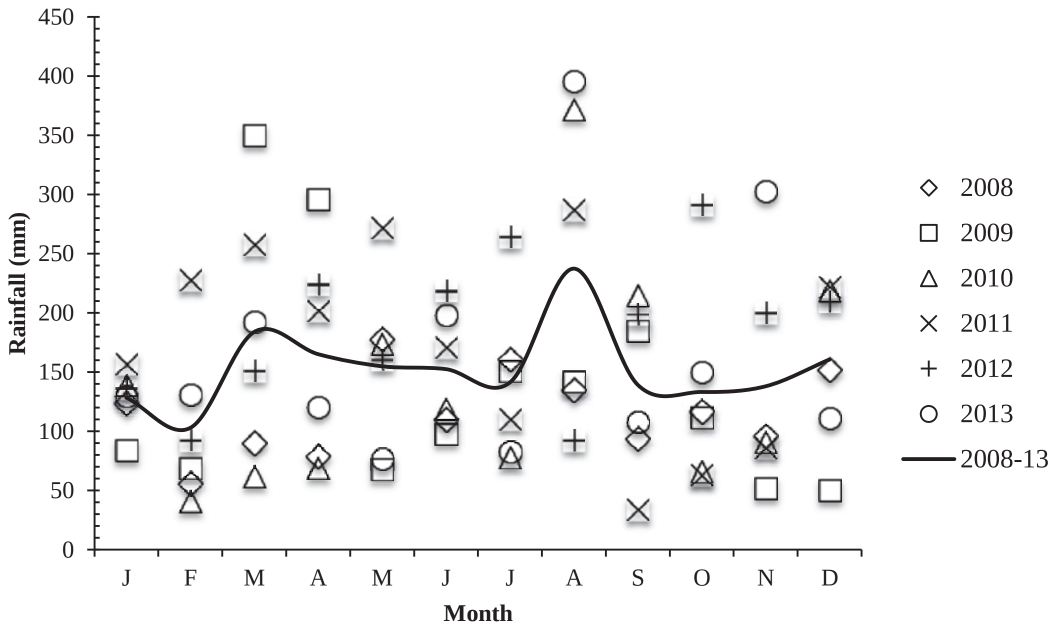


Figure 4.1 Monthly rainfall at SPT Tawau (2008–13).

4.2.1.1 Farm details for cut-and-carry feedlot systems at SPT Tawau

The farm has four feedlots, located adjacent to each other. All are roofed and have a concrete floor and iron-rail fences. The management of the feedlots has changed over time. Generally, from January 2008 to December 2013, three of the feedlots were used to raise entire male Brahman, Bali, and Droughtmaster beef cattle, and one was used to raise a small number of entire male dairy crossbred cattle (Friesian × Sahiwal). A few Bali crossbred (× Brahman sire) were farmed together with the Bali. The dairy and the Droughtmaster cattle, however, were phased out gradually. Hence, towards the end of 2009, all the dairy cattle were transferred out or sold. Only 7 Droughtmaster cattle were farmed in 2012, and only 3 in 2013. By the end of 2013, only two feedlots were active, the Brahman and Bali. Half of one of the feedlots was divided into a few small pens and used during the non-mating season to rear the breeding bulls (used by the farm for the grazing cattle farming system).

The calves for the feedlots were obtained from the grazing system operated by the farm adjacent to the feedlots. The calves were transferred in at weaning (by abrupt separation) as 7.5±0.8 mo old animals and 179±30 kg LWT Brahman, 10.0±1.3 mo old and 163±13 kg LWT Bali, and 9.8±1.0 mo old and 167±13 kg LWT Droughtmaster calves. The Brahman calves were raised until >250 kg LWT and after that returned to the grazing system. The Bali and Droughtmaster calves were raised to >290 kg LWT and >380 kg LWT on average, respectively, before being sold or distributed to farmers. All animals were treated for ecto- and endo-parasites as required on a case-by-case basis.

Similar types of herbage and feed concentrate were used as feeds for the cattle. The main herbage was *B. decumbens*. Occasionally, *S. sphacelata* 'Kazungula', planted on the paddocks used for the grazing system adjacent to the feedlots was used. The *B. decumbens* was planted on six cut-and-carry paddocks of 22.26 ha in total area. The herbage was harvested daily in the morning and fed *ad libitum* to the cattle in the afternoon (2–3 p.m.). The feed concentrate was fed to the cattle at 2–3 kg hd^{-1} d^{-1} in the morning (9–10 a.m.). The characteristics of the soil samples collected from the paddocks in August–September 2014 were: pH 5.2±0.3; Total N, 0.2±0.0%; available P, 4.7±0.7 ppm; K, 0.2±0.0 meq%; Ca, 11.8±4.1 meq%; and Mg, 5.7±0.8 meq%.

The financial information (average 2009–2013) obtained from the farm summarised key operational costs as follows: RM61 ha^{-1} yr^{-1} for herbicide, RM19 ha^{-1} yr^{-1} for all fertiliser, RM0.61 kg N^{-1} for N application, RM46 ha^{-1} yr^{-1} for all supplement (RM0.50 per kg supplement), RM30 ha^{-1} yr^{-1} for PKC (RM0.52 kg PKC^{-1}), RM7 ha^{-1} yr^{-1} for salt lick, and RM961 ha^{-1} yr^{-1} total costs. There are no separate expenses reported for the feedlot and grazing systems in SPT Tawau. Those costs are for the whole farm (355 ha). Hence, in reporting the operating cost of the feedlot system, there is a need to assume, first, that the above costs per ha per year are also applicable to the system and second, that the fertiliser cost is for N fertiliser (considering that most of the fertiliser used on the farm is urea).

4.2.2. Data collection

4.2.2.1 Animal data collected for MEB

The animal data used for this study were collected in July to October 2014 for farm operations from January 2008 to December 2013. The data were obtained from the record cards kept by the farm for each animal in the feedlots. Information on the card was sire and dam, date of birth, weaning, transfer-in, selling, transfer-out, and death (for cattle that had died); liveweight (LWT) records at birth, weaning, and during pre-weaning and post-weaning periods; and records of health treatment. The LWT was obtained using a digital scale (TRU–TEST™ HD800) and recorded once a month, but sometimes only once in two or three months. The key information of the feedlots is presented in Table 4.1.

Table 4.1 Key farm statistical information for cut-and-carry Brahman, Bali and Droughtmaster feedlots at SPT Tawau (2008–2013): (a) Annual and (b) Monthly.

(a)	2008	2009	2010	2011	2012	2013	Average	±SD	CV %
Rainfall on the farm (mm yr^{-1})	1392	1657	1645	2090	2238	1999	1836.8	321.9	17
N fertiliser (kg ha^{-1} yr^{-1})	NR	128	77	71	135	48	92	38	42
Animal LWT (kg LWT ha^{-1})	767	1075	994	1044	1044	988	1001	112	11
Brahman (hd)	29	35	36	43	58	57	43	12	28
Age (mo hd^{-1})	23.5	22.9	20.9	21.6	22.2	25.7	22.8	1.7	7
LWT (kg hd^{-1})	245.5	290.8	282.3	274.3	268.7	269.3	271.8	15.4	6
LWG (kg hd^{-1} yr^{-1})	84.8	135.2	107.5	69.9	87.5	56.6	90.3	27.9	31
LWL (kg hd^{-1} yr^{-1})	–12.0	–21.2	–18.4	–21.6	–14.5	–25.2	–18.8	4.9	26
Bali (hd)	23	31	25	22	24	22	25	3	13
Age (mo hd^{-1})	32.4	31.6	32.7	34.2	32.4	35.7	33.17	1.5	5
LWT (kg hd^{-1})	225.2	226.1	244.5	252.4	233.4	257.5	239.8	13.7	6
LWG (kg hd^{-1} yr^{-1})	56.2	67.6	84.4	85.6	120.3	88.3	83.7	21.8	26
LWL (kg hd^{-1} yr^{-1})	–21.9	–14.3	–26.8	–48.1	–56.7	–15.2	–30.5	17.8	58
Droughtmaster (hd)	21	26	20	18	7	3	16	9	56
Age (mo hd^{-1})	29.1	29.6	28.4	27.9	21.6	18.4	25.8	4.6	18
LWT (kg hd^{-1})	227.2	259.2	293.0	327.6	292.4	326.2	287.6	39.0	14
LWG (kg hd^{-1} yr^{-1})	82.5	109.7	180.9	140.7	247.5	203.7	160.8	61.5	38
LWL (kg hd^{-1} yr^{-1})	–14.7	–15.1	–66.9	–14.7	–37.1	0.00	–24.8	23.8	96

(b)	J	F	M	A	M	J	J	A	S	O	N	D	Average	±SD	CV %
Rainfall on the farm (mm mo^{-1})	128.3	102.9	183.9	165.1	154.9	152.4	141.2	237.3	139.1	133.2	137.9	160.6	153.1	33.5	22
N fertiliser (kg ha^{-1} mo^{-1})	13	3	14	5	0	18	6	3	2	17	9	2	8	6	82
N fertiliser (kg ha^{-1} $mo^{-1})^{2010}$	0	0	38	5	0	0	0	15	10	0	0	8	6	11	174
Animal LWT (kg LWT ha^{-1})	939	915	964	977	956	1003	993	996	1073	1093	1061	991	1001	54	5
Brahman (hd)	44	43	43	42	39	40	44	42	44	44	46	46	43	2	5
Age (mo hd^{-1})	21.3	21.6	22.2	22.7	23.4	23.8	22.0	23.1	23.5	24.0	23.6	22.4	22.8	0.9	4
LWT (kg hd^{-1})	259.0	261.2	264.1	267.5	271.2	278.3	268.6	276.4	278.9	283.0	283.6	270.2	271.8	8.2	3
LWG (kg hd^{-1} mo^{-1})	7.04	7.35	7.39	7.12	7.18	6.80	7.92	7.99	7.87	8.25	6.73	8.63	7.52	0.60	8
LWL (kg hd^{-1} mo^{-1})	–2.21	–2.28	–1.94	–1.38	–1.46	–1.58	–1.13	–0.99	–1.22	–1.11	–1.66	–1.85	–1.57	0.43	27
Bali (hd)	24	23	25	25	25	25	24	24	26	26	24	25	25	1	3
Age (mo hd^{-1})	31.5	32.1	31.7	32.5	32.9	33.6	34.2	35.1	34.1	34.6	33.3	32.6	33.2	1.2	3
LWT (kg hd^{-1})	233.5	235.7	234.8	236.7	236.9	238.6	239.0	245.1	245.4	246.2	244.6	241.7	239.8	4.5	2
LWG (kg hd^{-1} mo^{-1})	6.97	6.31	5.83	6.36	5.83	5.66	9.28	8.83	6.44	7.35	7.69	7.20	6.98	1.17	17
LWL (kg hd^{-1} mo^{-1})	–2.14	–2.43	–2.69	–2.79	–2.03	–3.18	–2.37	–2.56	–3.09	–1.62	–2.87	–2.74	–2.54	0.45	18
Droughtmaster (hd)	15	14	16	17	17	18	16	16	17	17	15	12	16	2	10
Age (mo hd^{-1})	26.6	26.3	25.4	25.2	25.6	26.3	25.0	25.9	26.1	26.9	26.2	24.5	25.8	0.7	3
LWT (kg hd^{-1})	260.8	266.1	264.8	270.3	281.2	290.2	284.0	292.3	307.4	321.7	313.5	298.8	287.6	20.1	7
LWG (kg hd^{-1} mo^{-1})	12.09	13.20	12.89	17.08	13.54	8.51	12.43	21.42	17.43	8.29	12.14	11.81	13.40	3.71	28
LWL (kg hd^{-1} mo^{-1})	–2.22	–4.58	–2.77	–0.91	–2.46	–2.01	–2.59	–1.69	–1.41	–1.90	–0.79	–1.45	–2.06	1.01	49

NR: no record available. LWT: Liveweight. LWG: Liveweight gain (averaged for cattle that gained weight). LWL: Liveweight loss (averaged for cattle that lost weight). LWG plus LWL is net LWG. The SD (standard deviation) is based on the annual or monthly means. The effective area of the cut-and-carry paddocks did not change from 22.26 ha over 2008–2013. The N fertiliser (kg ha^{-1} $mo^{-1})^{2010}$ is for comparison with the average fertiliser application since farming in 2010 had the highest FCE. The two sources of N fertiliser on the farm are urea and sulphate of ammonia (SOA). The small number of dairy cattle in 2008 and 2009 were included in the Brahman feedlot.

The information for each of the animals was collated into a Microsoft®Excel spreadsheet. Cattle tags were entered on the rows and other information for the cattle was entered into the columns (e.g., Appendix 4.1). For months where liveweight records were not available, the average of the previous and following months' LWT was used. Overall, the data involved 485 cattle and 5,981 monthly LWT records. Five of the cattle were cows (Brahman), kept in the feedlots at different times for a relatively short period (<3 mo), and 20 were the crossbred dairy cattle.

4.2.2.2 Animal feeding experiment

A small feeding experiment was carried out at the end of July to early August 2014 to obtain information on energy intake of cattle in the feedlots for comparison with published equations used in the MEB model (Section 4.2.3.l below). Weaner bulls (WB), heifers (H), and non-breeding bulls (NB) of the Brahman cattle were used. The animals in the same group were selected based on the close proximity in date of birth and liveweight obtained during the latest weighing routine on the farm. The weaner bulls were obtained from the Brahman feedlot (the cattle had been in feedlot condition for >6 mo). The heifers and bulls were obtained from the grazing system run by the farm adjacent to the feedlots. Five animals per group were placed in three 20 m × 15 m roofed pens with a concrete floor and iron-rail fences. The average liveweight and age of the cattle were 231.6 kg and 1.1 years old (WB), 203.4 kg and 1.0 year old (H), and 309.8 kg and 1.6 years old (NB). The heifers and non-breeding bulls were given a 10-day adjustment period for familiarisation with pen conditions before the experiment commenced (Yulaty et al., 2014). The experiment duration was 20 days. Fresh water was always made available to the cattle. Each group was fed daily with 15 kg of feed concentrate at 10 a.m. and 100 kg (WB), 153 kg (H), and 153 kg of herbage (NB) at 3 p.m. During the feed weighing, a separate sample of 500 g feed concentrate and a kilogram of herbage for each animal group was collected for dry matter (DM) determination. The feed residues were collected around 8–10 a.m. the following morning and weighed. The DM weight of the feed fed to the cattle and the feed residues were obtained by oven drying (60ºC for 2 days) and weighing technique. All animals were weighed again at the end of the experiment. Energy intake of the animals was assumed to be the ME content of the feed eaten.

4.2.2.3 Available data on feed supply

Although the primary thrust of this study was to define the feedlot system through the animal demand as calculated by MEB, information on supplement fed was collected to allow the energy from feed concentrate and from herbage to be quantified separately, and also information on herbage accumulation rate on the cut-and-carry paddocks was collected. While herbage accumulation could be measured for only part of a year, it was considered this information would still help to benchmark the outcome of the modelling.

(a) Supplement fed

Weekly historical records of feed concentrate fed to the cattle during 2008 to 2013 were obtained from the farm logbook. One sample of the feed concentrate was also collected weekly between July and October 2014 for DM determination and chemical analysis. The latter DM weight measurement was used to estimate the DM weight of the feed concentrate records. Palm kernel cake (PKC) mixture was the feed concentrate used on all feedlots. The components of the concentrate were PKC (65% by weight), milled corn (21%), milled soybean (11%), fishmeal (3%), and a small amount of Bovitas (Bovita-8) and Monensin sodium (Elancoban, Elanco®).

(b) Herbage accumulation

Herbage mass was measured at intervals during selected pasture regrowth cycles while the author was in Sabah in 2014 to carry out this study, and from this data herbage accumulation at this time of year could also be calculated. While it is appreciated this represents only a partial data set, having some actual herbage accumulation data from the farms in question to cross check with the MEB modelling results from January 2008 and December 2013 was still felt to be useful. The data collection strategy was to measure herbage mass to simulated harvesting height in mid regrowth and the day before herbage harvesting (for feeding the cattle) of selected paddocks, allowing calculation of accumulation rate by difference.

Data collection on the cut-and-carry paddocks — Herbage (*B. decumbens*) was collected between July and October 2014, 15 days and 2 days before the herbage was harvested for the cattle. The sampling procedures were adapted from the technique of Boswell (undated). In the mid-regrowth collection, two cut-and-carry paddocks were selected. On both selected paddocks, 10 typical patches of herbage were selected. Figure 2 in Boswell (undated) was used as a guide to selection of sampling points. A starting point at the centre of each paddock was identified by a throw of a stick to preclude human bias. From that point towards the North and South, two sampling points spaced at 50 m intervals were marked along a 100 m transect. Finally, a further six sampling points (making 10 in total) were selected 100 m distant from the central point, in East, West, Northeast, Northwest, Southeast and Southwest directions. At each sampling point, a patch typical of the paddock but without major weed presence was selected. A 0.26 m^2 quadrat was placed on the patch, and the location marked with a 1 m high × 21 mm diameter PVC stake. The biomass in the quadrats was harvested by hand with scissors to 7 cm above ground level for consistency with the normal harvesting residual height of the farm. The two paddocks sampled in this way yielded 20 herbage samples, a number identified by Hodgson et al., (2011) as being appropriate for this type of measurement. The samples were dirt free and thus were not washed. A sub-sample from each quadrat was separated to leaf, leaf sheath, stem and dead matter. The main sample and components of the sorted sub-sample were weighed, dried at 60ºC for 2 days and reweighed to obtain the dry weight.

For the second (pre-harvesting) sample collection, herbage was sampled from a quadrat placed adjacent to each of the previous quadrats and processed as above to obtain the pre-harvesting green mass and dry weight of total herbage to harvesting height and the components.

Data collection on adjacent grazing paddocks for comparison — on the grazing area adjacent to the cut-and-carry paddocks, the *B. decumbens* and *S. sphacelata* 'Kazungula' were each sampled on two of the paddocks planted with the herbage. The sampling was carried out 14 days and 1 day before grazing commenced and herbage was cut to 5 cm above ground for *S. sphacelata* 'Kazungula'. Other sampling procedures were similar to those on the cut-and-carry paddocks.

(c) Feed nutritive value analysis

During herbage sampling described above, samples from quadrats 2, 5 and 8 in each paddock were retained after oven drying, and these samples and the dried herbage samples used in the feeding experiment, were ground to powder, and sent to the Makmal Kesihatan Awam Veterinar, Department of Veterinary Services, West Malaysia (Lab references ST3385/14 and ST3596/14) for analysis of ME and CP content according to the protocols set out in the Malaysian Standard for Testing for Animal Feed Stuffs (MS: 3.1982).

Feed concentrate samples were collected monthly from July to October 2014 from the material currently being fed to the animals and sent, together with samples of feed concentrate used in the feeding experiment, to the same laboratory for the same chemical analyses.

4.2.2.4 Additional farm data collected

To assist with interpretation of herbage accumulation and animal performance data, monthly rainfall data recorded at the farm and N fertiliser use data were obtained from the farm logbook for production periods from January 2008 to December 2013 (Table 4.1). This is because rainfall and N fertiliser use are two factors that likely have a large influence on herbage accumulation and hence system performance.

4.2.3 Analysis of system feed profiles

4.2.3.1 Modelling of monthly and annual feed demand and consumption

The animal data used for the modelling were obtained as explained in Section 4.2.2.1. Overall, the data used comprised 5,981 monthly live weight records for 485 Brahman, Bali and Droughtmaster cattle (see Appendix 4.2 for samples of liveweight trajectories of the cattle). The metabolic energy requirements of the feedlots (Brahman, Bali or Droughtmaster feedlot) were modelled monthly from January 2008 to December 2013. The first step in the modelling process was to calculate the metabolic energy requirements of every animal in each feedlot, and the results were used to obtain the energy requirements of each feedlot and finally of the whole system (all three feedlots). The small number of cows and dairy cattle were included in the Brahman feedlot, and the bull sires were included in the feedlots of their respective breeds. The formulation of the metabolic energy equations used was similar to those of Chapter 3 and is set out in Appendix 4.3. Specifically, metabolic energy requirements of each animal were calculated for body maintenance (Eq. 2) and liveweight gain (Eq. 3.1). As there were no pregnant or lactating animals in the groups studied, energy requirements for pregnancy and lactation were not applicable.

The metabolic energy requirements of the animals in the feedlots were assumed equivalent to the feed demand of the feedlots, and the latter were taken to also represent the feed supply of the feedlots as herbage eaten. The results obtained and the data for feed demand associated with the feed concentrate fed to the cattle were both converted to herbage equivalents based on the energy content of herbage collected from the cut-and-carry paddocks. The difference between the feed demand and concentrate fed therefore were approximately the amount of herbage fed to the cattle. Not all cut forage and feed concentrate supplied to the feedlots were assumed eaten; so the amount of feed supplied to the feedlots was corrected by incorporating the estimate of feed wasted in the feedlots, which was taken from the feeding experiment described in Section 4.2.2.2. Finally, the feed demand and supply (monthly or annual) were expressed relative to the total area of the cut-and-carry paddocks as kg DM ha^{-1} yr^{-1}.

4.2.3.2 Feed conversion efficiency

The information on feed demand and animal liveweight gain was extracted from the analyses in Section 4.2.3.1 for every animal in each feedlot from Jan 2008 until Dec 2013 and used to evaluate the monthly and the annual FCE of each feedlot. FCE was calculated as the total feed demand (month or annual) divided by the total liveweight gain in the same period, and was calculated as a statistic that can allow evaluation of factors affecting system performance. Correlations (Pearson's) were calculated between the FCE and the N fertiliser application to the cut-and-carry paddocks and farm rainfall. For the monthly correlation (n = 12), data used to represent each month were the average of 6 years of data or 5 years for N fertiliser, as one year had no record (in fact for all fertilisers). For the annual correlation (n = 6), data used were the average of data from 12 months for each year. The correlation analyses were performed using the StatPlus:mac LE v5.9.50 (AnalystSoft Inc., www.analystsoft.com/en/).

4.2.3.3 Feed implications of animal weight loss

It is of interest in cut-and-carry feedlot systems to account for the feed implications of animal weight loss, which is a feed saving at the time of weight loss, but a feed cost at another time when the weight is regained, effectively creating a transfer of feed in time. The energy associated with weight loss (ME_{LWL}) or also termed 'mobilised body energy' is expressed as herbage equivalent. Feed saving from ME_{LWL} when animals lose liveweight was explicitly identified in the metabolic energy calculations (Section 4.2.3.1; Details in Appendix 4.3, Eq. 3.2.1.1 and Eq. 3.2.2.1) as a potential system efficiency factor and used to quantify the monthly and annual ME_{LWL} of each feedlot. Correlations (Pearson's) were calculated between the FCE and ME_{LWL}. For the monthly correlation (n = 12), data used to represent each month were the average of 6 years and for the annual correlation (n = 6), data used were the average of 12 mo data for each year.

4.2.3.4 Allocation of feed energy between body maintenance and growth

Information from the metabolic energy calculations was organised so as to give feedlot totals for the various metabolic activities defined by Eq. 2 and Eq. 3.1 in Appendix 4.3. In this way the variation in energy required for body maintenance and growth by the three cut-and-carry feedlots could be examined.

4.3 Results

4.3.1 Comparison between feed demand modelling and intake observed in the feeding experiment

It was of interest in this study to assess the MEB model before it was used to quantify the system. The feed demand modelling predicted 9% higher energy requirements for weaner bulls, 14% higher for bulls and 11% lower for heifers compared to the results of the feeding experiment (Figure 4.2; Appendix 4.4). The average difference was 4%.

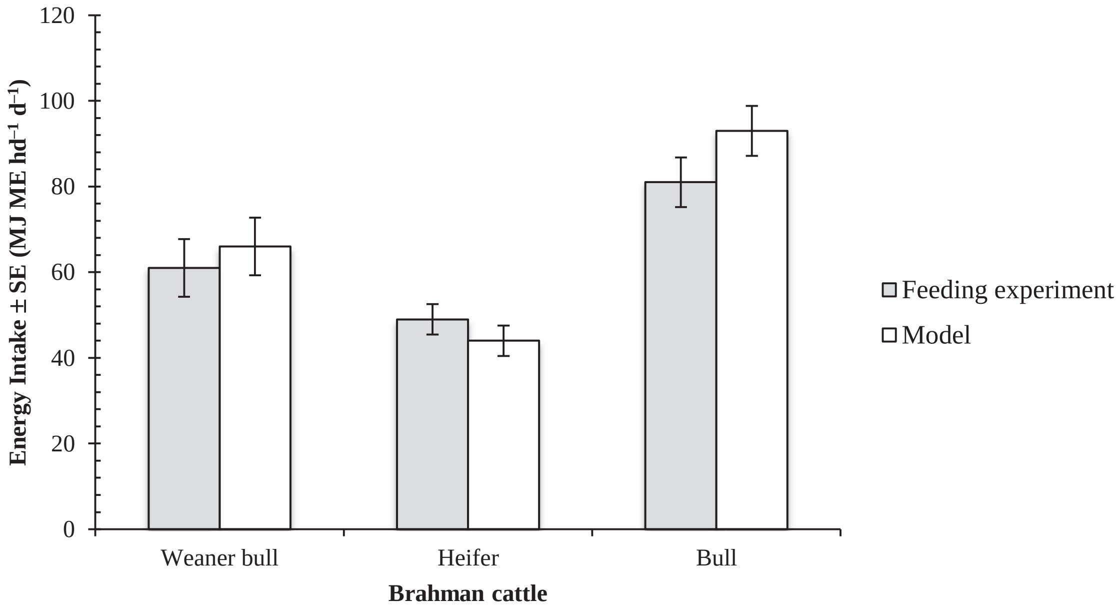


Figure 4.2 Comparison of animal energy intake between metabolic energy model and feeding experiment at SPT Tawau

4.3.2 System feed profile based on MEB

4.3.2.1 Annual feed demand and supply

When expressed per unit size of the cut-and-carry paddocks (22.26 ha), the feed demand (or supply of feed that was eaten) of the system (all feedlots) averaged across years was 8.02 t DM ha^{-1} yr^{-1}, comprising 6.22 t DM ha^{-1} yr^{-1} herbage eaten and 1.80 t DM ha^{-1} yr^{-1} concentrate eaten as herbage equivalent (Figure 4.3; Appendix 4.5). The highest annual feed demand across years occurred in 2012 at 9.03 t DM ha^{-1} yr^{-1} (7.42 t DM ha^{-1} yr^{-1} herbage + 1.61 t DM ha^{-1} yr^{-1} feed concentrate), followed by 2009 at 8.82 t DM ha^{-1} yr^{-1} (6.60 t DM ha^{-1} yr^{-1} herbage + 2.22 t DM ha^{-1} yr^{-1} feed concentrate). Feed demand in 2008 and 2013 were lower than the average. The amount of feed concentrate used, expressed as a proportion of annual DM intake ranged from 7%–19%; use of concentrate decreased in 2013. Based on the feeding experiment (Section 4.2.2.2), overall feed wastage was estimated as 0.167 t DM ha^{-1} yr^{-1} for herbage (3% of the herbage offered) and 0.095 t DM ha^{-1} yr^{-1} for feed concentrate (5% of the concentrate eaten as herbage equivalent).

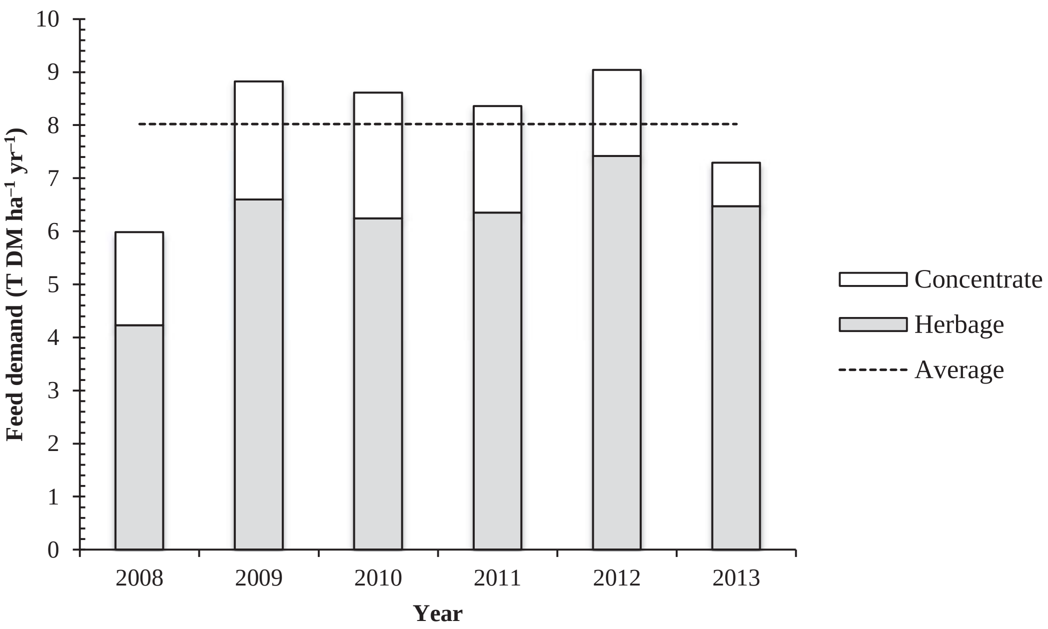


Figure 4.3 Annual feed demand of cut-and-carry feedlots at SPT Tawau (2008–2013).

4.3.2.2 Evaluation of seasonality of feed demand and supply

The monthly feed demand and herbage consumption in the system varied little through the months of the year, with 4% and 6% CV, respectively (Figure 4.4; Appendix 4.5). Because wastage was low, accounting for the feed wasted had little impact on the modelled average monthly herbage supply: for example, 517 kg DM ha^{-1} (before adding feed wasted) vs. 523 kg DM ha^{-1} (after). The variation in consumption of feed concentrate was slightly greater than the herbage consumption with 19% CV (Appendix 4.5) as a result of the low supply of feed concentrate during December (because the stock was depleting) and January to February (because during that period the budget to purchase the feed had not yet been confirmed and managers made the system work with low supply of supplement or without it).

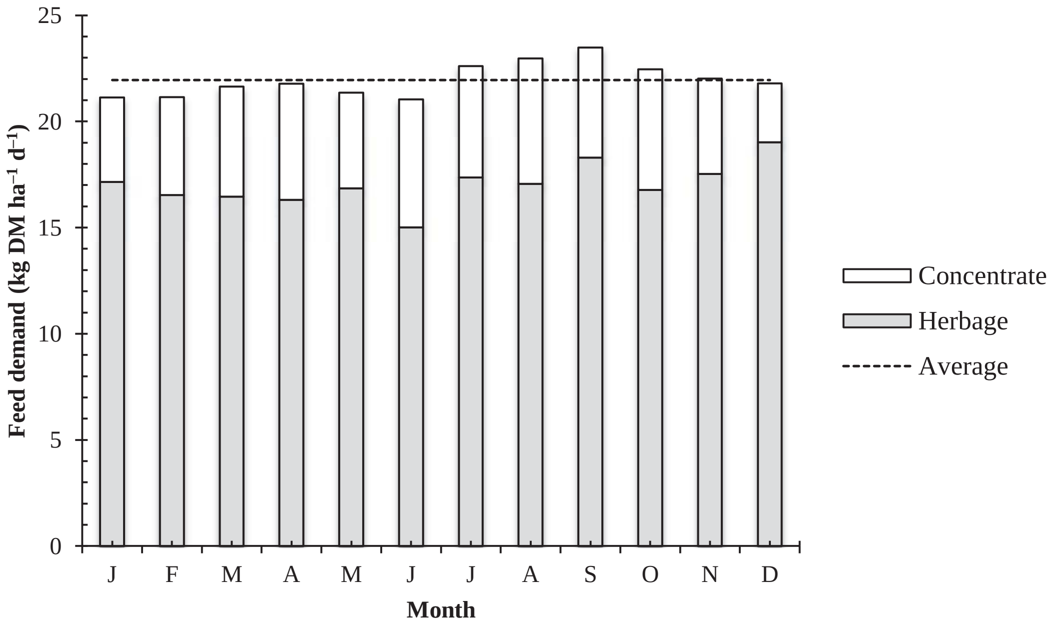
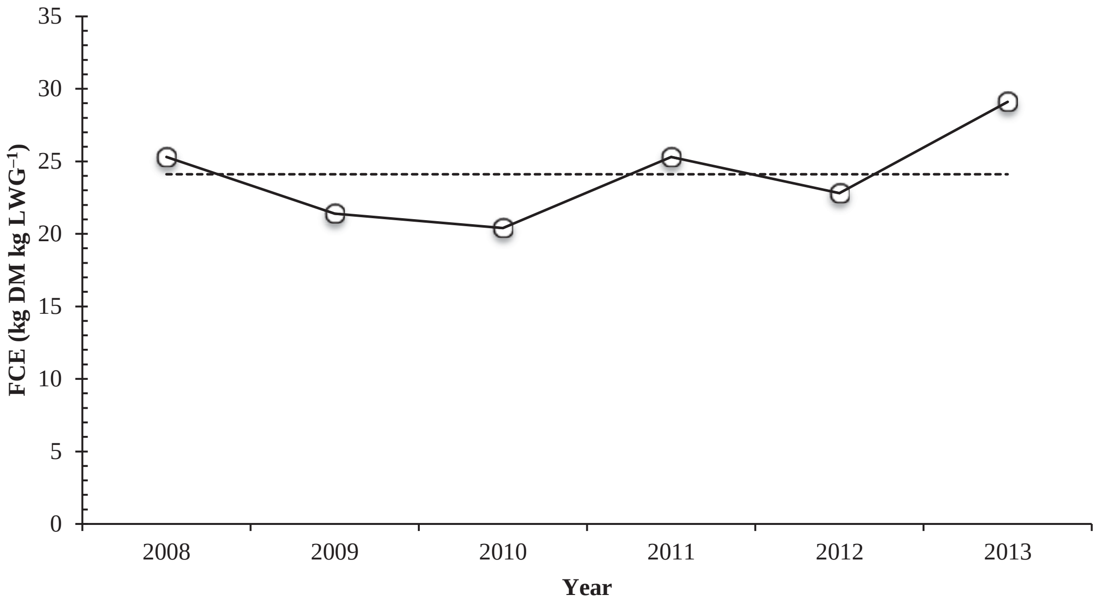


Figure 4.4 Monthly feed demand of cut-and-carry feedlots at SPT Tawau (average over 2008–2013).

4.3.2.3 Feed conversion efficiency

The FCE of the system averaged across years was 24.1 kg DM kg LWG^{-1} (Figure 4.5). There was no trend indicating that FCE improved over the 6-year production period studied (Figure 4.5). The ranking of feedlots for FCE (from most to least efficient) was the Droughtmaster (21.3 kg DM kg LWG^{-1}), followed by the Brahman (27.2 kg DM kg LWG^{-1}) and the Bali (28.7 kg DM kg LWG^{-1}) feedlots (Appendix 4.7).

(A)



(B)

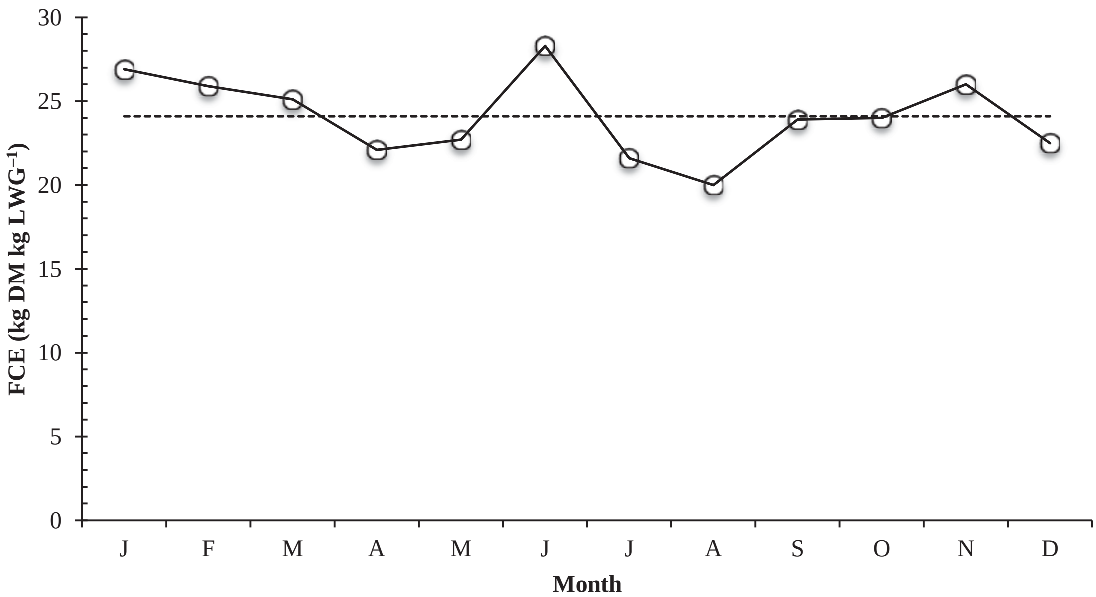


Figure 4.5 Feed conversion efficiency of cut-and-carry feedlots at SPT Tawau: (A) annual and (B) monthly (average over 2008–2013).
Dotted lines are the overall average. Note that a lower numerical value of FCE means increased efficiency.

The year with the most efficient FCE was 2010 (20.4 kg DM kg LWG^{-1}), followed by 2009 (21.4 kg DM kg LWG^{-1}) and 2012 (22.8 kg DM kg LWG^{-1}) (Figure 4.5; Appendix 4.7). The month with the most efficient FCE was August (20.0 kg DM kg LWG^{-1}), followed by July (21.6 kg DM kg LWG^{-1}), April (22.1 kg DM kg LWG^{-1}) and May (22.7 kg DM kg LWG^{-1}) (Figure 4.5; Appendix 4.7).

The correlation between monthly FCE and feed concentrate consumption was weak and not significant (R = –0.043, P = 0.894); the annual correlation was moderately strong but was also not significant (R = –0.735, P = 0.096). The correlation between monthly FCE and N application on the cut-and-carry paddocks was moderate and significant (R = 0.659, P = 0.020); the annual correlation was moderately strong, and was significant at the 10% probability level though not at 5% (R = –0.864, P = 0.059). The correlation between monthly FCE and rainfall on the farm was moderate and was also significant at the 10% probability level but not at the 5% (R = –0.569, P = 0.053); the annual correlation was weak and not significant (R = –0.057, P = 0.915).

It was noted that the correlation between monthly N application and rainfall was weak and not significant (R = –0.078, P = 0.809). The annual correlation was moderately strong but was also not significant (R = –0.342, P = 0.573). The negative correlation indicated that N application was increased out during low rainfall years.

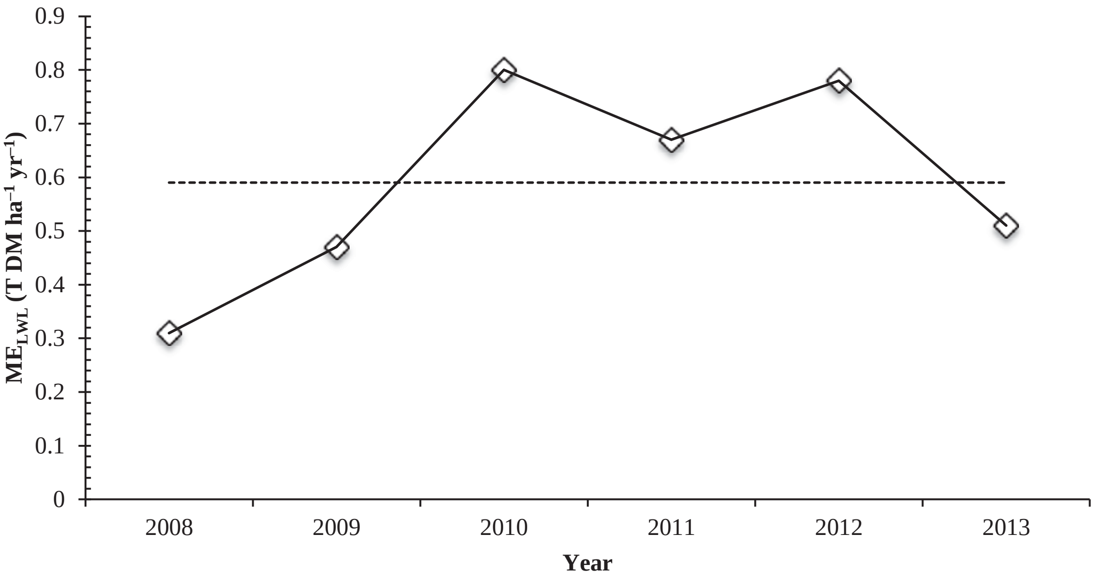
4.3.2.4 Feed implications of animal weight loss

The average ME_{LWL} of the system averaged across years was 0.59 t DM ha^{-1} yr^{-1} as herbage equivalent (Figure 4.6; Appendix 4.8). The years of high ME_{LWL} were 2010 (0.8 t DM ha^{-1} yr^{-1} as herbage equivalent), 2012 (0.78 t DM ha^{-1} yr^{-1}), and 2011 (0.67 t DM ha^{-1} yr^{-1}) (Figure 4.6). The difference between the Brahman, Bali and Droughtmaster feedlots in average ME_{LWL} was small at 0.01 t DM ha^{-1} yr^{-1} to 0.11 t DM ha^{-1} yr^{-1} (Appendix 4.8).

The average monthly ME_{LWL} of the system was 49.3 kg DM ha^{-1} as herbage equivalent (Figure 4.6). The coefficient of variation of monthly ME_{LWL} was 16%. The monthly ME_{LWL} in February (59.0 kg DM ha^{-1} as herbage equivalent), March (62.4 kg DM ha^{-1}) and June (56.3 kg DM ha^{-1}) were markedly higher than the average across month (Figure 4.6; Appendix 4.8).

The correlation between ME_{LWL} and FCE was moderate and significant (R = 0.643, P = 0.024). It should be noted that because a higher numerical value of FCE is a lower efficiency, this result is actually a negative correlation. The inter-annual correlation was also moderate but not significant (R = –0.589, P = 0.218).

(A)



(B)

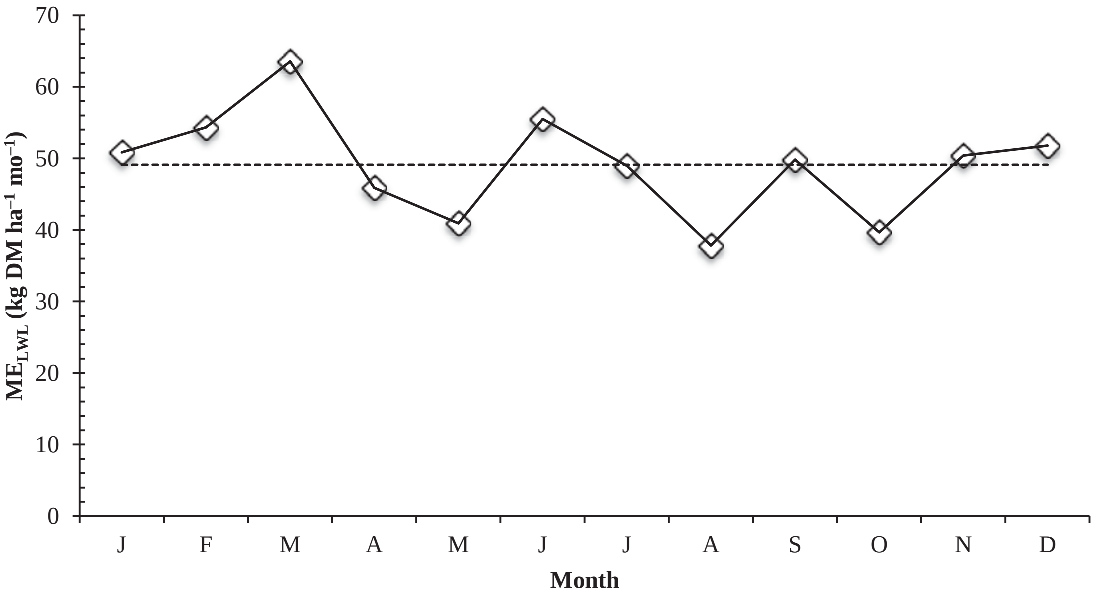


Figure 4.6 ME_{LWL} (energy associated with weight loss) as herbage equivalent of cut-and-carry feedlots at SPT Tawau: (A) annual and (B) monthly (average over 2008–2013). Dotted lines are the overall average.

4.3.2.5 Allocation of feed energy between body maintenance and growth

The average allocation of feed energy to body maintenance of the system was 69%. The highest was for the Brahman (73%), followed by the Bali (66%) and Droughtmaster (64%) feedlots (Table 4.2).

Table 4.2 Energy allocation (average over 2008–2013) for body maintenance and growth of cut-and-carry Brahman, Bali and Droughtmaster feedlots at SPT Tawau.

	MJ ME ha^{-1} d^{-1}			% of the Total	
	Total	Maintenance	Growth	Maintenance	Growth
Brahman	93.31	67.78	25.53	73	27
Bali	53.00	34.93	18.07	66	34
Droughtmaster	40.35	25.65	14.70	64	36
Average	62.22	42.79	19.43	69	31

4.3.3 Information on feed supply from short-term observations

4.3.3.1 Herbage accumulation from two month cutting experiments

The production of *B. decumbens* at the selected areas on the cut-and-carry paddocks was 21.3 t DM ha^{-1} yr^{-1} for total green DM and 13.1 t DM ha^{-1} yr^{-1} for total leaf DM (Table 4.3). In comparison, the production of the species on the adjacent grazing paddocks declined at the end of the regrowth cycle (Appendix 4.6). The production of *S. sphacelata* 'Kazungula' was 10.9 t DM ha^{-1} yr^{-1} for total green DM and 6.7 t DM ha^{-1} yr^{-1} for total leaf DM.

Table 4.3 Dry matter accumulation and nutritive value of herbage on cut-and-carry paddocks at SPT Tawau.

		Green DM		Leaf DM		MJ ME kg DM^{-1}	CP %
	Regrowth cycle days	Daily rate[B]	Annualised[C]	Daily rate	Annualised		
B. decumbens	14–28	58.5	21.3	36.0	13.1	7.7–8.5	9–11
S. sphacelata 'Kazungula'[A]	7–14	29.9	10.9	18.4	6.7	7.5–8.2	10–12
Feed concentrate	–	–	–	–	–	8.7–14.3	12–16

[A] Used only occasionally in the cut-and-carry feedlot system: the herbage was planted on paddocks used for grazing.
[B]Daily rate (kg DM ha^{-1} d^{-1}). [C]Annualised (t DM ha^{-1} yr^{-1}).

4.3.3.2 Feed nutritive value

(a) ME content

ME content of *B. decumbens* on the cut-and-carry paddocks (7.7–8.5 MJ ME kg DM^{-1}) was close to that on the grazing paddocks (7.7–7.9 MJ ME kg DM^{-1}) (Table 5.6). ME content of *S. sphacelata* 'Kazungula' on the grazing paddocks (7.8–8.2 MJ ME kg DM^{-1}) was also close to that of *B. decumbens*. There was a trend for the ME content of the grasses (on the grazing paddocks) to decline at the end of the regrowth cycle (Appendix 4.6). The ME content of the grasses was lower than that of the feed concentrate (Table 4.3; average 11.5 MJ ME kg DM^{-1}). However, different purchased batches of the feed concentrate varied markedly (24% CV) in ME content.

(b) CP content

The CP of *B. decumbens* on the cut-and-carry paddocks (9%–11%) was slightly higher than that on the grazing paddocks (8%–9%), but lower than that of *S. sphacelata* 'Kazungula' on the latter paddocks (11%–12%). There was a trend for herbage CP to decline at the end of the regrowth cycle (Appendix 4.6), except for *B. decumbens* on the cut-and-carry paddocks. The average CP of the feed concentrate (14%) was higher than that of the herbage.

4.4 Discussion

4.4.1 Performance of the feed demand modelling

In respect of the MEB model evaluation, it was found that the discrepancy between energy intakes calculated by the model and intakes measured in the animal feeding experiment was within the expected measurement error. Nicol and Brookes (2007) reported that feed demand modelling could predict the animal energy requirements only to ±10% accuracy. The average found in this study was 4%. In other words, the model is applicable to capture the system. A factor that may have affected the result of the feeding experiment is animal stress. Possibly, the heifers and bulls were stressed up when kept in pen conditions during the experiment and consumed more feed, as initially they were grazing in a spacious area (in the grazing system).

While the above discussion indicates the biological precision of the MEB model used, a comparison of the model results with those of the study by Quigley et al. (2014) indicates that the improvement suggested by Nicol and Brookes (2007) for the energy demand equations used in the model is reasonable. Quigley et al. (2014) reported that the CSIRO (2007) equation underestimated the energy requirement for gain. This problem, however, was not found in the present study. The likely reason is Nicol and Brookes (2007) had improved the CSIRO (2007) equation to estimate energy requirement for gain by using a 1.1 instead of 0.1 scalars. In brief, the energy requirements of Bali cattle calculated using the model differ by only 4%–5% from that obtained using the metabolic constant provided by Quigley et al. (2014), which they derived from feeding experiment. The latter study reported that an entire Bali male 6–12 mo old and in the weight range 55.4–120.9 kg hd^{-1} requires 0.47 MJ ME kg LW$^{-0.75}$ d^{-1} for body maintenance and 34 MJ ME kg LWG^{-1} for growth when fed with a diet of 5.0–12.7 MJ ME kg DM^{-1} energy content. In Sabah, entire male Bali of that age are much heavier, and thus a younger animal is used for comparison, that is, 3–5 mo old of 63–102 kg hd^{-1} growing at 0.65 kg hd^{-1} d^{-1}. If the energy requirements of the Bali cattle of that weight in Sabah were estimated using the constants reported by Quigley et al. (2014), the cattle would require 32.6 (10.5+22.1) to 37.2 (or 15.1+22.1) MJ ME hd^{-1} d^{-1}. The prediction of the model is 31.39 (or 12.9+18.49) to 39.29 (or 18.5+20.79) MJ ME hd^{-1} d^{-1} for the same animal at 8.3 MJ ME kg DM^{-1}. The present model predicts a slightly higher body maintenance energy requirement (12.9 and 18.5 MJ ME hd^{-1} d^{-1}) but only a slightly lower live weight gain energy requirement (18.49 and 20.79 MJ ME hd^{-1} d^{-1}) than the results obtained using the metabolic coefficients of Quigley et al. (2014). As a recommendation, considering that the feeding experiment in this study was relatively short, further feeding experiments should be carried out in the future to draw a deeper understanding about the MEB model predictions and actual energy intakes of cattle in Sabah. The experiment could potentially also involve comparison of the modelled against energy intake of different cattle breeds under different nutrient management regimes.

4.4.2 Current status of system and implications for beef production

4.4.2.1 Annual production and nutritive value of herbage

The MEB indicated that the operational herbage supply (6.22–7.42 t DM ha^{-1} yr^{-1}), or the herbage that was eaten and translated to animal growth, was lower than the local potential herbage production (10.9–21.3 t DM ha^{-1} yr^{-1}) measured in the cutting experiment. This implies that the amount of herbage in the system that was utilised for animal production is lower than that the system could offer. This problem may have limited the potential of the system for beef production. Valentine and Kemp (2007) state that the maximum potential animal production of a pastoral system is dependent on the maximum annual feed produced and available in the system. Specifically, it depends on the amount of the feed that can be eaten and converted to animal product (McMeekan, 1958).

The results of the cutting experiment indicate that the grass species sown on the farm could potentially achieve their maximum annual DM production. The results are similar to the herbage accumulation known for *B. decumbens* (14–26 t DM ha^{-1} yr^{-1}: Ng, 1972) and *S. sphacelata* ‘Kazungula’

(10–15 or occasionally 26 t DM ha^{-1} yr^{-1}: DVS, undated) in Malaysia. If that were true, the operational herbage production should be between 10 t DM ha^{-1} yr^{-1} and 26 t DM ha^{-1} yr^{-1}.

There are several possible reasons why the operational herbage production in the system is less than local potential herbage production. First, there is non-utilisation of herbage associated with harvesting of more herbage than animals will consume each day. There is no protocol reported to quantify the amount of herbage to be harvested for the cattle in the feedlots, other than being reported as based on experience, visual judgement of appetite of the cattle, and based on the notion that herbage fresh weight requirement of the cattle is equivalent to 10% of the cattle liveweight. The first two criteria are subjective; no scale is available. The third criterion is typically applied without weighing the herbage, so it is also subjective. In this situation, the amount of feed fed to the cattle in the system may be inconsistent especially when staff rotation occurs.

Second, there is non-utilisation associated with rejection of herbage. The farm staff reported that the cattle would reject damp feed, especially herbage, because of fungus colonisation on damp herbage. This rejection may occur at any time of the year, as there is no clear guide available on the farm or in Sabah about how to handle wet herbage for feedlot cattle. The common practice to mitigate this problem is to spread the herbage on the floor of an empty pen to let it dry before being fed to the cattle. The limitation is the effectiveness of the technique has been assessed only visually and little is known about the amount of waste. Herbage and concentrate waste in the system has so far never been sufficiently quantified. The herbage waste estimated during the animal feeding experiment in this study represents the period from August to September, and August is the wettest month based on the rainfall data for 2008 to 2013 (Figure 4.1), but caution is needed when making a generalisation about annual herbage and concentrate waste based on that result.

Third, there is loss of herbage production in the system associated with invasion by non-sown grass species, and from factors such as soil acidity, and low soil nutrient levels. These reasons could also explain why there is a wide range of herbage DM production between the cut-and-carry (Table 4.3) and grazing paddocks (Appendix 4.6) even for the same forage. The proportion of sown species in pastures as reported by the farm was 70%–80% for paddocks planted with *B. decumbens* and 40% for *S. sphacelata* ‘Kazungula’. The soil on the farm was acidic (pH 4.91–5.49, Section 4.2.1.1), while the average N application was only 92 kg ha^{-1} yr^{-1} (Table 4.1: 169 kg ha^{-1} yr^{-1} urea, and 66 kg ha^{-1} yr^{-1}

SOA; urea, 46% N, and SOA, 21% N), which is lower than the recommended rate for *B. decumbens*. Based on an experiment carried out in Sarawak, East Malaysia, 112–224 kg ha^{-1} yr^{-1} application of N is the optimum rate required to support 14.0–19.7 T DM ha^{-1} yr^{-1} production of *B. decumbens* (Ng, 1972).

Finally, the herbage ME in the system (and elsewhere in Sabah as indicated by data from the other farms; see also Chapter 5) is generally lower than of published ranges, and this could partly contribute to low consumption of the herbage. The intake of herbage of low ME would be low because of the low digestibility and low rate of passage of such herbage through the digestive tract (Colucci et al., 1982). The herbage ME in the system is in fact at times lower than the minimum value (8 MJ ME kg DM^{-1}) reported capable of supporting cattle liveweight gain, although it is similar to the value reported for similar herbage in West Malaysia. An ME content of 8.2–8.5 MJ kg DM^{-1} was reported for *B. decumbens* and 7.4–9.2 MJ kg DM^{-1} for *S. sphacelata* 'Kazungula' in West Malaysia (DVS, 2005). Smeaton (2003) reported (in respect of temperate pastures) that with feed of lower than 8 MJ ME kg DM^{-1}, animals would not grow irrespective of amount of the feed consumed.

In addition to the comparatively low herbage ME, herbage CP in this system is also lower than the value reported for the herbage in West Malaysia as well as lower than the minimum level of CP for efficient animal production. For example, *B. decumbens* in Malaysia is reported to have 19% CP (on DM basis) at 3 weeks of regrowth and 12% at 4 weeks of regrowth; *S. sphacelata* 'Kazungula' is reported to have 15% at 2 weeks of regrowth and 14% at 4 weeks of regrowth (DVS, 2005). The critical level of forage CP for ruminant production is 1.1%–1.3% N (Hennessy, 1980), which is equivalent to 6%–8% CP (equivalent to N × 6.25) (Humphreys, 1991); that is, the animal will be subject to deficiency of CP for body maintenance when the CP of the feed is lower than 6%.

4.4.2.2 Seasonality of herbage accumulation

From the available data it would appear that herbage supply in the system was aseasonal. The herbage data collected did not cover a 12-mo cycle because the author was in Sabah for data collection for only 4 months so it cannot be determined from that data if there is a seasonal pattern to herbage growth and production. However, from other considerations (as will also be noted later in Chapter 5 for the grazing system, Section 5.4.1.2) it appears that any seasonality of herbage production is slight. The animal demand data did not show seasonality (for example, 7% CV for animal demand compared across months for the Bali feedlot), PKC use was aseasonal (see below) and the farm managers reported no seasonal fluctuations in standing herbage mass on the farm. Where animal feed demand did fluctuate more markedly across months, this clearly related to implementation of major farm system change such as the transfer of >250 kg Brahman cattle to the grazing system, to phasing out of Droughtmaster cattle, to selling of >290 kg Bali and >380 kg liveweight Droughtmaster cattle, or to the rejection of wet herbage during rainy period as noted earlier (Section 4.4.2.1). The writer also observed nothing during collection of herbage data that would indicate seasonality. However, periods of above average rainfall may occur in any month, and it was noted that decisions on N application in the system were linked to expectations about rainfall. Monthly N application on the cut-and-carry paddocks was not positively correlated with monthly rainfall (Section 4.3.2.3), but the manager confirmed that in the cut-and-carry system (in contrast to the grazing system that will be covered in Chapter 5) application of N and other fertiliser is usually applied at the beginning of the month preceding the wettest months.

Although no seasonality of herbage supply was detected, a point for future study is whether or not global weather patterns like the El niño–Southern Oscillation (ENSO) affect pasture growth and production in a cut-and-carry system in Sabah. It is known that ENSO, which occurs with a cycle of 5 or sometimes 2 years (Curativo et al., 2013), affects mortality of forest plants in Sabah, depending on the intensity of the event (Walsh and Newbery, 1999). Thus, it might also affect the seasonality of herbage in a pastoral system. Another point for future study is whether or not monthly nutritive value of herbage in the system fluctuates, as this was not covered in the present study due to the limited duration of data collection.

4.4.2.3 Feed concentrate supply and nutritive value

One point about feed supplementation in the system is that feed concentrate use varied at 16%–26% CV through the year (Appendix 4.5), but the variation appears to be related to factors external to the system, such as implementation of major farm system change as stated earlier (Section 4.4.2.2); and this adds further evidence of aseasonality in system herbage supply mentioned earlier (Section 4.4.2.2), otherwise feed concentrate consumption would vary seasonally. The farm also reported that feed concentrate feeding was sometimes reduced at the start of a financial year because the budget was not yet confirmed rather than because of seasonality in supply of components of the concentrate (PKC, milled corn, milled soybean, and fishmeal; see Section 4.2.2.3). This suggests that the use of feed concentrate in the system needs to be evaluated for effectiveness in increasing animal production or reduction of operating cost.

The evaluation of the use of feed concentrate in the system is required, first, so that farm managers could use feed concentrate more effectively to improve growth of cattle. The ME (11.5 MJ ME kg DM^{-1}) and CP (14%) values of the feed concentrate are significantly higher than the minimum values required for efficient animal production stated earlier (>8 MJ ME kg DM^{-1} for ME and >8% for CP, see Section 4.4.2.1) and could compensate the low nutritive value of the herbage. ME of the feed concentrate is also within the expected value for feed concentrate of high PKC component. PKC in Malaysia has 10.5–11.5 MJ ME kg DM^{-1} (Alimon, 2004). However, PKC had high variability of ME content (Alimon, 2004), and this was also found in this study for the feed concentrate even though other grains had also been added (Appendix 4.6; Section 4.2.2.3). The risk is at low ME value, the use of the feed concentrate could lead to false expectation of its effect on liveweight gain of cattle. As a precaution, to avoid problems, nutritive value of purchased feed concentrate should have to be evaluated for every batch produced or purchased.

A second point about feed supplementation is relevant to future evolution of the system. Specifically, because feeding in cut-and-carry feedlot system can be regulated, there is a possibility of tactical use of feed concentrate targeted at increasing FCE. As will be discussed later (Section 4.4.2.4), ME_{LWL} occurrence and extra feeding of Bovitas (Bovita-8) by the farm to minimise this type of energy loss could lead to higher growth of cattle partly due to high energy intake and correction of factors contributing to reduced FCE.

A third point of interest relating to feed supplementation is the possibility of reducing the use of feed concentrate in the system to lower production costs. The current quantity of feed concentrate used in the system is not substantial (1.8 t DM ha^{-1} yr^{-1} as herbage equivalent) and there is possibility that better pasture management can lower the use of this feed. For this option to be effective, the present low nutritive value of the herbage (7.7–8.5 MJ ME kg DM^{-1} and CP approximately 8%–11%) would need to be improved to at least 9.5 MJ ME kg DM^{-1} and approximately 13% CP. It has to be noted, however, that eliminating the use of feed concentrate in this system may go against the goal of the system, that is, to grow the cattle to merchantable weight as soon as possible. The importance of concentrate for cattle in confinement has been highlighted in a previous study (Ibrahim et al., 1987) on the same farm used in this study. The study found that growth of cattle was only 0.39 kg hd^{-1} d^{-1} when feeding on herbage without feed supplementation, 0.58 kg hd^{-1} d^{-1} when supplemented with PKC, 0.68

kg hd^{-1} d^{-1} when supplemented with 75% PKC and 0.25% corn, 0.72 kg hd^{-1} d^{-1} when supplement with 50% PKC and 50% corn, and 0.81 kg hd^{-1} d^{-1} when supplemented only with corn. The only limitation of that previous study is that the ME and CP contents of the herbage and feed concentrate used in the experiment were not reported (or perhaps not tested), so it is an unconfirmed assumption that nutritive values of the various feeds tested in that study were similar to those found when herbage was tested in this study.

4.4.2.4 Feed conversion efficiency

The data indicated several factors important for future considerations to improve the FCE of the cut-and-carry feedlot system in Sabah. These include targeting a system configuration with the highest FCE, improving the herbage nutritive value, optimizing the use of supplements, and timing of the N application on the cut-and-carry paddocks in relation to rainfall and harvesting cycle.

The question of which feedlot, Brahman, Bali or Droughtmaster feedlot, uses feed most efficiently could not be addressed scientifically from this unreplicated study, but the data indicate that there is no marked difference between the feedlots. The Droughtmaster feedlot exhibited a much better FCE than the other feedlots. However, the difference in FCE between the feedlots was small once the values for 2012 and 2013 (where management changes known to impact negatively on farm efficiency occurred) are excluded in the comparison. The results in those years were heavily affected by the decision of the farm to phase out the breed. There were only a few Droughtmaster bulls in 2012 and 2013, and those animals had a better access to feed and thus gained weight faster. As a point for farmers in Sabah, this finding suggests that either one of the breeds tested here could be used for beef production using cut-and-carry feedlot system.

With respect to the factors linked to higher FCE, as noted above, improvement of herbage quality and quantity or tactical use of feed concentrate would have the potential to improve the efficiency of the system. Thus, one option to achieve high FCE is fertiliser application especially N addition as also indicated in this study. Presumably, if all other things were constant, after N application, increased animal energy intake from increased feed supply (and perhaps nutritive value especially CP content, which is affected by N application) could be allocated mainly to growth. This view is supported by the studies included by Chin (1995) in a review of pasture management in Malaysia. N addition close to harvesting date was reported to have improved the CP content of *B. decumbens*

(Minson, 1967). Moreover, Chen et al. (1982) reported that N application to pasture improves cattle production between 11% and 63% and attributed the improvement to the N input, although at the same time they noted that the effect of N addition on the herbage production was strongly evident only after almost a year. In fact, in this study, the CP content of the *B. decumbens* improved from 9% to 11% after fertiliser application; while in contrast, herbage CP on the unfertilised grazing paddocks, declined (Appendix 4.6), and in the three years of higher overall FCE (2009, 2010, and 2012), the annual N applications were higher than or close to the average. The effect of N application to the pasture on the cut-and-carry paddocks on system FCE, however, is expected to depend on rainfall. The correlation analysis indicated that years with higher N application had improved FCE, but months within years with higher N application did not. The farm reported that N tended to be applied in dry periods preceding wetter months. Correlation of N application and rainfall, though statistically non-significant, was negative, which is consistent with the farm information. The practice of N application preceding months of expected higher rainfall would mean that higher rainfall would coincide with the pasture response to N and the herbage would also tend to have higher CP. Minson (1967) reported that CP levels of *B. decumbens* increased following N application. This pattern is supported by the correlation analysis that indicated that higher monthly rainfall tends to be associated with improved FCE. It is also supported by the correlation analysis between annual FCE and N application; for example, the years with high rainfall but low N application (2011 and 2013: Table 4.1) have a less favourable FCE (25.3 kg DM kg LWG^{-1} and 29.1 kg DM kg LWG^{-1}, respectively: Figure 4.5). For FCE calculated on a monthly basis, the high FCE in August, July, April and May is also expected to be partly because of the relationship between N application and rainfall; more urea and SOA were applied in March and June (Table 4.1). Meanwhile, the correlation analysis at the annual level indicated no link between annual rainfall variation and variation in FCE. Another factor to consider during wet periods, however, is the rejection of damp herbage by cattle especially, when the drying technique used by the farm is not carried out properly. Therefore, it might be that the trend for enhanced FCE in wet months is partly negated by an animal herbage refusal factor. Further research on the possible use of fertiliser N as a tactical tool to increase FCE could be rewarding, considering also that the effect of N application on herbage nutritive value is reported to be indirect and not limited to only one pathway (Lambert and Litherland, 2000; Manning and Kesby, 2008). Tropical grass pasture fertilised with SOA (N + Sulphur), for example, has higher ME and CP compared with unfertilised pasture, but this was found to be because of an increment in legume yield in the pasture which is not a factor in the present study (Manning and Kesby, 2008).

Overall, at the present herbage quality in the system, with typical ME of 7.5–8.5 MJ kg DM^{-1} and CP values of 9%–12% (Table 4.3), lower FCE would be expected. This expectation is supported by the fact that around 64%–73% of total feed energy in the system is allocated to body maintenance (Table 4.2). By comparison, on New Zealand hill country sheep and beef cattle farming systems, 35%–71% of total feed energy is allocated to body maintenance, with the lower value being for lambs in a trading situation where their mother's body maintenance to breed the lamb is not included in the calculation (extracted from Microsoft®Excel spreadsheet used in Chapter 3). The typical herbage ME on New Zealand systems (10.2–12.2 MJ ME kg DM^{-1}, Appendix 3.3) was higher than for tropical pastures in Sabah and the FCE was also more favourable (14–19 kg DM kg LWG^{-1} of lamb weaned, Table 3.4, Chapter 3) compared with the cut-and-carry feedlot system in Sabah (21–29 kg DM kg LWG^{-1}).

Another important step to improve FCE is to mitigate ME_{LWL} in the system. One feature of pastoral system is that animal live weight can become 'an energy buffer' to absorb fluctuations in feed supply. Hence, when feed is scarce animals will mobilise body reserves and lose weight, and vice versa. Storage of surplus energy as live weight and later release in this way, reduces FCE, because the energy of feed saving on weight loss is less than the energy required for regain of the same weight. In the system studied, the calves were weaned in December, January, March, and May. Hence, the high ME_{LWL} occurrence in February, March and June is expected to be partly because of a post-weaning effect (as can also be interpreted from the growth data of the cattle: sample of growth data is given in Appendix 4.2). Liveweight loss was high in those three months (Table 4.1). Following weaning, calves experience distress and reduced liveweight gain, which can continue for >10 weeks (Price et al., 2003). The effect is marked for early-weaned calves. These calves would exhibit a noticeable drop in post-weaning growth compared to late-weaned calves (Morris and Smeaton, 2009), depending on the quality of feed fed to the calves (Schottler and Williams, 1975; Arthington et al., 2005). This problem could also be partly due to the slow familiarisation of the calves with feed concentrate and the calves relying on the low energy herbage as feed. In the feeding experiment in this study, the newly arrived cattle in the feedlot consumed only a small amount of feed concentrate during the 20 d observation (Appendix 4.4).

The higher ME_{LWL} occurrence in 2010 and 2012 (Figure 4.6) is associated with the higher liveweight loss in the Droughtmaster and Bali feedlots (Table 4.1). The reason for the higher ME_{LWL} in these feedlots during those years is not clear. Perhaps, it was due to the PKC used in the concentrate in some of the months in those years having a lower in ME content, and not supporting cattle growth to the same extent, to a higher degree of distress associated with weaning, or a higher herbage rejection due to moisture because rainfall in 2012 was the highest among the years for which data were collated. The higher annual growth of cattle in those years (Table 4.1), on the other hand, is also difficult to explain from the data available in this study. The manager, however, stated that the cattle that lost more weight would be fed a supplement of Bovitas (Bovita-8). Perhaps, the higher growth of cattle during those years was because of the extra feeding of Bovitas (Bovita-8).

An additional point noted by the author for potential future study was the positive inter-annual correlation between FCE and ME_{LWL} (Section 4.3.2.4), that is, greater ME_{LWL} occurrence was followed by a period of improved system performance (not formally tested in the data analysis). A possible factor in improved performance following weight loss is the phenomenon known as compensatory growth depending on the severity of weight loss. Compensatory growth could improve animal FCE (Wilson and Osbourn, 1960). A second possible factor is that the farm manager as stated earlier mentioned a practice of feeding Bovitas (Bovita-8, a protein supplement and appetite stimulant) to animals when marked weight loss was observed. Hence, a study could be carried out to gain a more complete scientific understanding of the energetics of the recovery of lost body weight and the potential role of dietary supplements in the context of feedlot system in Sabah.

4.4.3 Implications for future system design

Based on the analysis above the first step for future evolution of cut-and-carry feedlot system in Sabah would be to choose a configuration to optimise FCE of existing system, and over time develop higher herbage productivity and maintaining a system configuration that will utilise the additional herbage and increase animal production in parallel with the increased herbage production. The focus is on system of high FCE because in cut-and-carry feedlot where the feed is brought in for the cattle, higher conversion of feed to animal product is clearly desirable, so that the animals would grow to merchantable weight faster. This is also because cut-and-carry feedlot is already risky to operate, since the animals depend heavily on manual supply of feed and can lose weight rapidly when feed supplied is insufficient. When this happens, there will be more feed required per unit of meat produced. If herbage production were improved as the first step, besides continuation of feed utilisation inefficiencies just described, there would also be a lack of stock available to consume the extra herbage as the industry is currently very small and there would be little scope to purchase animals from other farms, with the calving presently below 50% (DVSAI, 2008; see also Chapter 5, Section 5.2.1.1). By focusing on configuring current system for optimal FCE, the cut-and-carry feedlot system can be operated at the current cost but with a higher beef production, and therefore more profitably (sell the cattle at a higher weight, or sell them sooner at the same weight with a faster growth rate, but this latter option means more replacements would still be needed).

Based on the results of the above analysis, the farm system configurations in 2010 or 2009 (all feedlots) are an example of a configuration from among those studied that could be used as a template for optimising FCE of current cut-and-carry feedlot system in Sabah. The key farm information for those years was presented in Table 4.1, and the relevant optimisation details for year 2010, for example, are as follows: 36 Brahman cattle (282.3 kg LWT hd^{-1}, 20.9 mo hd^{-1}), 25 Bali cattle (244.5 kg LWT hd^{-1}, 32.7 mo hd^{-1}) and 20 Droughtmaster cattle (293.0 kg LWT hd^{-1}, 28.4 mo hd^{-1}), and 1.60 t DM mo^{-1} of feed concentrate as herbage equivalent (this could simply be eliminated by increased herbage production). These stock were carried on 22.26 ha, giving a stocking rate per ha for the above system of 994 kg animal LWT ha^{-1}. Land area for different animal numbers or weights could be adjusted on a pro rata basis, and can be maintained constant throughout the year because herbage supply is aseasonal. N application in 2010 (77 kg N ha^{-1} yr^{-1}) was slightly lower than the average (92 kg N ha^{-1} yr^{-1}), but from another perspective, this means that an efficient system can still be attained even at lower N addition, as long as other system configuration factors are aligned correctly. The average cost of N application during 2009–2013 was RM0.61 kg N^{-1} (see Section 4.2.1.1), which means in 2010 the cost of N application was RM46 ha^{-1} yr^{-1} or RM9 ha^{-1} yr^{-1} cheaper than the average cost of N application. The advantage of this approach to farm operation is the system configurations recommended have been practically tested in the past and so would involve less risk for farmers implementing them, compared with a new system configuration devised from an untested combination of higher productivity and stocking rate.

Since the system is still pasture-based (cut-and-carry), to explore further the ideal balance between feed demand and supply for similar system in Sabah, the system analysed in this study can be used to develop a benchmark for a farm with the current pasture production characteristics (on cut-and-carry paddocks). In this study examples are seen of low, near optimal and overstocked production system by year: respectively, 2008 (FCE = 25.3 kg DM kg LWG^{-1}, without allowing for feed non-utilisation), 2010 (FCE = 21.4 kg DM kg LWG^{-1}), and 2011 (FCE = 25.3 kg DM kg LWG^{-1}). The average stocking rates for these three units calculated from data in Table 4.1 were respectively, 767, 994 and 1044 kg animal LWT ha^{-1}. In New Zealand, to account for imported feed in dairy farm systems a "comparative stocking rate (CSR)" (kg animal LWT ha^{-1} per tonne total feed DM offered ha^{-1}: Penno, 1999; MacDonald et al., 2008) is now used, with milk solid ha^{-1} maximised when CSR was 91 and operating profit was maximised when CSR was 76 (MacDonald et al., 2008). The optimal range is now considered to be 75–80 kg LWT t DM (DairyNZ, 2013). If the feed offered is taken as the average feed harvested of the production system (8.02 t DM ha^{-1}, see Figure 4.3) plus a 15% allowance for non-utilisation, then for the years of production values just mentioned, the CSR values are, respectively, 81, 105, and 111 kg LWT t DM^{-1}. Further evaluation is needed to establish the optimal values of this index for this particular system in Sabah. A higher CSR for a cut-and-carry system seems logical because, for an animal in confinement, energy requirement for grazing activity is zero and thus a higher animal production can be supported by a hectare of cut-and-carry paddock than a grazing paddock and this may explain the higher CSR for the system in this study.

To facilitate an incremental improvement of the system in the future, work recommended along with the optimisation adjustments proposed above is:

(i) Production of a management guide that mitigates the adverse effect of weaning on growth of feedlot beef calves — there are several methods proposed to condition feedlot cattle: performing acclimation lessons; training cattle to be confident; reducing stress; encouraging rehydration, nourishment, and rest; and treatments supporting immune function (Noffsinger et al., 2015; Reinhardt and Thomson, 2015). A trial, however, is necessary to confirm the benefits in Sabah, of implementing these suggestions from the literature.

(ii) Investigation of a concentrate feeding regime to prevent excessive weight loss (i.e. excessive ME_{LWL}) — the focus would be to mitigate ME_{LWL} to improve FCE and investigate the possible role of compensatory growth as noted above (without affecting the time the cattle achieve the maturity or preferred saleable liveweight). It has to be noted that fast growing calves that attain 150 kg (the weaning threshold on the farm) will be weaned at a younger age, and there is possibility that rumen function of these calves may have not yet fully developed to digest feed concentrate with a high PKC component (and weight loss after weaning may therefore become a more significant issue).

(iii) Exploration of ways to reduce the adverse effect of moisture on herbage intake during rainy periods (other than spreading the herbage on the floor) — a hypothesis for evaluation is that cattle reject damp herbage because of fungus that can propagate on damp herbage.

(iv) Development of a pasture husbandry package to define fertiliser (especially N) application regime, and harvesting cycle for increasing pasture production towards the potential DM yield (14–20.6 kg DM ha^{-1} yr^{-1}) and ME of 9.5 MJ kg DM^{-1} at harvesting — where feed supplement is used (see (ii) above), concentrate of consistent ME and CP content of at least at 11.5 MJ kg DM^{-1} and 14%, respectively, is needed. Important factors to be considered are types, rates and timing of fertiliser application, cutting intensity and interval, and the effects of both fertiliser and harvesting policies on herbage nutritive value (Chin, 1995). A component of the pasture husbandry package is to define the nutrient requirements and application schedule to prevent the cattle from death because of alkaloids and oxalate toxicity, especially when *S. sphacelata* 'Kazungula' is used in the system (as will be discussed in last paragraph of Section 5.4.1.4). In monitoring forage nutritive value, avoidance of the cost of unnecessary chemical analyses would be important. Hence occasional chemical analyses and development of assessments that can be made on farm, such as visual pasture quality and body condition scores would be essential monitoring tools for the improved future system. With respect to the fertiliser application component of a pasture husbandry package, there is also a need to produce a report about pasture nutrient management on the farm including the history of how the fertiliser scheme currently recommended for the farm was prepared, and especially on what logical basis it was formulated so that incoming managers (when staff turnover occurs) could better understand the present practice and options for revision. Another factor to be incorporated in formulating fertiliser policy is the economic cost and benefits of fertiliser use, since at the present time fertiliser application is often constrained by lack of funds, and confirmation of profitability of fertiliser use would provide more incentive not to miss applications to meet budget deficits.

(v) Investigation of the relevance of developing a conservation system to avoid feed waste in the event of a surplus occurring — in this system, where the cut-and-carry paddocks can be managed without the interference of the cattle, the pasture production could be lifted by fertiliser or N application. Possible approach for consideration includes drying and pelleting (if the farm budget permitted, as this is known to be expensive: Preston and Leng, 1987) or ensilage. The conserved feed could be used to meet the feed demand of the cattle during months of high rainfall or ENSO.

4.4.4 Future study related to the use of MEB for system quantification

The approach used to capture the system performance in this study is proposed for other beef cattle production systems in Sabah to identify the opportunities to improve the systems. In the present study, the MEB provides a tool to understand the cut-and-carry feedlot system beyond the conventional analysis of animal growth. For example, it allows assessment of annual feed demand and supply, which elucidates the upper limit of herbage production, and assessment of monthly feed demand and supply, which indicates the absence of seasonality of herbage supply. In addition, it allows assessment of FCE, which permits selection of an efficient system configuration from the past for future use and improvement, and analysis of relationship between FCE and key farm variables, such as, N application and rainfall, and allows an identification of key farm details of efficient system. Also it allows assessment of feed cost of liveweight loss and some evaluation of the impact of weaning-related weight loss on the FCE of the system.

4.5 Conclusions

Based on the analyses in this chapter, the following conclusions can be made:

- The current average herbage harvested in the system is 6.22 t DM ha^{-1} yr^{-1} with the highest value recorded being 7.42 t DM ha^{-1} yr^{-1}. This is much lower than the potential herbage production based on light and rainfall for the environment in the region.
- The animal production in this system is limited by marginal herbage ME and CP values (7.7–8.5 MJ ME kg DM^{-1} and 9%–11% CP), with currently about 69% of consumed metabolisable energy being allocated in the system to body maintenance. Part of the limitation is a technical

error associated with human judgement on the quantity and quality of herbage supplied to the cattle on a daily basis.

- Although the cattle in the system were raised in confinement, as the system is still pasture-based (cut-and-carry), the FCE is affected by N application and the relationship between the latter and farm rainfall.
- The feed concentrate use in the system is 1.80 t DM ha^{-1} yr^{-1} (as herbage equivalent), and feed concentrate use could be reduced by targeting improved pasture productivity and quality. However, with ME of 11.5 MJ kg DM^{-1} and CP of 14%, the feed concentrate is seen as a means to increase FCE, and especially to address marked reduction of liveweight after arrival of calves in the feedlots. Every batch of feed concentrate still needs to be tested before purchase or after production (on-farm) for quality assurance purposes.
- The first step to improving the animal production of the system should be to configure current system for optimal FCE. At the current pasture production levels in the system, optimal FCE is achieved at a stocking rate of approximately 994 kg animal LWT ha^{-1} (a CSR of 96 kg LWT T DM^{-1} offered).
- A second step to improve the animal production of the system would be development of a pasture husbandry package that included guidelines for nutrient (N, P and S) application, pasture ME and CP enhancement, and timing and intensity of harvesting. Suggested targets for this phase are 14–26 t DM ha^{-1} yr^{-1} herbage harvested with ME >9.5 MJ kg DM^{-1} and CP >13%.

Chapter 5

Feed Profile Analysis of a Grazing System Using Metabolic Energy Budgeting and Implications for Beef Production and Future System Design in Sabah

Abstract. Metabolic energy budgeting (MEB) was used to capture the feed demand and supply patterns and performance of a grazing cattle farming system in Sabah to identify the opportunities to improve these systems. The animal data used comprised 30,166 monthly liveweight records for 1,353 cattle, and key farm information kept by the case farm for Brahman Cow-calf, Bali Cow-calf, Droughtmaster Cow-calf, Heifer and Brahman Bull Units during January 2008 to December 2013. The analysis also involved summary statistics like FCE and its correlation with rainfall and N application, to assess which system configurations provide the best outcome. For further insight, nutritive value analyses of herbage being consumed, and pre-grazing herbage mass measurements (separated in time to estimate herbage accumulation) were conducted on the grazing farm studied, and on some other similar farms in Sabah for data comparison. The results indicated that the feed demand on the different units ranged from 4.59 to 8.57 t DM ha^{-1} yr^{-1} (3.74–7.16 t herbage DM ha^{-1} yr^{-1} + 0.85–1.41 t PKC as herbage DM ha^{-1} yr^{-1}). By contrast with the MEB modelling of estimated feed consumed, potential herbage production estimates derived from a short term cutting trial were 6.9–20.6 t DM ha^{-1} yr^{-1}. The reasons for the difference are not well defined in this study but may include poor grazing management, low herbage production due to soil acidity, low soil fertility and invasion of non-sown species, and low nutritive value of herbage (7.0–8.9 MJ ME kg DM^{-1}; 8%–14% CP) and sometimes PKC (e.g., 7.2 MJ ME kg DM^{-1}). FCE of the system was correlated with N application and rainfall, and was not necessarily high at high system per ha annual feed demand. The recommended first step for system development is to adjust a farm system configuration towards that of the most efficient FCE among those observed for the system studied. This occurred at 506 kg animal LWT ha^{-1}, or 94 kg animal body weight t^{-1} herbage offered (CSR), which is close to that recommended on dairy farms in NZ); The second step is improvement of pasture husbandry to improve herbage ME (e.g., 9–10 MJ ME kg DM^{-1}) and CP (e.g., 13%–16%) and revision of feed concentrate use either to eliminate it or to use it tactically to prevent marked animal liveweight loss and to improve pregnancy and calving rates; and a third step is change directed at increasing herbage production towards local yield potential (i.e., 14–26 t DM ha^{-1} yr^{-1}).

5.1 Introduction

Grazing systems are one of the system types used for beef cattle production in Sabah. Grazomg systems are practiced by almost 90% of the 1800 cattle farmers in this state. The productivity of the grazing system, however, needs to be improved to meet the beef demand (DVSAI, 2008). As noted earlier (Section 2.1.2), the local beef production in Sabah meets only 5% of the demand (DVSAI, 2014). Various constraints have hindered the development of the pasture-based beef production systems in Sabah. One is development of grazing land takes considerable time. A study in 1976 identified 175,185 ha in Sabah with potential to be developed for grazing (Thomas et al., 1976a–d). Fifteen years later, only 21,698 ha of land had been officially allocated to livestock farming (Awang Salleh, 1991), and of that area, only 8,128 ha was planted with improved pasture (Chew and Ibrahim, 1992). There is also a problem that only a few private individuals have access to capital to buy both land and cattle. Another fundamental limitation is a lack of knowledge on how to set up and maintain a grazing system in Sabah (Awang Salleh, 1991; DVSAI, 2008), which is apparently a long-standing problem with tropical pastures.

Formal pasture research on grazing system in Sabah commenced in 1963, with early research projects including introduction and evaluation of pasture species, study of herbage growth and nutrition, and investigation of animal performance on pasture under different management systems (Chew, 1991). While those studies covered the essential components of a pasture-based beef production system for conditions in Sabah, they resulted in a somewhat stagnant local beef production practice, and little further development of pastoral beef systems in Sabah has occurred subsequently. As stated earlier (Section 4.1), one of the problems is a lack of information about the operation of the systems, especially feed demand and supply, with which an analysis can be carried out to identify strategies for possible improvement of the systems. One factor contributing to this problem is a lack of analytical tools to capture the system details.

As a continuation of the work in Chapter 4 to explore how system analytical methodologies used in New Zealand might be applied to pastoral systems in Sabah, a feed demand and supply analysis of the current grazing system on a leading government demonstration farm (described below) was undertaken. The focus was to capture the feed profile of the system with the spreadsheet tool developed in the New Zealand phase of the study (Chapter 3) to identify opportunities to improve the system. As was the study in Chapter 4, the analysis is based on MEB that allows determination of feed demand, but also uses summary statistics like feed conversion efficiency (FCE) and its correlation with rainfall and N application, to assess which system configurations provide the best outcomes. Also for further insight, nutritive value analyses of herbage being consumed, and some pre-grazing herbage mass measurements (separated in time to estimate herbage accumulation) were conducted on the grazing farm studied, and on some other similar farms in Sabah for data comparison with those on the grazing farm studied.

5.2 Materials and methods

5.2.1 Case farm: SPT Tawau

The study was carried out at Stesen Pembiakan Ternakan Batu 16 Tawau (SPT Tawau), Sabah (see Section 4.2.1). The production records for the grazing cattle farming system included in this study were those for January 2008 to December 2013; the farm data were collected between June and October 2014, together with the cut-and-carry feedlot data reported in Chapter 4. As also stated in Chapter 4, operating costs (average 2009–2013) reported for the system were: RM961 ha^{-1} yr^{-1} total cost, RM61 ha^{-1} yr^{-1} herbicide, RM19 ha^{-1} yr^{-1} overall fertiliser application, RM0.61 kg N^{-1} nitrogen application, RM46 ha^{-1} yr^{-1} total supplement including PKC (i.e., RM0.50 per kg total supplement), RM30 ha^{-1} yr^{-1} PKC (RM0.52 kg PKC^{-1}), and RM7 ha^{-1} yr^{-1} salt lick. There is no specific financial information reported for the grazing units (see below) at SPT Tawau.

5.2.1.1 Farm details for grazing system at SPT Tawau

The grazing system at SPT Tawau to be analysed in this chapter has 5 subunits (or 5 subsystems): Brahman Cow-calf, Bali (*Bos javanicus* d'Alton, 1823) Cow-calf, Droughtmaster Cow-calf, Heifer and Brahman Bull Units. These occupy 322 ha land (effective area) of gently undulating topography.

(a) Brahman Cow-calf Unit

The Brahman Cow-calf Unit comprised 11 paddocks. The cattle were divided into 3 or sometimes 4 groups and allocated 3 or sometimes 4 paddocks per group. The total area of the unit in 2014 was 195 ha. Until 2012 the unit operated on 161.1 ha. However, the effective area was enlarged to approximately 175 ha in 2012 and to 195 ha in 2013, with the expansion occurring when the Droughtmaster Cow-calf Unit was phased out. The main grass species used on this unit were *B. decumbens*, *P. maximum* 'Guinea', and *D. milanjiana* 'Jarra'. Soil samples were collected from this unit and analysed and key soil characteristics were: pH, 4.5±0.0; total N, 0.1±0.1%; available P, 24.2±12.6 ppm; K, 0.1±0.0 meq%; Ca, 1.5±0.3 meq%; and Mg, 0.3±0.3 meq% (see Appendix 5.1 for the chemical tests used). The grazing rotation used for the cattle groups was 28 days (from the first day grazing on the first paddock until returning to the first paddock again). Calves born on this unit remained with the cows until weaning when the calves were >150 kg (Details in Appendix 5.2; including for Bali and Droughtmaster cattle described below). Cattle were weighed once monthly, or sometimes at two or three month intervals, using a digital scale (TRU–TEST^{TM} HD800). Once weaned, the female calves were transferred to the Heifer Unit (see below), while the male calves were transferred to the cut-and-carry feedlot (Chapter 4). Once >250 kg liveweight, however, the young bulls were returned to the grazing paddocks (in the Brahman Bull Unit, see below; the reason for not sending the weaned Brahman male calves directly to the Brahman Bull Unit is that they can be killed by older cattle.). Mating used a "bull-in/bull-out" system, with bulls run with the cows from Feb until April and from August until October, rather than being run with cows year round just as is normally practiced on other farms in Sabah. One characteristic of the system is that cows may have a high energy demand as a result of being pregnant while still feeding a calf. Cows that do not calve regularly are kept in the herd up to several years (3–5 years), but are eventually culled. The cattle are treated for parasites as required (both for internal and external parasites). Some of the cows in this unit were imported as heifers from Australia. The imported heifers were 18 months old and averaged 260 kg live weight on arrival. For 2008–2014, the average calving percentage in this unit was 42% (= 100 × calves born ÷ cows to bull), the cow productivity was 81.5 (= number of calves weaned × average weaning weight ÷ number of cows joined with bull), and the cow efficiency was 0.19 (= productivity ÷ cow liveweight). Calving interval was 19.0±8.1 months. The average calf loss (including Bali and Droughtmaster Cow-calf Units described below) was 9%, with the causes of loss including: dystocia, bleeding nose (epistaxis), abandonment by the mother, poor milk supply from the mother because of mastitis, accidental death (e.g. fell into a ravine, drowned in a muddy area, snake bite), and attack by stray dogs.

(b) Bali Cow-calf Unit

The Bali Cow-calf Unit is operated on two paddocks of 26.3 ha total area. Both paddocks were planted with *S. sphacelata* 'Kazungula'. However, many remnants of *A. compressus* and *B. decumbens* were found in the paddocks. Soil characteristics for this unit were: pH, 4.8±0.2; total N, 0.1±0.0%; available P, 14.4±10.4 ppm; K, 0.1±0.0 meq%; Ca, 1.4±0.7 meq%; and Mg, 0.7±0.5 meq%. The grazing rotation was 14 days. A few of the cattle in this unit were Bali crossbred (Brahman × Bali by conventional mating). The animal management was similar to that on the Brahman Cow-calf Unit, except that the weaned male calves sent to the cut-and-carry feedlot system were later sold once >290 kg liveweight and not returned to the grazing system. For 2008–2013, the average calving percentage, cow productivity, and cow efficiency were, respectively, 47%, 77.1, and 0.25 (The values were calculated as in 5.2.1.1(a) above). Calving interval was 19.5±9.8 months.

(c) Droughtmaster Cow-calf Unit

The Droughtmaster Cow-calf Unit had 38.5 ha total area in three paddocks, but as noted above was phased out from 2008 to 2013 (the breed was phased out by the farm because of the longer calving interval, i.e., 23.7±11.8 months, compared to the Brahman and Bali and not because of any animal growth rate issue), and the area had been reduced to 4 ha by 2013. However, the transfer of land to the Brahman Cow-calf Unit happened about a year after reduction in animal numbers (due to delay in repairing and realigning fences) so that in the interim a small number of remaining cattle were grazing the entire 38 ha area. The analysis for this unit is therefore compiled from the historical records before it was phased out. The main grass species planted on this unit were *B. decumbens* and *S. sphacelata* 'Kazungula'. Soil samples collected from this unit were included with the analyses of those from the Brahman Cow-calf Unit. The grazing rotation used was 28 days but was reduced to 14 days in 2012. The animal management was similar to that on the Brahman Cow-calf Unit, except that as with the Bali

Cow-calf Unit the weaned male calves sent to the cut-and-carry feedlot system were sold once >380 kg liveweight and not returned to the grazing system. Historical reproductive performance was: calving percentage, 46%; cow productivity, 82.9; and cow efficiency, 0.18 (The values were calculated as in 5.2.1.1(a) above).

(d) Heifer Unit

The Heifer Unit is operated on four paddocks of 52.6 ha total area, with *B. decumbens* and *S. sphacelata* 'Kazungula' as the main sown grasses. Soil characteristics were: pH, 4.8±0.2; total N, 0.1±0.0%; available P, 9.7±3.5 ppm; K, 0.2±0.2 meq%; Ca, 1.0±0.4 meq%; and Mg, 0.4±0.3 meq%. The grazing rotation used was 28 days. The Brahman, Bali, and Droughtmaster heifers were all farmed in this unit. The heifers were transferred to the Brahman, Bali or Droughtmaster Cow-calf Units once >250 kg liveweight.

(d) Brahman Bull Unit

The Brahman Bull Unit is operated on three paddocks of 43.3 ha total area. All three paddocks are planted with *B. decumbens*. Soil characteristics were: pH, 4.6±0.3; total N, 0.1±0.0%; available P, 17.6±5.3 ppm; K, 0.1±0.0 meq%; Ca, 1.6±0.3 meq%; and Mg, 0.3±0.1 meq%. The grazing rotation used was 28 days. The non-breeding bulls were brought in from the cut-and-carry feedlot at >250 kg liveweight. Some of the bulls were imported from Australia at 13 months of age at an average live weight of 350 kg. The number of bulls on the farm was gradually increased from 2008 and 2013, but the effective area was not enlarged to accommodate that change.

5.2.2 Data collection

5.2.2.1 Animal data for MEB

Data cards of cattle farmed at SPT Tawau during 2008 to 2013 were obtained from the farm manager. For all five grazing units at the farm, a comprehensive data card exists for every animal in the unit. Information recorded included: the identity of sire and dam; date records at birth, weaning, transfer-in, selling (and transfer-out) and death (if applicable); liveweight at birth and at approximately monthly intervals throughout the lifespan of the animal; records of health treatment received by the animal; and information on dates run with the bull and pregnancy test results for the cows. The key information for the grazing units studied is presented in Table 5.1.

Table 5.1 Key farm statistical information of grazing cattle farming system at SPT Tawau (2008–2013): (a) Annual and (b) Monthly.

(a)	08	09	10	11	12	13	$\overline{x}$	SD	CV %
Rainfall (mm yr^{-1})	1392	1657	1645	2090	2238	1999	1836.8	321.9	18
Brahman: (ha)	161.06	161.06	161.06	161.06	175.26	195.46	169.2	14.1	8
N fertiliser (kg ha^{-1} yr^{-1})	NR	25	62	30	26	5	30	21	70
Head, Cow/Calf	155/53	174/49	179/48	184/56	193/43	206/48	182/49	17/4	9/9
% Calving	71.0	40.2	48.6	30.1	29.1	32.2	41.9	17.2	41
Age (mo hd^{-1}), Cow/Calf	63.7/8.1	69.6/4.8	71.9/4.3	71.1/3.9	72.6/4.0	75.3/4.8	70.7/5.0	3.9/1.6	6/32
LWT (kg hd^{-1}), Cow/Calf	390/104	424/85	431/91	419/98	420/98	415/107	417/97	14/8	3/8
LWG, Cow (kg hd^{-1} yr^{-1})	78.0	74.8	87.6	63.9	68.6	55.4	71.4	11.3	16
LWG, Calf (kg hd^{-1} yr^{-1})	138.6	192.1	213.1	224.2	230.4	212.5	201.8	33.6	17
LWL, Cow (kg hd^{-1} yr^{-1})	–37.0	–55.6	–38.1	–47.7	–51.1	–43.3	–45.5	7.3	16
LWL, Calf (kg hd^{-1} yr^{-1})	–2.4	–0.2	–1.1	0.0	–1.5	–1.6	–1.1	0.9	82
Bali: (ha)	26.30	26.30	26.30	26.30	26.30	26.30	26.3	0.0	0
N fertiliser (kg ha^{-1} yr^{-1})	NR	26	53	39	13	0	26	21	79
Head, Cow/Calf	34/22	36/18	41/19	43/16	45/13	49/22	41/18	6/4	14/20
% Calving	64.0	69.0	33.2	35.6	32.5	49.7	47.3	18.0	40
Age (mo hd^{-1}), Cow/Calf	72.8/7.7	78.3/5.8	81.6/6.2	84.8/5.9	79.1/4.6	81.3/7.3	79.7/6.3	4.1/1.1	5/18
LWT (kg hd^{-1}), Cow/Calf	301/99	303/92	308/91	312/89	307/80	298/85	305/89	5/6	2/7
LWG, Cow (kg hd^{-1} yr^{-1})	38.0	51.1	42.9	26.7	43.6	27.7	38.3	9.6	25
LWG, Calf (kg hd^{-1} yr^{-1})	127.7	145.0	131.8	157.1	155.5	114.9	138.7	16.7	12
LWL, Cow (kg hd^{-1} yr^{-1})	–31.2	–39.6	–32.9	–31.6	–36.0	–40.9	–35.4	4.2	12
LWL, Calf (kg hd^{-1} yr^{-1})	–4.8	–1.5	–2.3	0.0	–3.2	–3.4	–2.5	1.7	65
Droughtmaster: (ha)	38.45	38.45	38.45	38.45	24.25	4.05	30.3	14.1	46
N fertiliser (kg ha^{-1} yr^{-1})	NR	0	121	41	33	0	39	50	127
Head, Cow/Calf	58/33	39/20	30/14	22/13	8/7	1/1	26/15	21/11	79/77
% Calving	81.0	43.3	33.6	22.2	50.0	–	46.0	36.5	79
Age (mo hd^{-1}), Cow/Calf	117.6/10.0	122.5/8.2	132.2/6.2	143.5/6.7	161.7/8.2	153.7/2.6	138.5/7.0	17.4/2.5	13/36
LWT (kg hd^{-1}), Cow/Calf	450/94	463/94	473/99	468/95	446/95	451/33	459/85	11/26	2/30
LWG, Cow (kg hd^{-1} yr^{-1})	48.3	70.5	55.8	42.4	28.5	34.2	46.6	15.2	33
LWG, Calf (kg hd^{-1} yr^{-1})	106.9	143.2	169.2	147.9	133.1	85.0	130.9	30.3	23
LWL, Cow (kg hd^{-1} yr^{-1})	–43.4	–51.6	–45.6	–67.1	–32.4	–0.5	–40.1	22.5	56
LWL, Calf (kg hd^{-1} yr^{-1})	–2.7	–9.1	–30.2	–34.0	–37.1	0.0	–18.9	16.8	89
Heifer: (ha)	52.61	52.61	52.61	52.61	52.61	52.61	52.6	0.0	0
N fertiliser (kg ha^{-1} yr^{-1})	NR	0	46	17	9	15	17	17	99
Head/Age (mo hd^{-1})	50/23.5	55/20.4	53/17.0	64/16.5	67/16.8	58/18.1	58/19	6/3	11/15
LWT (kg hd^{-1})	209	207	212	202	200	205	206	5	2
LWG (kg hd^{-1} yr^{-1})	69.31	75.74	85.85	67.60	74.02	73.95	74.42	6.41	9
LWL (kg hd^{-1} yr^{-1})	–8.65	–5.15	–7.70	–11.64	–15.22	–9.53	–9.64	3.47	36
Brahman Bull: (ha)	43.30	43.30	43.30	43.30	43.30	43.30	43.3	0.0	0
N fertiliser (kg ha^{-1} yr^{-1})	NR	0	57	34	70	27	38	27	73
Head/Age (mo hd^{-1})	6/72.4	7/28.5	14/25.7	32/26.1	47/31.5	72/37.3	30/37	26/18	88/49
LWT (kg hd^{-1})	428	322	313	331	378	386	360	45	12
LWG (kg hd^{-1} yr^{-1})	68.36	105.08	126.98	110.12	159.94	65.74	106.03	35.79	34
LWL (kg hd^{-1} yr^{-1})	–3.29	–17.45	–41.90	–21.86	–48.40	–32.49	–27.56	16.66	60

(Table 5.1 Continued.)

(b)	J	F	M	A	M	J	J	A	S	O	N	D	$\overline{x}$	SD	CV %
Rainfall (mm mo^{-1})	128.3	102.9	183.9	165.1	154.9	152.4	141.2	237.3	139.1	133.2	137.9	160.6	153.1	33.5	22
Brahman: (ha)	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	169.2	0.0	0
N fertiliser (kg ha^{-1} mo^{-1})	0.4	0.9	1.9	4.1	0.0	2.1	2.7	4.5	0.4	0.5	1.6	6.1	2.1	1.9	91
Head, Cow/Calf	172/45	176/45	178/42	178/41	180/57	182/63	182/56	186/57	185/50	187/46	186/41	190/48	182/49	5/7	3/15
Age (mo hd^{-1}), Cow/Calf	70.2/4.5	69.5/4.7	70.2/5.1	70.6/5.2	70.6/4.7	70.5/4.6	71.3/4.2	70.5/5.1	71.0/5.5	71.1/5.9	71.5/6.1	71.4/4.7	70.7/5.0	0.6/0.6	1/12
LWT (kg hd^{-1}), Cow/Calf	414/76	414/82	418/90	418/100	415/86	415/90	415/81	415/100	418/111	419/122	420/126	419/100	417/97	2/16	1/17
LWG, Cow (kg hd^{-1} mo^{-1})	6.95	6.67	5.12	4.58	4.66	5.27	7.16	7.15	5.94	5.78	5.82	6.29	5.95	0.92	15
LWG, Calf (kg hd^{-1} mo^{-1})	16.07	16.53	17.99	16.95	19.27	15.23	19.97	16.63	16.18	16.51	13.86	16.66	16.82	1.65	10
LWL, Cow (kg hd^{-1} mo^{-1})	–3.66	–2.78	–4.51	–4.76	–4.64	–3.73	–2.99	–3.01	–2.79	–3.54	–4.19	–4.90	–3.79	0.79	21
LWL, Calf (kg hd^{-1} mo^{-1})	–0.12	–0.12	–0.12	–0.20	–0.13	–0.06	–0.12	–0.11	–0.10	–0.01	–0.02	–0.01	–0.09	0.06	62
Bali: (ha)	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	0.0	0
N fertiliser (kg ha^{-1} mo^{-1})	0.0	0.0	0.0	4.4	0.0	0.0	6.1	2.6	0.0	0.0	0.0	10.7	2.0	3.5	174
Head, Cow/Calf	41/19	41/17	40/15	40/16	40/18	40/21	40/22	42/22	42/19	43/18	43/17	43/18	41/18	1/2	3/12
Age (mo hd^{-1}), Cow/Calf	77.9/6.5	79.1/6.7	80.2/6.5	78.4/6.4	78.9/6.1	79.9/5.6	80.5/5.0	79.0/6.1	80.0/6.2	79.9/7.0	80.7/7.1	81.5/6.0	79.7/6.3	1.0/0.6	1/9
LWT (kg hd^{-1}), Cow/Calf	304/83	304/91	305/88	306/86	306/81	305/79	305/82	304/96	304/93	305/102	305/106	305/84	305/89	0.7/8	0/9
LWG, Cow (kg hd^{-1} mo^{-1})	3.47	3.33	3.33	2.92	2.46	2.78	3.68	3.52	3.68	3.43	3.56	2.19	3.19	0.49	15
LWG, Calf (kg hd^{-1} mo^{-1})	10.77	9.76	9.80	10.84	13.70	13.58	12.96	10.80	11.75	12.01	11.16	11.56	11.56	1.32	11
LWL, Cow (kg hd^{-1} mo^{-1})	–2.68	–2.52	–2.13	–2.61	–3.10	–2.66	–2.64	–3.24	–2.49	–3.02	–3.24	–5.06	–2.95	0.74	25
LWL, Calf (kg hd^{-1} mo^{-1})	–0.21	–0.15	–0.20	–0.26	–0.12	–0.06	–0.19	–0.14	–0.23	–0.23	–0.42	–0.33	–0.21	0.10	45
Droughtmaster: (ha)	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	0.0	0
N fertiliser (kg ha^{-1} mo^{-1})	0.0	1.3	0.0	14.7	0.0	3.8	2.8	8.4	0.0	0.0	0.0	3.0	2.8	4.5	159
Head, Cow/Calf	35/17	30/18	29/17	30/16	29/16	26/15	26/15	24/14	23/12	23/12	22/13	21/13	26/15	4/2	16/15
Age (mo hd^{-1}), Cow/Calf	135/8.9	138/7.0	139/7.4	136/7.5	137/6.5	143/6.2	144/6.1	146/5.9	138/6.2	135/7.1	135/7.5	136/7.8	139/7.0	3.8/0.9	3/13
LWT (kg hd^{-1}), Cow/Calf	456/88	462/90	463/81	456/88	457/77	467/78	466/76	466/86	457/71	447/84	452/97	453/103	458/85	6/9	1/11
LWG, Cow (kg hd^{-1} mo^{-1})	4.95	3.91	4.69	4.45	4.62	3.19	2.08	3.67	3.41	5.12	3.55	2.98	3.88	0.91	23
LWG, Calf (kg hd^{-1} mo^{-1})	7.54	7.81	11.34	6.93	9.10	11.22	12.42	12.46	17.28	12.49	10.86	11.46	10.91	2.83	26
LWL, Cow (kg hd^{-1} mo^{-1})	–3.20	–3.50	–2.89	–3.97	–2.77	–3.87	–4.04	–3.23	–3.97	–2.15	–2.88	–3.62	–3.34	0.59	18
LWL, Calf (kg hd^{-1} mo^{-1})	–2.35	–2.43	–0.45	–1.75	–2.00	–0.67	–2.28	–2.29	–0.14	–1.61	–2.30	–0.60	–1.57	0.86	55
Heifer: (ha)	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	0.0	0
N fertiliser (kg ha^{-1} mo^{-1})	0.0	0.0	0.0	3.4	0.0	0.0	3.5	1.7	0.0	0.0	1.3	7.4	1.4	2.3	159
Head/Age (mo hd^{-1})	70/19.8	68/19.2	63/19.3	56/18.4	49/18.8	52/19.0	61/18.4	52/18.3	56/18.3	54/18.6	56/18.6	58/17.9	58/19	6/1	11/3
LWT (kg hd^{-1})	205	205	204	202	205	208	207	205	208	208	209	205	206	2	1
LWG (kg hd^{-1} mo^{-1})	5.09	5.18	5.31	5.93	6.99	6.73	6.52	8.28	6.54	6.81	6.03	5.03	6.20	0.97	16
LWL (kg hd^{-1} mo^{-1})	–0.83	–1.00	–0.71	–0.65	–1.04	–0.63	–0.47	–0.54	–0.50	–0.92	–1.00	–1.36	–0.80	0.27	33
Brahman Bull: (ha)	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	0.0	0
N fertiliser (kg ha^{-1} mo^{-1})	0.0	0.0	1.6	2.7	0.0	5.2	4.2	4.8	0.0	3.0	9.0	4.7	2.9	2.8	96
Head/Age (mo hd^{-1})	24/41.0	24/41.0	25/40.9	27/37.2	31/36.7	31/36.5	30/35.5	31/35.5	32/36.3	32/35.2	35/35.3	35/32.0	30/37	4/3	13/7
LWT (kg hd^{-1})	361	368	359	349	351	356	358	360	369	367	366	353	360	7	2
LWG (kg hd^{-1} mo^{-1})	6.07	5.92	6.51	15.16	10.56	8.25	10.38	11.10	9.15	6.11	7.27	9.59	8.84	2.75	31
LWL (kg hd^{-1} mo^{-1})	–1.90	–5.31	–7.61	–2.44	–0.57	–0.95	–1.24	–1.34	–0.27	–1.07	–3.43	–1.44	–2.30	2.17	95

A small number of crossbred dairy cows (*Bos indicus* × *Bos taurus*) in 2008 and 2009 were included in the Brahman Cow-calf Unit. NR: not reported by the farm. LWT: Liveweight. LWG: Liveweight gain (averaged for cattle that gain weight). LWL: Liveweight loss (averaged for cattle that lost weight). LWG plus LWL is net LWG. The two sources of N fertiliser on the farm are urea and sulphate of ammonia (SOA). SD (standard deviation) is based on the annual or monthly means.

Information from all cards for the period January 2008 to December 2013 was collected and collated into a Microsoft®Excel spreadsheet. Individual animals with their identity number were assigned to rows and the various data into columns. This arrangement allowed monthly cattle number in each unit, and live weight of individual animals, to be extracted for each unit, for calculation of system feed demand over the duration of the study period. Every calf was also linked to its mother to identify the pregnancy and lactation periods of each cow. Failed pregnancy was detected from the pregnancy test information in the report cards. In months where liveweight records were not available, the average of the previous and following month's liveweight data was used. At the start of the study period in 2008 there were 21 Friesian × Sahiwal dairy cattle included in the data collected, but these had all left the farm by the end of 2009. Overall, the data set contained 30,166 monthly live weight records for 1,353 cattle and the completed spreadsheet contained approximately 100 MB of data. The average total stock number at any one time for the 5 units (356 ha) was 250 cows, 82 calves, 58 heifers and 30 non-breeding bulls.

5.2.2.2 Available data on feed supply

Similar to the study in Chapter 4 (Section 4.2.2.3), while the primary thrust of this study was to define the system through the animal demand as calculated by MEB, information on feed supply was collected as opportunity allowed.

(a) Supplement fed

Amounts of PKC fed to the cattle during 2008 to 2013 were obtained from interview with the farm manager and staff and from the farm logbook. The cattle on all units were supplied with pure PKC at 2 kg per head per day. The farm recorded that approximately, 95% of the PKC was eaten. However, approval of expenditure budgets for each calendar year was normally not available until March. Therefore, during January to March animals had to be fed with PKC stock remaining from the previous year, and the supply per animal was halved on all grazing units in this period, except on the heifer unit where PKC feeding was maintained for this stock class as a priority. The energy value of herbage "grown and eaten" was thus able to be calculated as the difference between animal demand and supplement consumed.

(b) Herbage accumulation

To allow some cross checking of herbage accumulation against metabolic energy calculations (see Section 5.2.3.1 below), a partial set of herbage accumulation data was compiled in 2014. The data collection strategy was to measure herbage mass to simulate grazing height in mid regrowth and the day before grazing commenced of selected paddocks, allowing calculation of accumulation rate by difference. The sampling interval for these cuts was either 14 days or 7 days, depending on the forage species and rotation length of the sampled paddock.

Collection of herbage on the grazing paddocks — Herbage was collected between July and October 2014 at 7 days and 1 day before grazing for *S. sphacelata* 'Kazungula' and *A. compressus* pastures, and at 14 days and 1 day before grazing for *B. decumbens*, *P. maximum* 'Guinea' and *D. milanjiana* 'Jarra' pastures. The sampling procedures were adapted from the technique of Boswell (undated). In the mid-regrowth collection, the paddocks of the respective species were identified in each grazing unit. Two paddocks per species were selected. On both selected paddocks, 10 typical patches of the herbage were selected, and the sampling was carried out using the same methodology described in Section 4.2.2.3(b), except that the biomass was cut at 8 cm above ground level for *P. maximum* 'Guinea' and at 4 cm above ground level for *B. decumbens*, *S. sphacelata* 'Kazungula', *D. milanjiana* 'Jarra' and *A. compressus* for consistency with the normal grazing residual height of the farm. After collection, the samples were processed as described in Section 4.2.2.3(b).

For the second (pre-grazing) sample collection, herbage was sampled from a quadrat placed adjacent to each of the previous quadrats and processed as above to obtain the pre-grazing green mass and dry weight of total herbage to grazing height and the components.

Collection of herbage on other grazing farms in Sabah for comparison — to check for possible variability of herbage accumulation rate between farms, similar data were collected on two other government farms, named Pusat Pembanyakan Ternakan Timbang Menggaris (PPT Timbang Menggaris) and Entilibon (PPT Entilibon), located in north western and central Sabah, respectively. These farms are closely similar to SPT Tawau in grazing management. On PPT Timbang Menggaris, *B. decumbens*, *S. sphacelata* 'Kazungula' and *A. compressus* were available and all were sampled. On PPT Entilibon, only *B. decumbens* was available for sampling. The selected cutting intervals before grazing and the sampling technique used were similar to those described above for SPT Tawau.

(c) Feed nutritive value analyses

During herbage sampling described above, samples from quadrats 2, 5 and 8 in each paddock were retained after oven drying, ground to powder, and sent to the Makmal Kesihatan Awam Veterinar, Department of Veterinary Services, West Malaysia (Lab references ST3385/14 and ST3596/14) for analysis of ME and CP content according to the protocols set out in the Malaysian Standard for Testing for Animal Feed Stuffs (MS: 3.1982).

PKC samples were also collected monthly from July to September 2014 from the material currently being fed to the animals and sent to the same laboratory for ME and CP content analysis.

5.2.2.3 Additional farm data

Two factors that are likely have a large influence on herbage accumulation and hence, system performance are rainfall patterns and fertiliser use. Therefore, to assist with interpretation of herbage accumulation and animal performance data, monthly rainfall data recorded at the farm and fertiliser use data were obtained for 2008–2013 from the farm logbook (Table 5.1).

5.2.3 Analysis of system feed profiles

5.2.3.1 Modelling of monthly and annual feed demand and consumption

The feed demand in the six grazing units was modelled with one month time steps from January 2008 to December 2013. As in Chapter 4 (Section 4.2.3.1), the monthly feed demand was assumed to equal the monthly metabolic energy requirements (including energy for weight gain) of cattle in the units during the study period and was taken as the feed consumption in the system. The equations used to calculate the metabolic energy requirements were similar to those stated in Chapter 3 and Chapter 4 and set out in Appendix 4.3. The Microsoft®Excel spreadsheet model developed for the analysis performs a separate calculation for each animal and sums the results for individual animals to arrive at a total for each grazing unit. Specifically, the metabolic energy requirements of each animal were calculated for: body maintenance (Eq. 2), liveweight gain (Eq. 3.1), grazing activity (Eq. 4), pregnancy (Eq. 5), and lactation (Eq. 6). The animal data used in the calculation of metabolic energy requirements were the 1,353 cattle and 30,166 monthly live weight records (see Appendix 5.3 for samples of liveweight trajectories of the cattle). For simplicity, the metabolic energy requirements from the small number of dairy cattle on the farm were included in the Brahman cow–calf unit. Based on the laboratory results for ME of herbage available on the farm, the monthly total metabolic energy requirements in each unit were converted as herbage equivalent to obtain the monthly total feed demand. The monthly amount of PKC fed to the cattle was also converted to herbage equivalent and deducted from the total feed demand to obtain the estimated herbage consumption of the cattle in the system. To account for the differences in area between farm units, data are presented variously as MJ ME ha^{-1} d^{-1}, kg herbage DM ha^{-1} d^{-1} or kg herbage DM ha^{-1} yr^{-1} according to the context of discussion.

5.2.3.2 Feed conversion efficiency

The information on feed demand and animal liveweight gain was extracted from the analyses in Section 5.2.3.1 for every animal on each grazing unit from Jan 2008 until Dec 2013 and used to evaluate the monthly and the annual FCE of each grazing unit. FCE was calculated as the total feed demand (per month or annual) divided by the total liveweight gain in the same period. FCE was calculated as a statistic that can potentially help with evaluation of factors affecting system performance. Correlations (Pearson's) were calculated between FCE, N fertiliser application, and rainfall across 6 years of data (or 5 years for N application, as one year had no records of fertiliser use). The correlation analyses were performed using the StatPlus:mac LE v5.9.50 (AnalystSoft Inc., www.analystsoft.com/en/). Two further factors relevant to understanding reasons for differences in system FCE, occurrence of animal weight loss and the percentage allocation of feed between body maintenance, growth, and other metabolic functions, were also assessed.

5.2.3.3 Feed implications of animal weight loss

It is also of interest in the grazing system to account for the feed implications of animal weight loss, as feed associated with animal weight loss is a feed saving at the time of weight loss, but a feed cost at another time when the weight is regained. Effectively, this creates a transfer of feed in time, but it has a consequence for the system FCE. The weight-loss energy is termed here 'mobilised body energy', or ME_{LWL}. Feed saving from ME_{LWL} when animals lose liveweight was explicitly identified in the metabolic energy calculations (Section 5.2.3.1; Details in Appendix 4.3, Eq. 3.2.1.1 and Eq. 3.2.2.1) and the monthly and annual ME_{LWL} of each grazing unit was calculated. Independent Student's t-Test of unequal variance was performed using the standard statistical functions imbedded in Microsoft®Excel to compare means ME_{LWL} of the 5 grazing units (n = 5) between (a) years of highest feed demand and average years, and (b) years of highest feed demand and years of highest FCE.

5.2.3.4 Allocation of feed energy between metabolic functions

The allocation of feed energy between body maintenance, growth and other metabolic functions in the grazing system was investigated to assess possible relevance to the system FCE. Information from the metabolic energy calculations was organised so as to give grazing unit totals for the various metabolic activities defined by Eq. 2 (body maintenance), Eq. 3.1 (liveweight gain), Eq. 4 (grazing), Eq. 5 (pregnancy) and Eq. 6 (lactation) in Appendix 4.3, so that, the variation in categories of energy required by the various grazing units could be examined. For the cow-calf units, the calculation of energy spent was also separated between the cow and calf.

5.3 Results

5.3.1 System feed profile based on MEB

5.3.1.1 Annual feed demand and supply

Based on MEB, the feed demand (or feed eaten), averaged for grazing units and years, was 4.59 t DM ha^{-1} yr^{-1}, comprising 3.74 t DM ha^{-1} yr^{-1} grazed herbage and 0.85 t (herbage equivalent) DM ha^{-1} yr^{-1} from PKC eaten (Table 5.2). Comparing grazing units, the lowest average feed demand was on the Heifer Unit (2.90 t DM ha^{-1} yr^{-1}) and the highest was on the Bali Cow-calf Unit (6.64 t DM ha^{-1} yr^{-1}). Comparing the data for different years, the average across grazing units for the highest feed demand in any year was 6.70 t DM ha^{-1} yr^{-1} (5.49 t DM ha^{-1} yr^{-1} herbage + 1.21 t DM ha^{-1} yr^{-1} PKC as herbage equivalent; see values in bold in Table 5.2). The highest annual feed demand of any grazing unit was recorded on the Droughtmaster Cow-calf Unit in 2008 at 8.57 t DM ha^{-1} yr^{-1} (7.16 t DM ha^{-1} yr^{-1} herbage + 1.41 t DM ha^{-1} yr^{-1} PKC as herbage equivalent).

Annual herbage consumption for the different grazing units differed between years, especially where changes in farm policy led to differences in animal numbers or stocking rate and system variability ranked: Brahman Cow-calf <Bali Cow-calf <Heifer <Droughtmaster Cow-calf <Brahman Bull Units, as indicated by the coefficient of variation of the annual mean (Table 5.2). Output per unit of feed consumed (FCE) is described and discussed in detail below (Sections 5.3.1.3 and 5.4.1.4), but it is of interest to note at this point that the year of highest herbage consumption does not necessarily align with the year of highest FCE for each grazing unit. For example, for the years of highest FCE in the

respective units, the average feed demand was 5.37 t DM ha^{-1} yr^{-1} (4.43 t DM ha^{-1} yr^{-1} herbage + 0.94 t DM ha^{-1} yr^{-1} PKC).

Table 5.2 Feed demand and supply of grazing cattle farming system at SPT Tawau (2008–2013): (a) Annual and (b) Monthly.

(a) **t DM ha^{-1} yr^{-1}**	08	09	10	11	12	13	$\overline{x}$	SD	CV %
Herbage:									
Brahman	4.20	5.13	*5.26*	**5.23**	4.98	4.57	4.90	0.42	9
Bali	4.64	*4.81*	5.28	5.23	5.55	**6.02**	5.25	0.50	10
Droughtmaster	**7.16**	*5.10*	3.96	2.89	1.68	1.18	3.66	2.24	61
Heifer	1.76	*2.02*	*2.06*	2.27	**2.41**	2.08	2.10	0.22	11
Brahman Bull	0.56	0.59	1.17	2.70	*4.97*	**6.64**	2.77	2.53	91
PKC:									
Brahman	0.82	0.89	*0.91*	**0.95**	0.89	0.85	0.88	0.05	5
Bali	1.23	*1.23*	1.39	1.39	1.43	**1.65**	1.39	0.15	11
Droughtmaster	**1.41**	*0.92*	0.70	0.53	0.35	0.28	0.70	0.42	60
Heifer	0.69	*0.76*	*0.73*	0.88	**0.92**	0.79	0.80	0.09	11
Brahman Bull	0.10	0.12	0.22	0.50	*0.75*	**1.14**	0.47	0.41	88
Total	22.6	21.6	21.7	22.6	23.9	25.2	22.9	1.4	6
Average	4.51	4.31	4.34	4.51	4.79	5.04	4.59	0.28	6

(b) **kg DM ha^{-1} d^{-1}**	J	F	M	A	M	J	J	A	S	O	N	D	$\overline{x}$	SD	CV %
Herbage:															
Brahman	12.6	12.6	13.1	13.2	13.5	13.3	13.3	13.8	13.4	13.8	14.0	14.4	13.4	0.5	4
Bali	14.3	13.9	13.5	13.7	14.0	14.0	14.1	14.9	14.5	15.1	15.3	15.3	14.4	0.6	4
Droughtmaster	12.8	11.5	11.1	11.2	10.7	9.8	9.5	8.8	9.0	8.8	8.6	8.4	10.0	1.4	14
Heifer	6.7	6.5	6.0	5.4	5.0	5.3	6.0	5.5	5.6	5.6	5.7	5.7	5.8	0.5	8
Brahman Bull	6.2	6.5	7.0	7.3	7.5	7.2	7.4	7.9	7.9	7.8	9.3	9.2	7.6	0.9	12
PKC:															
Brahman	2.28	2.33	2.33	2.33	2.45	2.51	2.46	2.52	2.46	2.46	2.43	2.51	2.42	0.08	3
Bali	3.81	3.71	3.61	3.61	3.70	3.82	3.87	3.97	3.88	3.89	3.86	3.87	3.80	0.12	3
Droughtmaster	2.43	2.20	2.12	2.09	2.03	1.88	1.89	1.73	1.66	1.68	1.63	1.62	1.91	0.26	14
Heifer	2.65	2.55	2.38	2.12	1.84	1.96	2.28	1.96	2.09	2.05	2.09	2.19	2.18	0.24	11
Brahman Bull	0.83	0.84	0.87	1.23	1.40	1.40	1.35	1.43	1.44	1.47	1.58	1.61	1.29	0.28	22
Total	64.6	62.6	62.0	62.2	62.1	61.2	62.2	62.5	61.9	62.7	64.5	64.8	62.8	1.2	2
Average	12.9	12.5	12.4	12.4	12.4	12.2	12.4	12.5	12.4	12.5	12.9	13.0	12.6	0.2	2
Pregnancy:															
Brahman	0.18	0.16	0.25	0.38	0.22	0.15	0.05	0.08	0.14	0.23	0.35	0.24	0.20	0.10	49
Bali	0.19	0.26	0.38	0.47	0.43	0.24	0.06	0.10	0.15	0.27	0.43	0.28	0.27	0.13	49
Droughtmaster	0.25	0.21	0.19	0.25	0.24	0.19	0.05	0.07	0.11	0.18	0.13	0.06	0.16	0.07	46
Lactation:															
Brahman	1.20	1.24	1.31	1.34	1.84	1.84	1.73	1.81	1.69	1.65	1.43	1.44	1.54	0.24	16
Bali	3.27	2.90	2.52	2.71	3.05	3.49	3.51	3.62	3.39	3.41	3.14	2.95	3.16	0.34	11
Droughtmaster	2.46	2.43	2.26	2.11	2.05	1.96	1.99	1.82	1.71	1.76	1.94	1.86	2.03	0.25	12
Droughtmaster^{A}:															
Herbage	14.8	13.6	14.2	15.4	14.6	13.8	14.1	13.5	13.8	13.2	13.3	13.4	14.0	0.7	5
PKC	3.07	2.76	2.53	2.50	2.58	2.56	2.63	2.48	2.32	2.32	2.32	2.30	2.53	0.22	9
Pregnancy	0.13	0.24	0.45	0.49	0.50	0.09	0.05	0.10	0.07	0.13	0.23	0.08	0.21	0.17	80
Lactation	3.22	3.14	2.54	2.49	2.37	2.17	2.27	2.23	2.12	2.16	2.32	2.20	2.43	0.37	15
Brahman Bull^{B}:															
Herbage	9.6	10.9	12.7	12.6	13.4	11.5	13.5	14.7	14.9	13.1	18.3	18.1	13.6	2.6	19
PKC	1.17	1.17	1.17	1.56	2.20	2.20	2.20	2.38	2.38	2.34	2.89	2.89	2.05	0.63	31

Total feed demand per grazing unit = herbage demand + PKC (as herbage equivalent) demand. Feed demand associated with pregnancy and lactation was already incorporated in the herbage demand. Values in bold are the highest feed demand for the respective grazing units across the 6 years studied; those in italic are the highest FCE for the respective grazing units. *Note*: Droughtmaster^{A} (= 2009) and Brahman Bull^{B} (= 2012) are for comparison, considering that the average data of those units were affected by the decision of the farm to modify the cattle number markedly over 2008–2013; production system in both years were the most efficient for the respective units across the 6 years studied.

In general, PKC fed to the cattle varied in proportion to animal number and hence also in proportion to herbage consumption (Table 5.2), so that the average ratio of PKC:herbage consumption was comparatively consistent between the production units, except for Bali Cow-calf and Heifer Units (18%, 26%, 38%, 19% and 17%, for Brahman Cow-calf, Bali Cow-calf, Heifer, Droughtmaster Cow-calf, and Brahman Bull Units, respectively).

5.3.1.2 Evaluation of Seasonality of feed demand and supply

In contrast with the Brahman Bull and Droughtmaster Cow-calf Units where feed demand increased as animals were added or removed, respectively, the demand and PKC allocation, and hence herbage consumption on the other units varied little through the months of the year (Table 5.2; relevant data on monthly stocking rate are presented in Table 5.1). For example the highest and lowest monthly feed demands on the Bali Cow-calf Unit were 465.4 and 398.5 kg DM ha^{-1}, respectively, and for the Brahman 438.1 and 383.3 kg DM ha^{-1} (4% CV in both cases), with the major factors in this limited variation being pregnancy and lactation.

5.3.1.3 Feed conversion efficiency

The amount of feed required per kg animal live weight gain (FCE) varied between farm units and years. The FCE calculated on an annual basis was highest (a higher efficiency is a lower number) for the Heifer Unit (40.2 kg DM kg LWG^{-1}), followed by the Brahman Cow-calf Unit (45.3 kg DM kg LWG^{-1}), Bali Cow-calf Unit (46.5 kg DM kg LWG^{-1}), Brahman Bull Unit (75.8 kg DM kg LWG^{-1}) and Droughtmaster Cow-calf Unit (117 kg DM kg LWG^{-1}) (Table 5.3).

The most effective system configuration as measured by FCE occurred in 2010, 2009, 2009, 2009 (also 2010), and 2012 on the Brahman Cow-calf, Bali Cow-calf, Droughtmaster Cow-calf, Heifer and Brahman Bull Units, respectively (Table 5.3). FCE was higher than average for the months of July to September, and was lower than average for the months October to April (Table 5.3).

FCE appeared to improve with N application as shown by its negative correlation to N fertiliser use. During the year of higher FCE, four of the grazing units had the highest annual N application (see Table 5.1). An exception to this trend was the Bali Cow-calf Unit where higher annual N application was not associated with higher FCE. The correlation between annual FCE and N application was significant on the Brahman Cow-calf Unit (R = –0.863, P = 0.016). The correlations between annual FCE and N application on the other units were not significant: Brahman Bull (R = –0.662, P = 0.152), Droughtmaster Cow-calf (R = –0.522, P = 0.288), Bali Cow-calf (R = –0.174, P = 0.741), and Heifer (R

= –0.028, P = 0.958). In another analysis, monthly N application was found to be significantly correlated with monthly rainfall (R = 0.591, P = 0.043).

Table 5.3 Feed conversion efficiency (FCE) of grazing cattle farming system at SPT Tawau (2008–2013): (a) Annual and (b) Monthly.

(a) kg DM kg LWG^{-1}	08	09	10	11	12	13	$\bar{x}$	SD	CV %
Brahman	42.7	45.5	39.2	45.5	46.6	52.1	45.3	4.3	10
Bali	38.9	37.4	42.8	56.2	50.4	53.3	46.5	7.9	17
Droughtmaster	55.0	46.4	47.2	48.8	50.0	457	117	167	142
Heifer	52.2	36.0	36.3	41.0	38.6	37.4	40.2	6.1	15
Brahman Bull	78.9	97.9	50.7	43.7	38.3	146	75.8	41.1	54

(b) kg DM kg LWG^{-1}	J	F	M	A	M	J	J	A	S	O	N	D	$\bar{x}$	SD	CV %
Brahman	41.1	41.8	50.2	55.3	44.3	44.1	35.3	39.8	43.1	49.6	53.6	45.0	45.3	5.9	13
Bali	43.3	48.2	47.7	57.2	47.0	39.7	34.4	40.3	44.5	50.8	51.2	53.7	46.5	6.4	14
Droughtmaster	61.4	56.5	46.0	305	311	332	50.9	44.2	39.1	52.2	59.7	51.4	117	120	102
Droughtmaster^{A}	78.6	77.8	42.8	34.9	41.1	38.5	55.1	42.1	30.7	33.1	35.4	47.2	46.4	16.2	35
Heifer	49.3	49.7	46.8	40.9	35.1	34.9	36.6	29.0	36.1	36.9	43.4	44.0	40.2	6.5	16
Brahman Bull	203	154	139	31.3	39.7	49.7	40.7	40.2	46.9	71.2	62.9	30.9	75.8	57.1	75
Brahman Bull^{B}	26.6	29.6	39.5	28.2	26.6	82.9	26.7	33.1	30.5	56.9	50.2	28.5	38.3	17.2	45

LWG: liveweight gain. The average of FCE of the five grazing units represents the average FCE for the whole system. *Note*: Droughtmaster^{A} (= 2009) and Brahman Bull^{B} (= 2012) are for comparison, considering that the average data of those units were affected by the decision of the farm to modify the cattle number markedly over 2008–2013; production system in both years were the most efficient for the respective units across the 6 years studied.

A possible decrease in FCE with high rainfall was observed on the cow-calf units (positive numeric correlation) but the opposite trend was seen on the Heifer and Brahman Bull Units (negative numeric correlation). The correlation between annual FCE and rainfall was significant on the Bali Cow-calf Unit (R = 0.856, P = 0.029). The correlations between annual FCE and rainfall on the other units were not significant: Brahman Cow-calf (R = 0.574, P = 0.233), Heifer (R = –0.479, P = 0.336), Droughtmaster Cow-calf (R = 0.242, P = 0.645), and Brahman Bull (R = –0.187, P = 0.722).

5.3.1.4 Feed implications of animal weight loss

The extent to which ME_{LWL} occurred, differed between the grazing units, with the lowest on the Heifer Unit (as would be expected) and highest on the Bali Cow-calf Unit (Table 5.4). The average ME_{LWL} for the whole farm was 0.31 t DM ha^{-1} yr^{-1}. There was a tendency for occurrence of ME_{LWL} to be higher in years of higher feed demand. For example, mean ME_{LWL} of the 5 grazing units was 0.48 t DM ha^{-1} yr^{-1} in the years of highest feed demand compared to 0.31 t DM ha^{-1} yr^{-1} for the average ME_{LWL} (T = 3.785, P = 0.019), or compared to 0.36 t DM ha^{-1} yr^{-1} for the ME_{LWL} during the year of highest FCE of each grazing unit (T = 6.025, P = 0.004).

Table 5.4 Mobilised body energy (ME_{LWL}) of grazing cattle farming system at SPT Tawau (2008–2013): (a) Annual and (b) Monthly.

(a) **t DM ha^{-1} yr^{-1}**	08	09	10	11	12	13	$\bar{x}$	SD	CV %
Brahman	0.34	0.58	0.42	0.52	0.54	0.44	0.47	0.09	19
Bali	0.37	0.49	0.47	0.48	0.57	0.68	0.51	0.11	21
Droughtmaster	0.68	0.54	0.40	0.39	0.18	–	0.36	0.24	67
Heifer	0.04	0.04	0.05	0.09	0.11	0.06	0.07	0.03	43
Brahman Bull	0.01	0.01	0.09	0.11	0.32	0.39	0.15	0.16	106

(b) **kg DM ha^{-1} d^{-1}**	J	F	M	A	M	J	J	A	S	O	N	D	$\bar{x}$	SD	CV %
Brahman	1.23	0.91	1.53	1.64	1.56	1.25	1.00	0.96	0.94	1.26	1.46	1.84	1.30	0.31	24
Bali	1.25	1.12	0.96	1.23	1.47	1.22	1.18	1.49	1.15	1.50	1.67	2.56	1.40	0.42	30
Droughtmaster	1.27	1.21	1.02	1.35	0.96	1.04	1.12	0.79	0.98	0.61	0.70	0.91	1.00	0.23	23
Droughtmaster^{A}	1.25	1.22	1.18	1.93	1.32	1.93	2.55	1.49	1.64	0.73	0.56	1.88	1.47	0.56	38
Heifer	0.21	0.26	0.17	0.15	0.16	0.13	0.12	0.12	0.11	0.20	0.24	0.29	0.18	0.06	33
Brahman Bull	0.44	0.71	1.17	0.42	0.14	0.21	0.16	0.27	0.08	0.18	0.97	0.31	0.42	0.35	83
Brahman Bull^{B}	0.01	0.86	2.79	2.25	0.37	0.78	0.01	0.62	0.01	0.13	2.67	0.14	0.89	1.06	120

The average of ME_{LWL} of the five grazing units represents the average ME_{LWL} for the whole farm. *Note*: Droughtmaster^{A} (= 2009) and Brahman Bull^{B} (= 2012) are for comparison, considering that the average data of those units were affected by the decision of the farm to modify the cattle number markedly over 2008–2013; production system in both years were the most efficient for the respective units across the 6 years studied.

The seasonal occurrence of higher ME_{LWL} was similar for the Brahman and Bali Cow-calf Units. On these units, higher than average ME_{LWL} occurred from March to May and again from October to December (Table 5.4). For the Droughtmaster Cow-calf Unit, higher ME_{LWL} occurred from April to July, and from September and December. Higher ME_{LWL} occurred from October to February on the Heifer unit and March–April and in November on the Brahman Bull Unit. Overall, ME_{LWL} was higher in March–May and October–December. Occurrence of ME_{LWL} was highly variable across the months on all grazing units (24%–83% CV, Table 5.4).

5.3.1.5 Energy allocation to body maintenance and growth

System-level allocation of feed energy to body maintenance was highest for the Heifer Unit (82%), followed by the Brahman Bull (81%), Bali Cow-calf (79%), Droughtmaster Cow-calf (79%) and Brahman Cow-calf (76%) Units (Table 5.5). However, for years when the Brahman Bull (2012) and Droughtmaster Cow-calf (2009) Units were operating under a stable policy and highest FCE (see Section 5.3.1.3) the system allocation to body maintenance was slightly lower than the average on these units at 75% and 77%, respectively.

Table 5.5 Energy allocation (average over 2008–2013) for maintenance, growth and other metabolic energy requirements of cattle in grazing cattle farming system at SPT Tawau.

	MJ ME ha^{-1} d^{-1}								%T						
	T	M	G	P	M^A	G^A	M^C	G^C	M	G	P	M^A	G^A	M^C	G^C
Heifer	65.8	54.2	11.6	–	54.2	11.6	–	–	82.4	17.6	–	82.4	17.6	–	–
Brahman Bull	73.7	59.8	13.9	–	59.8	13.9	–	–	81.1	18.9	–	81.1	18.9	–	–
Brahman Bull^B	130	97.4	32.6	–	97.4	32.6	–	–	74.9	25.1	–	74.9	25.1	–	–
Brahman	131.4	100	29.4	1.7	92.5	24.5	7.9	5.0	76.3	22.4	1.3	70.4	18.6	6.0	3.8
Bali	151	119	29.4	2.3	101	21.1	17.9	8.3	79.1	19.5	1.5	67.2	14.0	11.9	5.5
Droughtmaster	99.1	78.0	19.8	1.33	66.4	14.6	11.7	5.2	78.7	19.9	1.3	67.0	14.7	11.9	5.2
Droughtmaster^A	136.9	105	30.1	1.78	90.9	24.0	14.1	6.1	76.8	22.0	1.3	66.4	17.5	10.3	4.5
Average	123.0	95.3	26.6	1.9	87.3	22.8	13.3	6.5	77.9	21.3	1.4	72.3	18.6	9.4	4.6

T: Total. M: energy required for body maintenance. G: energy required for growth. P: pregnancy. ^{A}Adult. ^{C}Calf: M^C + G^C is equivalent to energy required for lactation. The average included Droughtmaster^A and Brahman Bull^B instead of Droughtmaster and Brahman Bull, respectively. *Note*: Droughtmaster^A (= 2009) and Brahman Bull^B (= 2012) are for comparison, considering that the average data of those units were affected by the decision of the farm to modify the cattle number markedly over 2008–2013; production systems in both years were the most efficient for the respective units across the 6 years studied.

5.3.2 Information on feed supply from short-term observations

5.3.2.1 Herbage accumulation from two month cutting experiments

(a) Herbage accumulation at SPT Tawau

The limited cutting work undertaken in this study was able to provide indicative herbage accumulation rates in 2014 for 5 species under farm conditions for the five studied grazing units and on the two other farms measured for comparison (Table 5.6; Appendix 5.4). The data for green herbage DM production per year data were slightly higher than the DM ha^{-1} yr^{-1} calculated by modelling animal demand, ranging from 6.9 t DM ha^{-1} yr^{-1} for *D. milanjiana* 'Jarra' to 15.1 t DM ha^{-1} yr^{-1} for *P. maximum* 'Guinea' grass. A point of interest was that for two species (*B. decumbens* and *A. compressus*; Appendix 5.4) the standing herbage mass declined between cuts in the later stages of the regrowth cycle.

For comparison, data for the cut-and-carry feedlot system adjacent to the grazing units showed somewhat higher herbage productivity of 21.3 t DM ha^{-1} yr^{-1} for *B. decumbens* (see Table 4.3, Chapter 4), and no decline in standing herbage mass at the end of the regrowth cycle (Appendix 4.6).

Table 5.6 Dry matter accumulation rates (kg DM ha^{-1} d^{-1}) and annualised values (t DM ha^{-1} yr^{-1}), and ME (MJ ME kg DM^{-1}) and CP contents (%) of 5 major grass species used for beef production on grazing cattle farm at SPT Tawau and on two other farms in Sabah.

		Green DM		Leaf DM		ME	CP
	Regrowth cycle days	Daily rate	Annualised (t yr^{-1})	Daily rate	Annualised (t yr^{-1})		
P. maximum 'Guinea'[A]	14–28	41.4	15.1	25.2	9.2	8.5–8.9	12–14
D. milanjana 'Jarra'[A]	14–28	18.8	6.9	11.4	4.2	7.0–7.6	12–15
S. sphacelata 'Kazungula'[A, B]	7–14	29.9	10.9	18.4	6.7	7.5–8.2	10–12
A. compressus[A, B]	14–28	25.1	9.2	17.2	6.3	7.5–8.7	11–12
B. decumbens[A, B, C]	14–28	56.4	20.6	38.5	14.1	7.3–8.3	7–9

[A] Grazing units on SPT Tawau. [B] PPT Timbang Menggaris. [C] PPT Entilibon.

(b) Herbage accumulation on other farms

The green DM accumulation data for PPT Timbang Menggaris was consistent with that from the SPT Tawau, with a range from 5.4 t DM ha^{-1} yr^{-1} for *S. sphacelata* 'Kazungula' to 9.2 t DM ha^{-1} yr^{-1} for *A. compressus* (Table 5.6). As with SPT Tawau, a decline in standing herbage mass at the end of the regrowth cycle was observed in *B. decumbens*. The green DM yield of *B. decumbens* on PPT Entilibon was similar to that for the SPT Tawau cut-and-carry feedlot system at 20.6 t DM ha^{-1} yr^{-1} and the leaf DM yield was 14.1 t DM ha^{-1} yr^{-1}.

5.3.2.2 Herbage ME and CP content

(a) ME and CP content of herbage harvested at SPT Tawau

The ME contents of the forages in use fell in the range of 7–9 MJ kg DM^{-1} (Table 5.6; Details in Appendix 5.4). A number of the species showed a decline in ME value with advancing maturity. For example, *B. decumbens*, *D. milanjiana* 'Jarra' and *S. sphacelata* 'Kazungula' showed a reduction of 0.2–0.6 MJ ME kg DM^{-1} and the *A. compressus* showed a reduction of 1.1 MJ ME kg DM^{-1}. However, during grazing of *B. decumbens* the ME content of the herbage improved by approximately 0.3–0.6 MJ ME kg DM^{-1} with the accumulation of young leaves in the forage being grazed.

The highest mean CP contents recorded for the grass species studied were 9%, 14%, 15%, 12% and 12% for *B. decumbens*, *P. maximum* 'Guinea', *D. milanjiana* 'Jarra', *A. compressus* and *S. sphacelata* 'Kazungula', respectively. Again, there was a decline with advancing herbage maturity, except for *B. decumbens* and *P. maximum* 'Guinea' (Appendix 5.4).

(b) ME and CP content of herbage harvested on other farms

Herbage ME and CP values for PPT Timbang Menggaris and PPT Entilibon farms were consistent with those for SPT Tawau given above (Table 5.6), for all forage species tested, and a decrease in forage quality with advancing maturity was again observed (Appendix 5.4).

5.3.2.3 Feed supplement

The amount of PKC used by the farm was reported earlier in Sections 5.3.1.1 and 5.3.1.2. The PKC had an average energy content of 9.5 MJ ME kg DM^{-1} and CP content of 16% (Appendix 5.4). There was some variation in PKC energy value (24% CV) with some samples tested having an energy value of only 7.2 MJ ME kg DM^{-1}.

5.4 Discussion

5.4.1 Current status of system and implications for production

5.4.1.1 Annual production and nutritive value of herbage

The maximum potential animal production of a pastoral system will depend on the maximum annual feed produced in the system (Valentine and Kemp, 2007) and the amount of the feed consumed and translated to animal product (McMeekan, 1958). Although there is no limit of feed supply and quality when feed supplement is used since this feed can be formulated and brought into the system, the economic reality and profit margin of farming is known to depend on the supply and quality of the cheapest feed available to the farm, which is usually herbage (Hogan, 1996). Data from this study indicated that the total herbage supply that is consumed and the nutritive value of the herbage appear to be the factors limiting the animal production of the grazing system studied.

Herbage harvested in the system indicated by the feed demand modelling (3.74–7.16 t DM ha^{-1} yr^{-1}) is lower than the yield of the herbage estimated by cutting on the grazing units or on the other farms in Sabah (6.9–20.6 t DM ha^{-1} yr^{-1}). The cutting data (apart from those for *D. milanjiana* 'Jarra') are similar to the yields expected for the other grass species in Malaysia (7–30 t DM ha^{-1} yr^{-1}) known to the author. In Malaysia, Wong et al. (1985), DVS (undated) and Ng (1972) reported that *B. decumbens*, *P. maximum* 'Guinea, *S. sphacelata* 'Kazungula', and *A. compressus* produced, respectively, 14–26 t, 15.1–17.6 t (or sometimes up to 30 t), 10–15 t (or sometimes 20–26 t), and 7.4–7.9 t DM ha^{-1} yr^{-1}, respectively. With respect to *D. milanjiana* 'Jarra' (Syn. *D. setivalva* Stent or Mardi digit), based on an experiment in West Malaysia, Chen and Devendra (1990) reported that the species produced 4.4 t DM ha^{-1} yr^{-1} with addition of 150 kg N ha^{-1} yr^{-1} and stocked with 20 goats ha^{-1} (7–12 kg liveweight), which is markedly lower than the estimate obtained on the grazing units in this study. It has to be noted, however, that the low liveweights of the goats used by Chen and Devendra (1990) raises questions about how the data should be interpreted. Elsewhere, reported yields of *D. milanjiana* 'Jarra' range from 6.33 t DM ha^{-1} yr^{-1} (e.g., Roberts, 1970a, b as cited in FAO, undated) to 10–20 t or even 34 t DM ha^{-1} yr^{-1} (Cook et al., 2005). Theoretically, based on 3% DM conversion efficiency of light in the tropics (Singapore), with no nutrient or water limitation, the potential herbage production is 49–85 t DM ha^{-1} yr^{-1} (Cooper, 1970). Hence, the 'environment potential' in terms of light availability for plant growth in Sabah is still much higher than the production indicated by the modelling of animal intake and the herbage production estimated by cutting.

Given that the procedure for selecting herbage yield sampling sites (see Section 5.2.2.2) was designed to identify the upper level of yield available from the local Sabah pastures, the gap between the harvested yield as calculated by modelling animal intake and the measured yield in the cutting experiments can be taken as an indication of the yield increase that may be possible if heterogeneity and occurrence of poorer patches within paddocks could be reduced by better pasture husbandry, and if no other factors such as soil fertility were limiting. As the limited cutting experiments for the various species were carried out on the more vigorous patches of herbage, the modelled yield represents 'operational production' and the cutting yield represents 'current local potential' production of the system. To what extent this local potential herbage production can be improved towards the environment potential and to what extent the gap between herbage harvested and current local potential can be narrowed by grazing management that reduces non-utilisation of herbage, are topics for future research. Such information will be important for beef cattle farmers to improve the animal production of the grazing system under their care in Sabah.

In explaining the herbage cutting results in this way, it needs to be considered if the herbage accumulation data collected in 2014 within a two month sampling in Sabah during the PhD study are representative of the whole year's seasonal cycle. Considering that herbage accumulation rates in Sabah appear to lack marked seasonality (Section 5.4.1.2) and that the accumulation measured by cutting exceeds harvested yield by an amount similar to non-utilisation in grazing systems elsewhere, and as the data are largely within the range expected for the grass species in Malaysia (14–26 t DM ha^{-1} yr^{-1}), the 2 month cutting yield probably can be used to make a first estimate of annual herbage production. A relevant question that needs to be examined in the future is: how much non-utilisation of herbage grown occurs? Within this study, the difference between the feed demand modelling and herbage cutting is 3.16–16.86 t DM ha^{-1} yr^{-1}.

There are several possible lines of future investigation for raising the operational herbage production towards local potential herbage production. First, there is non-utilisation of herbage associated with a low stocking rate. The various grass species have different requirements for regrowth interval and residual herbage mass and when they are included as different paddocks on the same farm unit it is hard for managers to create a grazing rotation that optimises the grazing cycle for each grass species. Because of this, the grazing duration on some paddocks sometimes had to be extended to allow the grazing process to reach the target herbage residual mass or to allow the herbage on the next paddock to grow denser and taller (because of the belief that thicker or taller herbage indicates high DM yield). However, these assumptions were in fact found to be untrue, at least for the *B. decumbens* and *A. compressus*, as the standing herbage mass of these grasses had declined between cuts in the later stages of the regrowth cycle. The 28 d grazing interval used for some paddocks on the farm is longer than the limit suggested for the herbage in the paddocks. For example, the grazing interval for *B. decumbens*, *P. maximum* ‘Guinea’ and *S. sphacelata* ‘Kazungula’ in Malaysia is recommended to be 18–21 days (DVS, undated) and not 28 days.

Lax grazing is expected to have occurred in some of the grazing units in some years and this and the associated poor herbage nutritive value contribute to poor herbage consumption. For example, the Droughtmaster breed was phased out gradually between 2008 and 2013. However, the effective area of the Droughtmaster Cow-calf Unit was not reduced until 1–2 years after the major cattle number reduction (Table 5.1), which means grazing pressure was not sufficient to maintain the herbage quality. The delay in stocking rate adjustment happened because of constraints in resources to repair old or build new fences. After completion of fencing the area was re-allocated to the Brahman Cow-calf Unit, resulting in a reciprocal problem, of the Brahman Cow-calf Unit having a reduced stocking rate until animal numbers had increased.

Second, there is a reduction in herbage production associated with non-sown grass species, acidity and low N and P content of the soils (see Section 5.2.1.1), and over grazing. This could also explain why there is a wide range of herbage DM production between the grazing paddocks even for the same forage (Table 5.6; Appendix 5.4). The farm reported the proportion of sown species in pastures to be 70%–95%, 70%, 40% and 40% for paddocks planted with *B. decumbens*, *P. maximum* 'Guinea', *S. sphacelata* 'Kazungula', and *D. milanjiana* 'Jarra', respectively. Non-sown species (making up the balance of the herbage) included *A. compressus* (60%–70% of the paddock area in extreme cases), and weeds, such as *Cyperus aromaticus* and *Mimosa pudica* (typically occupying 5%–10% of the paddocks). The pasture botanical composition reported by the farm was also confirmed visually by the writer while making the herbage accumulation measurements described in Section 5.2.2.2. Hence, the non-sown species component of pastures would have likely reduced the herbage production. Moreover, the soil on the farm was acidic (pH 4.5–4.8, Section 5.2.1.1), while the average N application was only 30 kg ha^{-1} yr^{-1} (Table 5.1). There were years where N application was not carried out or the application was much lower than the average. (At SPT Tawau, the highest average N application was in the cut-and-carry feedlot system at 92 kg ha^{-1} yr^{-1}: Table 4.1, Chapter 4). By contrast, Ng (1972), for example, reported that in Sarawak, East Malaysia 112–224 kg ha^{-1} yr^{-1} of N are required to support 14.0–19.7 t DM ha^{-1} yr^{-1} production from *B. decumbens*.

Overgrazing is expected to have occurred on the Brahman Bull Unit. The Brahman bull numbers were increased gradually during the 2008–2013 period. The effective area of the Brahman Bull Unit, on the other hand, was never enlarged to accommodate the increasing number of bulls (Table 5.1). In 2013, the liveweight gain on the bull unit was markedly lower than that in the previous years, although the bull average age range for that year was similar to previous years (Table 5.1). The lower liveweight gain on the Brahman Bull Unit was also low compared to other years, but this can be attributed to the farming of older bulls (e.g., 2008, 72.4 months old, 428 kg liveweight) rather than feed shortage.

Finally, the herbage ME in the system (and in Sabah as indicated by data from the other farms) is generally at the low end of the normal range and this could partly contribute to low consumption of the herbage. In addition, while higher values of herbage ME were sometimes recorded, these appear to relate more to variability of growth stage than to species characteristics that are consistently expressed across time. Intake of herbage of low ME would be low because of the low digestibility and low rate of passage of such herbage through the digestive tract (Colucci et al., 1982). In fact, the herbage ME in the system is lower than the value desired for efficient beef cattle production. As noted in Chapter 4 (Section 4.4.2.1), Smeaton (2003) reported that feed of lower than 8 MJ ME kg DM^{-1} energy content is insufficient to support weight gain in cattle, irrespective of the amount eaten. The herbage ME in the system is even slightly lower than the values expected for the species in question under pastoral environments in Malaysia. DVS (2005) and DVS (undated) reported that in Malaysia, ME content of grasses after 3–4 weeks regrowth was approximately 8.1–8.5 MJ kg DM^{-1} for *B. decumbens*, 7.1–7.8 or sometimes 8.1 MJ kg DM^{-1} for *P. maximum* ‘Guinea’, 9.2 MJ kg DM^{-1} at 3 weeks regrowth and decreased to 7.4 MJ kg DM^{-1} at 4 weeks regrowth for *S. sphacelata* ‘Kazungula’, and 8.2–8.6 MJ kg DM^{-1} *D. milanjiana* ‘Jarra’. No information is available on ME content of *A. compressus* in Malaysia. Elsewhere, the ME value of this species has been reported as 6.4 MJ kg DM^{-1} (Feedipedia–INRA, CIRAD, AFZ and FAO, undated), which is even lower than in the present study.

Linked to factors resulting in reduced ME, CP content of the herbage in the system is also at the lower end of the range considered ideal for cattle production. As noted in Chapter 4 (Section 4.4.2.1), the critical level of herbage CP for animal production is 1.1%–1.3% N (Hennessy, 1980), which is equivalent to 6%–8% CP (Humphreys, 1991). The CP contents of the herbage on the grazing units were similar to those on other farms in Sabah (Table 5.6), indicating common grazing practice in Sabah as a whole. However, elsewhere in Malaysia somewhat higher CP values have been reported. DVS (2005) reported the following CP values (on a DM basis) for forages in Malaysia: *B. decumbens*, 19% and 12% after 3 and 4 weeks of regrowth, respectively; *P. maximum* ‘Guinea’ 14% and 12%; and *D. milanjiana* ‘Jarra’ 16% and 16%. *Setaria sphacelata* ‘Kazungula’ was reported to have 15% CP at 2 weeks regrowth 14% after 4 weeks of regrowth. Information is not available on CP content of *A. compressus* in Malaysia, but the species is reported elsewhere to contain 9% CP (Feedipedia–INRA, CIRAD, AFZ and FAO, undated). Most of the above values were reported without information on the N application regime, which is known to strongly affect herbage CP content (Minson, 1967). A report by Cook et al. (2005) did link CP to N fertiliser application where CP level was 22% for swards of *A. compressus* after 3 weeks regrowth and 18% CP after 6 weeks regrowth with addition of 100 kg N ha^{-1} yr^{-1}. The average N application in this study (92 kg N ha^{-1} yr^{-1}; Table 5.1) was close to the latter, but the CP level of the *A. compressus* (Table 5.6) was much lower than 18%, indicating that the response of CP content of this grass to N addition varies and also that inconsistent N application such as the case on the grazing units studied (CV of application >70%) may not lead to higher CP level in this grass or perhaps generally in pasture at SPT Tawau.

5.4.1.2 Seasonality of herbage accumulation

As with the study in Chapter 4, the herbage data collected did not cover a 12-month cycle so it cannot be determined from that data if there is a seasonal pattern to herbage productivity. However, as also noted in Chapter 4 (Section 4.4.2.2), from other considerations it appears that any seasonality of herbage production in the system is slight. The animal demand data did not show seasonality (for example, CV was 4% for animal demand compared across months for the Brahman and Bali Cow-calf Units), PKC use was aseasonal (see below) and the farm managers reported no seasonal fluctuations in standing herbage mass on the farm. Where animal demand did fluctuate more markedly across months this clearly related to the implementation of major farm system changes. The writer also observed nothing during collection of herbage data that would indicate seasonality. Even so, periods of above average rainfall may occur in any month, and it was noted that decisions on N application were linked to rainfall. Monthly N application was positively correlated with monthly rainfall (Section 5.3.1.3) and the manager confirmed that N application is less effective when applied in a dry period. The advantage associated with this monthly pattern of herbage supply is the chance to maintain the same rate of grazing pressure and animal production in the system throughout the year.

While it is true that in New Zealand beef production systems, pregnancy, lactation and weaning periods would have marked impacts on the seasonality of herbage consumption; on the cow-calf units in Sabah twice yearly mating and split calving (as stated in Section 5.2.1.1) has the effect of "flattening" the feed demand curve to better match the aseasonal feed supply curve. However, at the present time rates of pregnancy, calving (<47%) and cow efficiency (<45%) on the farm are low and weaning is carried out (when animals reach a live weight threshold of 150 kg) and spread throughout the year. In future, if calving rate and cow efficiency are to improve or if the calving and weaning are fixed at particular times of the year to meet particular beef market niches, a marked seasonality of feed demand might be introduced. In that case, higher herbage production, increased use of supplementary feed, or some other system feed buffer will be required during the pregnancy and lactation periods.

As noted also in Chapter 4 (Section 4.4.2.2), a point for future study is whether or not global weather patterns like El niño–Southern Oscillation (ENSO) affects pasture productivity in grazing system in Sabah. Depending on its severity, ENSO is known to affect mortality of forest plants in Sabah (Walsh and Newbery, 1999). Also another point for future study is whether or not monthly nutritive value of herbage in the system fluctuates. This study can be carried out alongside the study suggested for the cut-and-carry feedlot system (Chapter 4).

5.4.1.3 Feed supplement supply and nutritive value

Two points for comment pertaining to feed supplement use in the studied system are: (i) a lack of evidence that PKC consumption and supply is seasonal, and (ii) the use of PKC in the system needs to be evaluated for effective animal production or reduction of operational cost. PKC supply and consumption in the system is aseasonal as indicated by the small coefficient of variation of PKC consumption (3% or sometimes 11% CV, Table 5.2), and this adds further evidence of aseasonality in system feed demand mentioned earlier in Section 5.4.1.2; otherwise PKC consumption would be varied seasonally where the farm will use more PKC to compensate the fluctuation of herbage productivity in the system. In fact, variation in PKC use that was observed usually related to factors external to the system, such as, stocking policy change by the farm. In addition, the farm reported that during rainy days, the cattle rejected damp PKC and this could lead to variation in its consumption. This problem has not yet been addressed on the grazing units studied. Mitigation of the problem may be achieved by adjusting PKC feeding time during the rainy period or building an appropriate feeding stall. As stated earlier (Section 5.2.2.2) and in Chapter 4 (Section 4.4.2.3), the farm also reported that PKC feeding was sometimes reduced or temporarily suspended at the start of a financial year, but this is because the budget was not yet confirmed rather than because of seasonality of animal demand or in supply of PKC from the manufacturers.

The evaluation of the use of PKC in the system is required, firstly, so that farm managers would not wrongly rely on PKC to improve overall growth of the cattle. PKC supplement may not necessarily be effective to improve the growth of the cattle because the ME value (mean 9.5 MJ ME kg DM^{-1}) of the supplement is only slightly higher than that of the herbage (8.3 MJ ME kg DM^{-1}), or can even be lower (7.2 MJ ME kg DM^{-1}, Section 5.3.2.3). The PKC used in the grazing system is simply a PKC rather than a mixture of PKC, grains, fishmeal and Bovitas such as that is used in the cut-and-carry feedlot system on the same farm where the ME is 11.5 MJ kg DM^{-1} (see Section 4.3.3.2). The ME of the PKC also varies markedly between batches purchased from the manufacturers (24% CV across samples from different batches), a point that is also noted by Alimon (2004). If the ME content of PKC received is lower than expected, this could lead to misdirected reliance on PKC of lower feeding value to improve animal growth. This managerial reliance on a particular feed supply tactic without supporting data may explain why even with the higher feeding of PKC, the animal growth rates achieved on the Heifer Unit were the lowest across all grazing units (Table 5.1). In contrast to the ME, the CP of the PKC would not be a problem for animal production in the system because it is at the higher end of the range stated by Hennessy (1980) and Humphreys (1991) as the minimum CP requirement of animal rumen microbes.

A second reason why PKC use needs to be evaluated is to establish the possibility of tactical use of PKC at key times, rather than continuous use as a percentage of the diet throughout the year; this tactic would also be important as future evolution of the system. For example, PKC feeding (or some equivalent focus on pasture allowance for animals at times of high energy need) might be targeted to improve conception rate, or pregnancy and early lactation needs. Targeting of pasture and supplement allocation to animal demand in the way suggested has now become standard practice in New Zealand (De Ruiter et al., 2007) and research on how to implement this concept would be relevant to future evolution of beef production systems in Sabah.

Another question to be considered is the possibility of reducing or even eliminating PKC input altogether to lower production costs. The current quantity of PKC used in the system is not substantial (0.67 t DM ha^{-1} yr^{-1} on average or 0.85 t DM ha^{-1} yr^{-1} as herbage equivalent; in terms of cost, as stated in Subtopic 5.2.1, it was approximately RM30 ha^{-1} yr^{-1} for the 322 ha of grazing system at SPT Tawau) and there is a possibility that better grazing management can offset the use of this supplement. For this option to be effective (as noted also in Chapter 4, Section 4.4.2.3), however, the present low nutritive value of the herbage (7.8–8.3 MJ ME kg DM^{-1} and CP approximately 8%) would need to be improved to at least 9.5 MJ ME kg DM^{-1} and approximately 13% CP through grazing manipulation and nutrient inputs.

5.4.1.4 Feed conversion efficiency

The data indicate several important factors for future considerations to improve the FCE of the grazing system in Sabah. These include targeting the highest FCE rather than the highest feed consumption, coordinating the animal management of different units so that actions in one unit do not compromise the performance of another unit, improving herbage nutritive value, and timing and controlling the rate of fertiliser especially N application in relation to rainfall and grass species, respectively. Two other considerations, which are important, but are not studied in detail here, include improving cow reproductive performance and improving calf growth rates.

As with the cut-and-carry feedlot system studied in Chapter 4 (Section 4.4.2.4), breed appears not to be a significant factor in FCE considerations because no marked differences in FCE were found between the grazing units of different cattle breeds. For example, the cow-calf units of the Brahman, Bali and Droughtmaster breeds had a similar FCE. The Droughtmaster Cow-calf Unit had a poor average FCE during the 6 yr period, and this was evident in monthly FCE (April, May, and July; Table 5.3) where the values were >300 kg DM kg LWG^{-1}. However, this could be attributable to forage quality issues linked to low stocking rate during the phasing out of this unit.

With respect to the factors linked to higher FCE, in a farming system, the pursuit of high feed consumption has to be balanced with the goal of high output per animal and on the other side, the cost of production. The former is indicated by the years of highest feed consumption (Table 5.2) not being the years of highest FCE (Table 5.3). Considering the Brahman Bull Unit, increasing cattle number from 2009 to 2012 resulted in increased feed consumption and growth and also FCE, but further increase in cattle numbers (2013) increased consumption further and led to high feed consumption but poor animal growth (Table 5.1) and FCE (Table 5.3). This principle of matching animal numbers or stocking rate to feed supply has been reported internationally. In New Zealand, for example, McMeekan (1958) reported that milk production per ha increases with stocking rate increment but with a corresponding reduction in milk production per animal, and that milk production per animal increases with stocking rate reduction but production per ha also decreases, partly because pasture is less productive under high grazing pressure and less pasture is eaten, and partly because at lower growth rate with high stocking, a higher % of total feed is allocated to body maintenance with a correspondingly smaller % of feed supply allocated to body weight gain. Similar stocking rate optima have been reported in other studies in New Zealand (e.g., Muir et al., 1992; MacDonald et al., 2001) and in China (e.g., Dong et al., 2015) where with increasing kg LWT t DM^{-1} ha^{-1} (or stocking rate), efficiency of pasture utilisation (kg or t DM ha^{-1}) also increases but per animal efficiency (kg DM kg LWG^{-1} hd^{-1}) decreases.

The importance of coordinating the animal management of the units is highlighted by the finding that the best FCE of the various grazing units was not attained in the same years. This data feature arose from the impacts of managerial actions on one unit on the performance of another unit. For example, when calves are weaned from one of the Cow-calf Units to the Heifer Unit, there is a decrease in stocking rate on the former and an increase in stocking rate on the latter, creating a situation of lax grazing on the former and an over grazing and liveweight loss on the latter. In fact, stock management was one of the factors contributing to the occurrence of ME_{LWL} in the system. As stated earlier in Chapter 4 (Section 4.4.2.4), animal live weight can become an 'energy buffer' to absorb fluctuations in feed supply, that is, when feed is scarce animals will mobilise body reserves and lose weight, and vice versa. Storage of surplus energy as live weight and later release in this way, reduces FCE, because the energy of feed saving on weight loss is less than the energy required for regain of the same weight. ME_{LWL} occurrence on all grazing units was generally higher from October–December and March–May. On the cow-calf units, those two periods fall towards the end of pregnancy and the start of calving, respectively, and coincide with significant weight loss of cows (Table 5.1). During calving, the live weight threshold for weaning of the previous year's calves on the farm studied was 150 kg, but there were times that this was arbitrarily reduced to 140–145 kg. This decision results in a greater number of calves than usual being transferred to the Heifer Unit. Meanwhile male calves are sent to the cut-and-carry feedlot system belonging to the farm (Chapter 4), and previous years weaned Brahman cattle in the feedlot, over 250 kg live weight (around two years of age), are sent to the Brahman Bull Unit. (Bali and Droughtmaster male cattle in the feedlot reaching respectively 290 and 380 kg liveweight threshold are sold). While adapting to their new environment, both the weaned female calves (partly because of a post-weaning effect (see growth data of the cattle given in Appendix 5.3) and the 250 kg liveweight Brahman bulls (when moved in from the feedlot system) lost weight, and as a result FCE was lower. In addition to this discussion is the higher occurrence of ME_{LWL} during years of higher feed demand, which means during overstocking. Clearly, another option is to proactively manipulate feed supply to reduce incidence of weight loss of this type.

FCE was generally lower than the average in the months from October to April and was higher than the average in the months from July to September. This is simply a reflection of the same system factors that resulted in liveweight loss. Elimination of liveweight loss is expected to improve FCE, and this might be achieved through improved pasture management or supplementary feeding.

Another example where improved coordination would be beneficial was the ad hoc adjustment of effective area and cattle number on the farm units. The FCE on the Brahman Cow-calf Unit declined (Table 5.3) once the effective area was enlarged in 2012 and 2013 without corresponding increase in animal numbers (Table 5.1). On the Droughtmaster cow–calf unit (which was overstocked in 2008), the FCE improved once the number of animals was reduced in 2009. However, in 2010 and 2011 FCE declined with further reduction of animal number without parallel reduction in the area of the unit. In 2012 the FCE was higher than in the preceding two years after the area was belatedly reduced (Tables 5.1 and 5.4). The performance of the farm as a whole could be improved if there was attention to coordination of feed demand and supply planning between units.

One of the emphases in optimisation of pasture systems in Australasia has been feed quality (Waghorn and Clark, 2004; Shakhane et al., 2013; Chapmen et al., 2014). High forage quality results in increased energy intake by animals and as a result the growth:body maintenance energy allocation ratio is improved. The ME and CP (and other nutrient) of tropical herbage are known to limit the FCE of tropical pastoral system (Stobbs, 1975). The herbage quality on SPT Tawau and on other farms in Sabah in this study, with typical ME and CP values of 7.0–8.5 MJ kg DM^{-1} and 7%–15%, respectively (Table 5.6), are definitely in the range where reduced FCE would be expected. This interpretation of the data is supported by the fact that around 75%–82% of total feed energy is allocated to body maintenance (Table 5.5). By comparison, in a case where more energy is allocated for weight gain, such as on New Zealand hill country sheep and beef cattle farming system, where as little as 35% of total feed energy is allocated to body maintenance for weaned lambs (extracted from Excel spreadsheet used in Chapter 3), and typically around 70% for breeding systems where the mother’s body maintenance is accounted for, and in these cases the FCE is much higher. The typical ME value on New Zealand system (10.2–12.2 MJ ME kg DM^{-1}, Appendix 3.3) was higher than for Sabah tropical pastures and the

FCE also more favourable (14–19 kg DM kg LWG^{-1} of lamb weaned, Table 3.4, Chapter 3) compared to the system in Sabah (38.3–46.5 kg DM kg LWG^{-1}). It has to be noted that the high FCE of the New Zealand systems is also partly because the systems studied were configured by the farmer to take advantage of the high growth and lower percentage allocation of feed energy to body maintenance of young animals to increase FCE; lambs are usually the main product and in these particular systems, more lambs are produced (lambing percentage >116%) and grown to as high a weight as possible within a relatively short period (4–6 mo) before being sold, which reduces the body maintenance energy requirement of the system.

Nitrogen application is known to improve DM yield, and perhaps the nutritive value, of herbage and also growth rate of cattle (Chen et al., 1982). Based on the discussion outlined above for the relationship between FCE and DM yield, the N application effect would have been expected to increase FCE where it acted to alleviate overstocking and decrease FCE where it increased herbage yield or quality beyond animal demand. Hence units with higher animal demand would likely exhibit a correlation between N application and FCE. Of the two units with the highest per ha animal demand, such an effect was seen on the Brahman Cow-calf Unit but not on the Bali cow-calf Unit (Section 5.3.1.3). Quigley et al. (2014) reported that the Bali breed is not suitable for high input-high output systems, as the breed has low efficiency use of ME (feed ME) for liveweight gain. In other words, increment of herbage quantity or quality as a result of higher nutrient inputs may not markedly improve the growth of the breed.

The effect of high rainfall years on annual FCE is confounded with the effect of N (and other fertilisers) application, as the application tended to be planned with the occurrence of rainfall, and annual N application was significantly correlated with annual rainfall. Hence, the higher annual FCE on the heifer and Brahman Bull Units in the years of higher rainfall (Table 5.1) can be at least partly linked to N application (and other fertilisers) which would have increased herbage ME and CP and may have alleviated a slight overstocking situation. The decrease of FCE during the high rainfall years on the Bali Cow-calf Unit, on the other hand, may be associated with alkaloids and oxalates in *Setaria*, which comprises 40% of the pasture on this unit (and the highest among grazing units). Chew (1991) reported that *Setaria* herbage contains those chemicals, and may cause deaths of cattle, especially during rapid growth following rainfall and heavy N application.

5.4.2 Implications for future system design

From the analysis above the sensible first step for future evolution of beef grazing system in Sabah, or at least on SPT Tawau, would be to use the insights from the above analysis to choose a configuration to optimise FCE of existing system, and then over time develop higher herbage production and maintaining a system configuration that will utilise the additional herbage and increase animal production in parallel with the increased herbage production. The primary focus must be on FCE, because the system configuration with the highest herbage demand is not necessarily the most productive, and targeting high FCE will increase system output per unit of feed input. Indeed high animal demand can reflect over grazing arising from above-optimal stocking rate. Opting for an efficient system is also in line with the general farming principle that pastoral productivity will depend on the quantity of the feed produced that is actually translated to animal product in the system (*sensu* McMeekan, 1958). It has to be noted that increasing the herbage production or other efforts to improve the productivity of the system would be less successful, if herbage nutritive value is not improved in parallel because under the present pasture management, the value is at or below the minimum requirement for a productive animal system. As noted in Section 4.4.3, if herbage production were improved as the first step, there is a shortage of stock to purchase to consume the extra herbage, as the industry is currently very small. Currently, there would be little scope to purchase animals from other farms, or even to obtain them from natural increase, with calving percentage presently below 50%. Focus on improving calving percentage would also be an important system development step, but would come later in the system evolution sequence, as discussed below.

Based on the data obtained, nomination of herbage production targets for the grazing system in Sabah is difficult and will need further system evaluation and research. Operational production identified in this study ranges from 3.74 t DM ha^{-1} yr^{-1} for the average of all grazing units, through 5.49 t DM ha^{-1} yr^{-1} for the average of the highest herbage harvested for each grazing unit, to 7.16 t DM ha^{-1} yr^{-1} for the highest system performance recorded. The average herbage production (as determined by MEB) during the year of highest FCE of each grazing unit was 4.43 t DM ha^{-1} yr^{-1}. This may well reflect the ideal stocking rate at the present level of production so that FCE could be maintained at a high level if stocking rate and herbage accumulation were jointly raised. Maybe a range of specific targets will be needed for every land unit. To set the appropriate system herbage harvest target (and stocking rates), it will be also necessary to consider the avoidance of lax grazing on the one hand and over grazing on the other hand, both for different land units within a farm, and for the system as a whole.

As with the cut-and-carry system studied in Chapter 4, the grazing system analysed in this study could be used to develop a benchmark for a farm with the current pasture production characteristics to establish the ideal balance between feed demand and supply for a grazing system in Sabah. In this study examples of low, near optimal and overstocked grazing units were, respectively, the Droughtmaster Cow-calf Unit (2011) (FCE = 48.8 kg DM kg LWG^{-1}, without allowing for feed non-utilisation), the Brahman Cow-calf Unit (2010) (FCE = 39.3 kg DM kg LWG^{-1}), and the Brahman Bull Unit (2013) (FCE = 145.6 kg DM kg LWG^{-1}). The average stocking rates for these three units calculated from data in Table 5.1 were respectively, 300, 506 and 642 kg animal LWT ha^{-1}. As in Chapter 4, CSR was calculated for the grazing system. If the feed offered is taken as the average feed harvested of all grazing units (3.74 t herbage DM ha^{-1} yr^{-1} + 0.85 t herbage equivalent PKC DM ha^{-1} yr^{-1}) plus a 15% allowance for non-utilisation, then for the three grazing units just mentioned, the CSR values are, respectively, 56, 94, and 117 kg LWT t DM^{-1}. This result (94 kg kg LWT t DM^{-1}) appears close to that recommended for the New Zealand dairy systems. (The optimal range of CSR for New Zealand dairy farms is reported to be 76–80 kg LWT t DM^{-1}: DairyNZ, 2013). However, again, further evaluation is needed to establish the optimal value of this index for a grazing system in Sabah.

Based on the results of the above analysis, the 2010 Brahman Cow-calf, 2009 Bali Cow-calf, 2009 Droughtmaster Cow-calf, 2009 (or 2010) Heifer, and 2012 Brahman Bull configurations are examples of farm system configurations from among those studied that could be used as a template for optimising FCE of current grazing system in Sabah. The key farm information for those years was presented in Table 5.1, and the relevant optimisation details are given in Table 5.7 for farmers in Sabah to work out on their farms. The estimated CSR values in Table 5.7 are close to those recommended in New Zealand (listed just above) especially for the Brahman Cow-calf and Droughtmaster Cow-calf Subsystems.

Table 5.7 Farm stocking rate details for subsystems with superior performance in the present study. Assuming similar herbage supply in a similar climate/soil/management environment, these data would be a guideline for stocking rate determination for future grazing system optimisation in Sabah.

Year	Subsystem	Adult/Cow			Calf			Area (ha)	Estimated
		Head	LWT (kg)	Age (mo)	Head	LWT (kg)	Age (mo)		CSR
2010	BRCC	179±7	431±7	72±2	48±13	91±24	4.3±1.2	161.1	74
2009	BACC	36±1	303±5	78±3	18±3	92±12	5.8±1.0	26.3	62
2009	DMCC	39±3	463±7	122±3	20±4	94±16	8.2±2.6	38.5	69
2009	Heifer	55±5	207±9	20±1	–	–	–	52.6	63
2012	BRB	47±11	378±13	31±2	–	–	–	43.3	63

BRCC: Brahman Cow-calf. BACC: Bali Cow-calf. DMCC: Droughtmaster Cow-calf. BRB: Brahman Bull. Note that the area can be used for the calculation of stocking rate (animal number or animal weight per ha). CSR: kg LWT^{-1} t DM^{-1}.

In Table 5.7, the heifer system comprises Brahman, Bali and Droughtmaster heifers and “age” is only an indicative and not a decisive factor, because animals of superior genetics and well fed may reach the stated liveweight at younger age. Constant stock numbers can be maintained throughout the year because there is no seasonality in herbage supply in the system. However, animal production under grazing is a complex and interactive system (Detmann et al., 2014) and the set up in Table 5.7 is not an attempt to fix the system on one particular stocking rate, but is given as a starting point for future adjustment of the system configuration. Identifying the optimal stocking rate is also an important requirement in order to achieve coordination between the grazing units at SPT Tawau and attain the best FCE for the whole system, or to extrapolate the findings to similar farms in Sabah. In each case the recommended stocking rate is benchmarked to herbage harvested, also.

To facilitate an incremental improvement of the system in the future, work recommended (in a sequence of priority) along with the optimisation adjustments proposed above is:

(i) Production of a management guide that mitigates the adverse effect of weaning on calf growth in grazing systems (note that the methods to address the effects of weaning in this case are different from that for calves in cut-and-carry feedlot system; see Section 4.4.3). Several methods proposed in literature to mitigate the weaning effect in grazing systems are fenceline separation (Price et al., 2003; Lambertz et al., 2015) and use of nose-flaps (Enríquez et al., 2010) before a complete separation. The effectiveness of these methods will depend on various factors (Enríquez et al., 2011) and thus, a trial is necessary to confirm the benefits in cattle production systems in Sabah.

(ii) Investigation of a supplement feeding regime (e.g., PKC) that prevents excessive liveweight loss during lactation (or at other times such as during weaning) and ensures a mating weight that will increase conception and improve calving percentage (note that the specific objective of the use of supplement in this case is different from that for cut-and-carry feedlot system; see Section 4.4.3). Ideal mating weights for these animals in Sabah need to be defined.

(iii) Development of a pasture husbandry package to define N, P and S application regime, and grazing cycle for increasing pasture productivity towards the potential DM yield (14–20.6 kg DM ha^{-1} yr^{-1}) and ME of 9.5 MJ kg DM^{-1} at grazing. Where feed supplement is used (see ii above), concentrate of consistent ME and CP content of at least at 11.5 MJ kg DM^{-1} and 14%, respectively, is needed. Important factors to be considered are types, rates and timing of fertiliser application, and intensity (amount and frequency) and timing of grazing rotation, herbage nutritive value (Chin, 1995), and as well as a year-long rigorous cutting experiment to estimate the annual herbage DM production in the systems. A component of the pasture husbandry package is to define the fertiliser application schedule to avoid the toxic effect of the herbage to the cattle, especially when *S. sphacelata* 'Kazungula' is used. In addition, paddock(s) of a grazing unit may need to be reassigned to another unit to avoid herbage of different species with different growth rate and grazing interval requirements being in the same unit. In monitoring forage nutritive value, avoidance of the cost of unnecessary chemical analyses would be important. Hence, occasional chemical analyses and development of assessments that can be made on farm such as visual pasture quality and animal body condition scores would be essential monitoring tools for the improved future systems.

(iv) Investigation of the relevance of developing a conservation system to avoid feed waste in the event of a surplus occurring. Pastoral systems are inherently variable and even in an aseasonal tropical system there can be occasional periods of surplus after unusually good growth conditions. In such cases the feed surplus could be harvested and transferred to the feedlot system, or in future sold. Possible systems for consideration include drying and pelleting (if the farm budget permits, as this is known to be expensive: Preston and Leng, 1987) or ensilage.

(v) Although, a detailed investigation was not carried out in this study, it has to be noted that a long-term aim important for systems in Sabah is to incrementally and improve the genetic merit of the cattle breeds over time to increase the reproductive performance and coupled with the efficient system (initiated from the present study), this could expand the animal production of the whole beef industry.

5.4.3 Overview of MEB as a system analysis tool

The MEB in this Chapter (and in previous chapter: Chapter 4) revealed defining features of the feed profile and FCE of the grazing system in Sabah that would have been more difficult to assess using other available methodologies. Intuitively, it would have been expected that grazed dry matter would have been higher than the modelled range of 3.74–7.16 t DM ha^{-1} yr^{-1} and closer to the potential of 6.9–20.6 t DM ha^{-1} yr^{-1} identified above (Table 5.2). Conventional techniques for establishing pasture yield involve either cage cutting over a 12-month period (Radcliffe, 1974, 1975) or dosing animals with a marker such as chromium oxide or n-alkane compound (Carruthers and Bryant, 1983; Oliveira et al., 2007). Both of these methods have high resource demands, significant opportunity for systematic error (Carruthers and Bryant, 1983; Hatfield et al., 1991) and involve cost to purchase the chemicals. By contrast the values obtained by MEB involve a comparatively small resource investment of professional time and modelling, and the errors associated are less than 10% (Nicol and Brookes, 2007), and in this study were assessed at less than 5% (see Section 4.4.1). The methodology also provided unexpected insights, especially with respect to the use of FCE as an indicator for system performance and stocking rate optimisation, which in turn led to a deduction that optimising present systems based on FCE would be a better option than intensification as a first step in system evolution. MEB as a farm systems analysis tool is comparatively unknown in Malaysia. Further, the potential for use in technology transfer is little used in New Zealand, given the tool has been developed through software like Farmax (www.farmax.co.nz) for local system evolution. For these reasons guidelines for organisation of the Sabah data for MEB analysis and for application of New Zealand methodologies to that data had to be developed *de novo*. There is a need for a publication to establish a framework for the use of MEB in farm system technology transfer.

5.5 Conclusions

Based on the data analyses in this chapter, the following conclusion can be made:

- The current average for herbage harvested is 3.74 t DM ha^{-1} yr^{-1} across all units (or subsystems), with the highest value being recorded on any unit being 7.16 t DM ha^{-1} yr^{-1}. This is much less than the regional environment potential based on light and rainfall (6.9–20.6 t DM ha^{-1} yr^{-1}), similar to that found for the cut-and-carry feedlot system studied in Chapter 4.

- The animal production of the system is also limited by marginal herbage ME and CP values (7.7–8.5 MJ ME kg DM^{-1} and 9%–11% CP), similar to the cut-and-carry feedlot system studied in the previous chapter, with currently about 78% of consumed metabolisable energy being allocated in the system to body maintenance. Part of the limitation is a technical error associated with human judgement on the quantity and quality of herbage and grazing cycle.
- In contrast to temperate pastoral systems, herbage production appears to be aseasonal and local farm systems could use split calving to avoid a seasonal peak of animal feed demand.
- The PKC use in the system was quantified as 0.47–1.39 t DM ha^{-1} yr^{-1} (as herbage equivalent); thus, some or all PKC use could be eliminated to reduce farm operation cost by targeting improved pasture productivity and quality. If PKC were used, it is targeted tactically to reduce liveweight loss occurrence and enhance mating performance, and to some extent to address the reduction of liveweight loss that currently occurs after weaning. Batches of PKC should be tested before purchase for quality assurance purposes, as some batches purchased are of low energy value (<9.5 MJ ME kg DM^{-1}), although the CP value is high (16.0%).
- The first step to improve the animal production of the system is to adjust the system configuration (by using that in 2010 and 2009 as a starting set up) especially stocking rate for optimal FCE. At the current pasture production levels in the system, optimal FCE is achieved at a stocking rate of approximately 506 kg animal LWT ha^{-1} or a CSR of approximately 94 kg LWT t DM^{-1} offered.
- Following the initial adjustments of system configuration, a second step would be development of a pasture husbandry package that included guidelines for N application (including avoidance of alkaloids and oxalate toxicity on *Setaria* pastures), pasture ME and CP enhancement, and timing and intensity of grazing management. In the medium term, the feasibility of mitigating the limiting factors to herbage production and quality could be investigated in paddock scale trials and introduced as successful solutions were identified. Suggested targets for this phase are 14–26 t DM ha^{-1} yr^{-1} herbage harvested with ME >9.5 MJ kg DM^{-1} and CP >13%.

Chapter 6

Feed Profile Analysis of Oil Palm Integrated Beef Cattle Farming Systems by Metabolic Energy Budgeting and Implications for Beef Production and Future System Design in Sabah

Abstract. Metabolic energy budgeting (MEB) was used to model the feed demand patterns of oil palm integrated cattle (OPIC) farming systems in Sabah to gain insight into herbage supply and feed conversion efficiency (FCE) of the system. The animal data used involved 550–800 cattle farmed in three OPIC farms. Two farms were 9 yr old plantations (9OP1 and 9OP2) and one farm was a 12 yr old plantation (12OP). Animal liveweight data available were weights at birth, weaning, 24 months of age, and sale. Liveweight data used to fit growth curves to the supplied weights were obtained from the nearest government farm that had compatible animal growth data to those provided by the farms studied. For additional insight, measurements were also carried out on nutritive value of herbage being grazed, botanical composition, mid-regrowth herbage mass, and pre-grazing herbage mass. (The latter two provided for estimation of herbage accumulation). Results of the MEB indicated that herbage supply as herbage eaten in the system was 2.0–2.4 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 1.42–1.69 t DM ha^{-1} yr^{-1} for 12OP. These values were lower than the DM production values obtained by cutting (6.5 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 3.4 t DM ha^{-1} yr^{-1} for 12OP) or estimated based on light availability under oil palms (4.53 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 2.95 t DM ha^{-1} yr^{-1} for 12OP), but all estimates indicated that a 9 yr old oil palm plantation can still supply >2 t DM ha^{-1} yr^{-1}, which is higher than values reported in the literature. When dry matter of leaf harvested by cutting was compared with herbage dry matter consumed (estimated by MEB), the differences were smaller (1.3–1.7 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 0.6–0.9 t DM ha^{-1} yr^{-1} for 12OP), indicating that the cattle may have grazed mostly leaves. Herbage ME (8.3–8.5 MJ ME kg DM^{-1}) in the system was at the lower edge of the range for supporting high cattle liveweight gain, but herbage CP (10%–16%) was at the upper edge of the optimal range. The FCE values of the system were 32.2 kg DM kg LWG^{-1} for 12OP and 94–99 kg DM kg LWG^{-1} for 9OP1/9OP2, which are lower than that of the grazing cattle farming system in Sabah.

6.1 Introduction

Sabah has 1.511 million ha of agricultural land cultivated with oil palms, which is the largest area of any state in Malaysia (MPOB, 2014). The plantations are increasingly used for beef cattle farming for profit maximisation (Azid, 2008). Information on the actual area of oil palm plantation being used for cattle farming in Sabah is not available, but SKSB (2010) reported that it has used 22,949 ha of oil palm plantation to farm 8,018 cattle. Initially, cattle were introduced into oil palm plantations to control the undergrowth, but were later farmed systematically to produce beef commercially (Chen, 1990; Azizol and Norlizan, 2004; Azid, 2008).

The fundamental issue of feed planning in OPIC farming system is the lowering of herbage dry matter yield, ME and CP which occurs in response to shading as the oil palms in the plantation develop from isolated individuals to canopy closure and as herbage matures during its regrowth cycle. In a 3–4 yr old un-weeded oil palm plantation, herbage dry matter yield is reported to be approximately 3.0 t DM ha^{-1} yr^{-1} or sometimes 5.5–9.5 t DM ha^{-1} yr^{-1}, but this decreases to 400–800 kg DM ha^{-1} yr^{-1} by the time the plantation is 6–7 years old (Chen, 1990). The understorey herbage production is reported to remain at 400–800 kg DM ha^{-1} yr^{-1} for the next 20 years (Jalaludin and Halim, 1998). There are also reports of seasonal variation in dry matter yield. For example, in the northeast of West Malaysia, herbage production in a 5 yr old oil palm plantation was reported to be 1991 kg DM ha^{-1} yr^{-1} in the 4-month wet season from October–January and 1463 kg DM ha^{-1} yr^{-1} in 8-month dry season from February–September (Hassan et al., 2004). In respect to the energy content, the total energy of herbage per unit area per day is reported to decrease from 34 MJ ME ha^{-1} d^{-1} in a 3 yr old oil palm plantation to 10 MJ ME ha^{-1} d^{-1} in a 15 yr old oil palm plantation (Dahlan et al., 1993). The corresponding reported decrease in CP is from 15% to 11%, when grasses replace the broad leaf plants in older plantations (>5 years old). These data indicate that low herbage DM production and nutritive value would limit the cattle carrying capacity of older plantations.

In Sabah, OPIC farming has been practiced for more than a decade. However, little information is published on the quantity of feed harvested and stocking rates in this category of beef production system. Most studies of this type published in Malaysia are based on data collected in West Malaysia. Hence, defining the feed demand and supply for OPIC farming system in Sabah would provide some quantitative basis for planning the future development of beef production under the local oil palm plantation conditions. An alternative approach to gain an insight into the feed profile of OPIC farming system was the application of methodologies developed in New Zealand over recent decades, which was captured in the study described in Chapter 3, and adapted for use in Sabah in Chapter 4 for cut-and-carry feedlot cattle farming system and in Chapter 5 for grazing cattle farming system.

The present study was carried out in 2014. The oil palm company that agreed to participate in this study has been involved in OPIC farming since the 1990s and has a well-organized rotational stocking system in its oil palm plantations (Azid, 2008). In this study, a key part of the analysis was to capture the feed demand and supply of three separate beef cattle farms under OPIC farming system in Sabah: two 9 yr old plantations (9OP1 and 9OP2) and one 12 yr old plantation (12OP). As was the case in Chapter 4 and 5, the focus of the present chapter was to capture the feed demand and supply with a spreadsheet tool developed in the New Zealand phase of the study (Chapter 3) to first describe, and then to identify the opportunities to improve the OPIC farming system. As in the previous two chapters, the analysis is based on determination of feed demand using MEB, but also uses summary statistics like FCE. For further insight, measurements were also carried out on some nutritive value of herbage being grazed and some pre-grazing herbage mass (separated in time to estimate herbage accumulation). For data comparison with the results of the MEB and herbage cutting, the theoretical potential herbage productions of the system were also calculated based on the method described by Wilson and Ludlow (1990) and Cooper (1970).

6.2 Materials and methods

6.2.1 Case farms: 9OP1, 9OP2 and 12OP

The 9OP1, 9OP2 and 12OP noted above were located in Lahad Datu in southeastern Sabah (Lat. 4.9652, Long. 118.5314; 5–20 m a.s.l.). Based on the nearest weather station, the annual rainfall on these farms is 2286±511 mm. The monthly average rainfall is highest in January (288 mm), then reducing to 118 mm in June and a low of 103 mm in August, before increasing again to 202 mm in December (DOA, 2015). The monthly mean temperature is highest from June to August (31ºC) and lowest from December to January (26ºC), although generally the temperature can be regarded as almost constant with an average of 28ºC throughout the year. This is consistent with the general pattern of temperature in the eastern coastal region of Sabah described by Walsh and Newbery (1999).

6.2.1.1 Farm details for OPIC farming system at 9OP1, 9OP2 and 12OP

Farms 9OP1 and 9OP2 were adjacent to each other, and the oil palm plantation where these farms were located had previously been used for 5–6 years as a single unit for cattle farming, before 9OP2 was operated for cattle farming independently from 9OP1 from November 2013. Farm 12OP was situated 3–4 km from 9OP1 and 9OP2. The farm has been used for cattle farming for 5–7 years. The total area of 9OP1 was 760 ha and 9OP2 was 360 ha, and the average paddock size on 9OP1 was 13 ha and that on 9OP2 was 6 ha. The total area of 12OP was 360 ha and the size of the paddocks was 6 ha. "Paddock" is used here for simplicity to refer to the grazing area enclosed temporarily by the farm staff, using electric fencing.

The topography of 9OP1 and 9OP2 can be described as flat to gently undulating. The characteristics of the soil samples collected from these farms in August 2014 were: pH, 5.0±0.1; total N, 0.1±0.0%; available P, 51.5±9.4 ppm; K, 0.5±0.3 meq%; Ca, 4.0±1.9 meq%; and Mg, 1.8±1.5 meq%. The topography of 12OP is similar to that of 9OP1 and 9OP2. Soil samples were not collected and analysed due to time constraint and a limited budget, but similar values to 9OP1 and 9OP2 could be expected.

The cattle breed used on all farms was Brahman and all bull sires and cows were animals of certified breed imported from Australia. The management of cattle on the farms had changed several times, depending on the past managers. 9OP1 was used for breeding cows (+calves) and bulls; 9OP2, for weaner female cattle and some weaner male cattle (6–24 mo old); and 12OP, for weaner male cattle (6–24 mo old). The heifers joined the cows in 9OP1 at approximately 24 mo of age for breeding. The stocking rate was less than one animal per hectare on each farm (Table 6.1).

Table 6.1 Animal class and stocking rate on 9OP1, 9OP2 and 12OP farms.

	9OP1		**9OP2**		**12OP**	
	2013	2014	2013	2014	2013	2014
Animal class	Cows, calves and bulls	Cows, calves and bulls	Weaner bulls, some Cows, calves and bulls	Heifers, some weaner bulls	Weaner bulls, some heifers	Weaner bulls
Cattle ha^{-1}	0.779	0.666	0.344	0.735	0.597	0.686
Liveweight (kg hd^{-1})	320±11	321±23	331±51	253±30	212±22	211±18
Liveweight (kg ha^{-1})	249	212	106	185	126	144

(± Standard deviation)

The grazing interval on all farms was 60 days. The cattle were transferred to a new temporary paddock every day. The cows and bulls are run together throughout the year, and cows calve in almost every month. Weaned female calves were transferred to other farms (in Sabah) belonging to the company, and weaned female calves from the other farms were transferred to 9OP2 to avoid inbreeding. Weaned male calves were transferred to 12OP or 9OP2, and at 24 months old, the bulls were transferred to a cut-and-carry feedlot cattle farm for finishing.

Based on the farm record, the calving rate was approximately 33%–40% a year. The average calf birth weight was reported to be 18–18.5 kg. The male and female calves were weaned between the ages of 6 and 12 months (average 10 months). The average weaning weight was reported to be 130 kg and the average weight at 24 months old was approximately 233 kg. The average daily gain was reported to be 368 g hd^{-1} d^{-1} from birth to weaning and 242 g hd^{-1} d^{-1} from weaning to 24 months.

6.2.2 Data collection

6.2.2.1 Acquisition of animal data

The animal records used for the MEB (Section 6.2.3.1 below) were supplied by the farm manager for farm operation from January 2013–December 2014 for 12OP and 9OP1 and from November 2013–December 2014 for 9OP2. The records available included details of number of animals in various classes recorded monthly (overall, 600–700 head), but body weight data supplied to the author was averaged across stock classes, with data for individual animal classes only available for important events; primarily birth, weaning, 24 months old and selling. To obtain monthly body weight estimates for individual animal classes for modelling purposes, relevant live weight trajectories of cattle on a government cattle breeding farm in the district nearest to these farms were obtained and used to interpolate animal weight trajectories between the measured values supplied (Appendix 6.1).

6.2.2.2 Measurements of effective area

The "effective area" for the MEB was calculated (as distinct from total farm area) by first selecting 3 ha as representative of the total area on each farm, and mapping in detail the areas not available for grazing, and deducting these from the total area. The areas excluded from the effective area included tree trunks and associated circle weeding, stacked pruned palm fronds, and drains and roadways (Table 6.2).

Table 6.2 Effective area of 9OP1, 9OP2 and 12OP farms.

	9OP1 2014	9OP2 2014	12OP 2014
Total area (ha)	760	360	360
Oil palm tree density ha^{-1}	138	138	138
Area under stem ha^{-1}	0.016	0.016	0.016
Area under circle weeding ha^{-1}	0.173	0.173	0.043
Area under frond debris ha^{-1}	0.12	0.12	0.06
Area under road ha^{-1}	0.02	0.02	0.02
Area under drain ha^{-1}	0.02	0.02	0.02
Non grazeable area (ha)	265	126	57
Effective area (ha)	495	234	303

Non-grazeable area is obtained by summing the areas per ha occupied by stems, circle weeding, frond debris, roads and drains and multiplying by total area, and was assumed to be the same in 2013 as in 2014.

6.2.2.3 Available data on feed supply

Similar to the studies on cut-and-carry feedlot cattle farms in Chapter 4 (Section 4.2.2.3) and grazing cattle farms in Chapter 5 (Section 5.2.2.2), the primary thrust of this study was to define the system through the animal demand calculated by MEB. However, available information on feed supply and nutritive value of the feed was also collected to support the discussion of the modelling results.

(a) Herbage accumulation

Data on herbage dry matter yield and botanical composition on each farm were collected three times during August–September 2014. A first series of herbage cuts was carried out to assess herbage mass in 5 selected paddocks: 60 days, 45 days, 30 days, 15 days and 1 day before grazing commenced. The sample collection was carried out on the same day on all farms. The second and third series of sampling cuts were carried out on the same paddocks 15 days after grazing and again 30 days later. Ten 0.26 m^2 quadrats were placed at 10 m intervals towards the centre of each paddock. The starting location for sampling was approximately 10 m inside the paddock, selected by a throw of a stick to preclude human bias in selecting the starting point. The sampling transect was aligned across rather than parallel to the palm rows to increase sampling heterogeneity. All sampling points were marked with 30 cm long wooden sticks (the tip was coloured red), buried 20 cm into the soil to avoid the herbage from the same point from being resampled at the subsequent sampling. Herbage mass in the quadrats was harvested by hand to ground level using scissors (Boswell, undated). A sample of cut herbage from outside of each quadrat was preserved for assessment of botanical species composition. Botanical identification was achieved by comparison with specimens deposited in the Sandakan (SAN) Herbarium, Sabah. A sub-sample from each quadrat was separated into leaf, leaf sheath, stem and dead matter. The main sample and components of the sorted sub-sample were weighed, dried at 60ºC for 2 days and reweighed.

(b) Herbage ME and CP analysis

Dried herbage from quadrats 2, 5 and 8 from each transect of the sampling described earlier were ground to powder and sent to Makmal Kesihatan Awam Veterinar, Department of Veterinary Services, West Malaysia (Lab references ST3385/14 and ST3596/14) for the analyses of ME, CP and crude fat contents following protocols set out in the Malaysian Standard of Test for Animal Feedstuffs MS: 3.1982.

6.2.3 Analysis of system feed profiles

6.2.3.1 Modelling of monthly and annual feed demand and consumption

The metabolic energy requirements of the animals were assumed to be the feed demand of the system, and a basis for calculation of the feed supply in the system, as in Chapters 4 (Section 4.2.3.1) and 5 (Section 5.2.3.1). Metabolic energy calculations to determine feed demand were performed for all 3 farms, for each month. The Microsoft®Excel spreadsheet model developed for the analysis performs a separate calculation of energy requirements for individual animal classes based on the relevant liveweight trajectories of the classes and the results were multiplied by the number of animals in each class to arrive at a total for each farm. Based on laboratory results for herbage ME (Section 6.3.2.3 below) and the "effective area" of the respective farms, the herbage DM data are presented as kg DM ha^{-1} d^{-1} or t DM ha^{-1} yr^{-1} according to the context of discussion. As the farms did not use feed supplement, no adjustment for supplement used was made when estimating herbage demand from the animal metabolic energy demand. The foundation of the metabolic energy equations used is similar to those of Chapter 5 as set out in Appendix 4.3. Specifically, metabolic energy requirements of each animal were calculated for: body maintenance (Eq. 2), liveweight gain (Eq. 3.1), grazing activity (Eq. 4), pregnancy (Eq. 5), and lactation (Eq. 6).

6.2.3.2 Feed conversion efficiency

The information on feed demand and animal liveweight gain was extracted from the analyses described in Section 6.2.3.1 from January 2013–December 2014 for 12OP and 9OP1 and from November 2013–December 2014 for 9OP2 and used to evaluate the monthly and the annual FCE of each farm. FCE was calculated as the total feed demand (month or annual) divided by the total liveweight gain in the same period.

6.2.4 Theoretical potential of system herbage production

For benchmarking the estimate of herbage supply of the herbage cutting and MEB, theoretical potential herbage production based on light availability estimate under oil palms was calculated using method adapted from Wilson and Ludlow (1990) and Cooper (1970) as set out in Appendix 6.2. The calculation was based on daily solar energy input in Sabah (15.87 MJ m^{-2} d^{-1}: Kartini et al., 2015), light penetration through the oil palm canopy (46% for a 9 yr old plantation and 30% for a 12 yr old plantation: Dahlan et al., 1993), light captured by herbage (51.5%: Figure 10 in Wilson and Ludlow, 1990), light energy as photosynthetically active radiation (PAR) or photon irradiance on the herbage canopy (27%: Baldocchi et al., 1984), and conversion of PAR light energy to herbage dry matter (3.5%: Cooper, 1970).

6.3 Results

6.3.1 System feed profiles based on MEB

6.3.1.1 Annual and monthly herbage demand

The MEB indicated that feed demand of the system ranged from 2.0–2.4 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 1.4–1.7 t DM ha^{-1} yr^{-1} for 12OP (Table 6.3). Vegetation under the oil palms, and sometimes ferns on the palm trunks and oil palm fronds, was the main source of feed for the cattle. The farm did not use feed supplement. The monthly feed demand per cattle beast) ranged 250 to 256 kg DM hd^{-1} for 9OP1/9OP2 and 198 to 204 kg DM hd^{-1} for 12OP. The high and low values of monthly feed demand were, respectively, 192 and 158 kg DM ha^{-1} mo^{-1} for 9OP1, 231 and 97 kg DM ha^{-1} mo^{-1} for 9OP2, and 149 and 112 kg DM ha^{-1} mo^{-1} for 12OP. Counterintuitively, no spike of monthly feed demand was detected on 9OP1 (cow–calf unit) during calving and weaning periods (Figure 6.1). Monthly feed demand showed some marked fluctuations towards the end of the year on all farms, but these were attributable to movement of cattle between the farms (Figure 6.2).

Table 6.3 Feed demand for 9OP1, 9OP2 and 12OP farms in 2013 and 2014.

	9OP1		9OP2		12OP	
	2013	2014	2013[A]	2014	2013	2014
Feed demand (t DM ha^{-1} yr^{-1})	2.40	2.00	1.01	2.02	1.42	1.68
(Feed demand, kg DM hd^{-1} d^{-1})	8.44	8.23	–	7.53	6.52	6.71
(Energy demand, GJ ha^{-1} yr^{-1})	20.42	17.03	8.62	17.15	12.06	14.28

Data for 12OP and 9OP1 are the average of 2 yr, while 9OP2 is for 1 yr. [A] 9OP2 was commenced in November 2013.

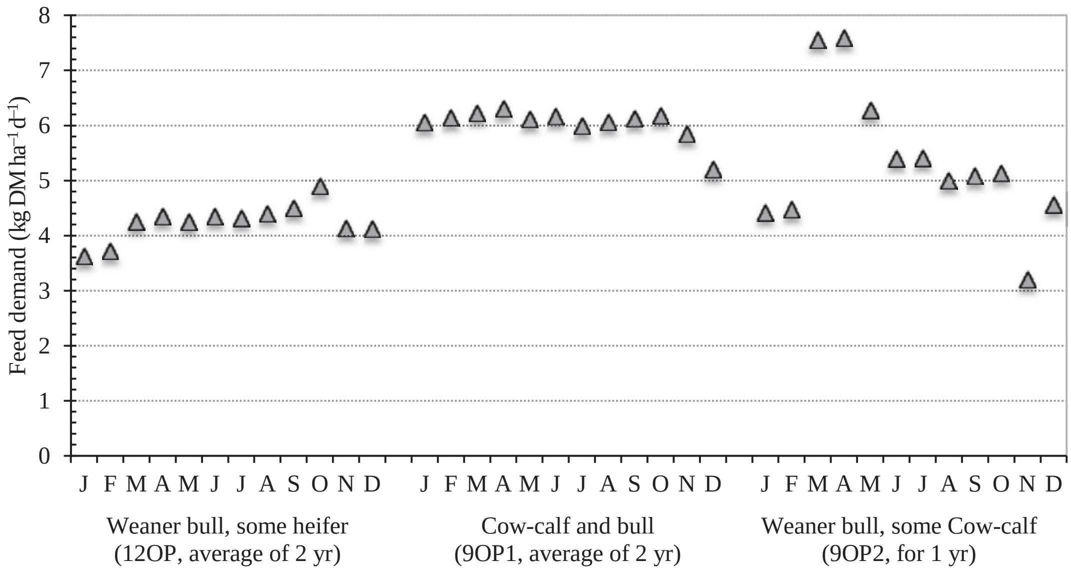


Figure 6.1 Monthly feed demand for 9OP1, 9OP2 and 12OP farms.

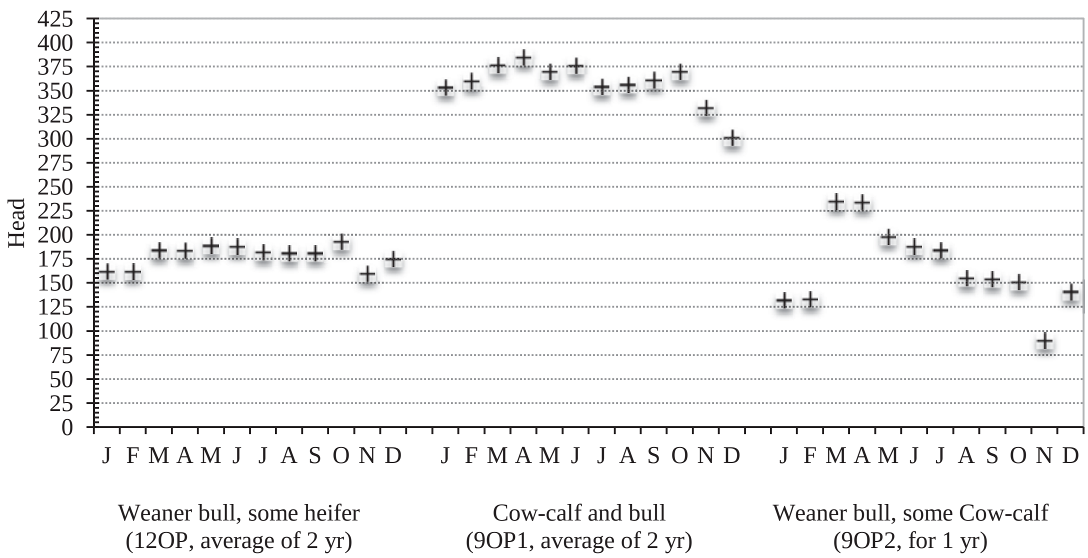


Figure 6.2 Monthly cattle numbers for 9OP1, 9OP2 and 12OP farms.

6.3.1.2 *Feed conversion efficiency*

FCE of the system was 32.2 kg DM kg LWG^{-1} for 12OP, 94.0 kg DM kg LWG^{-1} for 9OP1, and 99.0 kg DM kg LWG^{-1} for 9OP2 (Table 6.4). Months of most efficient FCE for each system were April for 9OP1 (72.3 kg DM kg LWG^{-1}), June for 9OP2 (28.8 kg DM kg LWG^{-1}), and May for 12OP (27.5 kg DM kg LWG^{-1}). The coefficient of variation of monthly FCE ranged from 9% (12OP) to 30% (9OP2).

Table 6.4 Feed conversion efficiency (FCE) of 9OP1, 9OP2 and 12OP farms in 2013 and 2014: (a) Annual and (b) Monthly.

(a) kg DM kg LWG^{-1}	2013	2014	$\bar{x}$	SD	CV%
Overall	91.3	58.8	75.1	22.9	31
9OP1	89.4	98.6	94.0	6.5	7
9OP2	152.1[A]	45.9	99.0	75.1	76
12OP	32.3	32.0	32.2	0.2	0.5

(b) kg DM kg LWG^{-1}	J	F	M	A	M	J	J	A	S	O	N	D	$\bar{x}$	SD	CV%
Overall	63.6	63.9	51.4	51.6	50.8	44.5	51.1	54.1	54.3	53.9	78.4	70.8	57.4	9.8	17
9OP1	90.0	88.3	74.5	**72.3**	80.0	75.5	92.3	93.3	90.1	84.6	154.3	132.9	94.0	24.7	26
9OP2[B]	71.3	72.3	49.3	50.3	44.7	**28.8**	30.0	36.6	38.5	41.0	43.1	44.8	45.9	13.8	30
12OP	29.4	31.2	30.5	32.2	**27.5**	29.1	30.9	32.5	34.2	36.0	37.8	34.6	32.2	3.0	9

[A] 9OP2 was commenced on November 2013. [B] Involved only 2014. LWG: liveweight gain.

6.3.2 Information on feed supply from short-term observations

6.3.2.1 *Herbage accumulation from two month cutting experiments*

In the cutting experiment, the average green dry matter increase during the 60 d grazing interval was 17.8 kg DM ha^{-1} d^{-1} for 9OP1/9OP2 and 10.1 kg DM ha^{-1} d^{-1} for 12OP (Table 6.5; Appendix 6.3). If it can be assumed that these data are also representative of herbage accumulation in months not sampled (as rationalised in Section 6.4.1.2), then annualised green dry matter accumulation was 6.5 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 3.4 t DM ha^{-1} yr^{-1} for 12OP. The average green dry matter production of 12OP was 48% less than that of 9OP1/9OP2. The average leaf dry matter accumulation during the 60 d grazing interval was 10.1 kg DM ha^{-1} d^{-1} for 9OP1/9OP2 and 6.3 kg DM ha^{-1} d^{-1} for 12OP (Table 6.5). Annualised leaf dry matter was 3.7 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 2.3 t DM ha^{-1} yr^{-1} for 12OP.

Table 6.5 Herbage accumulation rate at various stages in regrowth cycle of the 60 d rotation.

	9OP1/9OP2				12OP			
Stage of regrowth (days)	60-45	45-30	30-15	15-0	60-45	45-30	30-15	15-0
Growth (kg DM ha^{-1} d^{-1})	24.4	–3.1	22.2	36.0	–20.5	18.6	9.4	13.1
Green matter (kg DM ha^{-1} d^{-1})	22.7	–4.1	22.1	26.3	–13.8	13.5	9.7	14.0
Leaf, kg DM ha^{-1} d^{-1}	15.4	–4.1	11.9	13.1	–5.1	6.1	6.8	12.3
Leaf sheath (kg DM ha^{-1} d^{-1})	3.9	0.5	5.0	3.8	–3.0	4.6	1.6	3.1
Stem (kg DM ha^{-1} d^{-1})	3.4	–0.6	5.2	9.4	–5.7	2.8	1.4	4.8
Dead matter (kg DM ha^{-1} d^{-1})	1.7	1.0	3.8	6.1	–6.7	5.1	–0.4	–0.9

Data were collected only during the months of August and September so must be interpreted with care.

6.3.2.2 Herbage botanical composition

The botanically important species on all farms were similar (Table 6.6). In total, 14 species, of which two were identified only to genus level, and two taxa (one fern and one unknown) were recorded in all quadrats. There were 9 species on 9OP1/9OP2 and 12 species on 12OP. Two species, *Axonopus compressus* and a *Digitaria* sp., on 9OP1/9OP2 were not recorded on 12OP, and five species of mostly broadleaf plants on 12OP were not recorded on the other two farms (Table 6.6). *Ottochloa nodosa*, *Asystasia intrusa*, *A. compressus*, *Panicum* sp. and *Paspalum conjugatum* were the important species on 9OP1/9OP2. With the exception of *A. compressus*, the four other species and *Cyrtoccocum* cf. *patens* were also numerous on 12OP.

Table 6.6 Species composition, production and nutritive value of ground herbage on 9OP1, 9OP2 and 12OP farms every 15 days within the 60 days grazing interval.

	9OP1/9OP2					12OP				
Day before grazing	60 d	45 d	30 d	15 d	0	60 d	45 d	30 d	15 d	0
Green matter (kg DM ha^{-1})										
Ottochloa nodosa	63	107	373	356	505	333	37	285	0	172
Panicum sp.	0	257	0	0	453	0	0	0	393	0
Paspalum conjugatum	79	0	0	11	108	0	32	0	87	0
Asystasia intrusa	0	8	19	128	12	0	60	0	0	39
Axonopus compressus	1	109	28	15	0	0	0	0	0	0
Digitaria sp.	0	0	0	147	0	0	0	0	0	0
Turnera subulata	0	3	0	83	53	2	0	9	0	1
Borreria latifolia	0	0	0	13	0	0	3	0	0	0
Crytoccocum cf. *patens*	0	0	0	0	0	0	0	36	0	267
Alocasia sp.	0	0	0	0	0	3	0	0	0	0
Commelina nudiflora	0	0	0	0	0	0	0	3	0	0
Ageratum conyzoides	0	0	0	0	0	0	0	0	0	58
Urochloa cf. *mutica*	0	0	0	0	0	0	0	0	0	3
Mucuna bracteata	0	0	0	0	0	0	0	0	0	149
Ferns	0	0	0	0	7	0	0	0	0	1
Unknown taxa	0	0	0	0	9	0	0	0	0	0
Total (kg DM ha^{-1})	142	483	421	752	1146	338	131	333	480	689
(S.D.)	(38)	(111)	(55)	(107)	(239)	(35)	(20)	(58)	(79)	(201)
CP (%)		17.6	18.1	17.6	16.3		16.8	14.5	10.2	15.4
ME (MJ ME kg DM^{-1})		8.4	8.4	8.6	8.3		8.4	8.1	8.6	8.5

Samples at 60 d were not analysed for CP and ME content.

6.3.2.3 Herbage ME and CP content

On all farms, the changes in herbage ME through the regrowth cycle were not large (Table 6.6), although herbage ME at 15 d (8.6 MJ ME kg DM^{-1}) before grazing was a little higher than that at a day before grazing on 9OP1/9OP2 (8.3 MJ ME kg DM^{-1}) or on 12OP (8.5 MJ ME kg DM^{-1}). The lowest (7.4 MJ ME kg DM^{-1}) and highest herbage ME (9.5 MJ ME kg DM^{-1}) were recorded on 12OP. Herbage CP (%), varied little during the grazing cycle on 9OP1/9OP2 and tended to be lower on 12OP than on 9OP1/9OP2 (Table 6.6).

6.3.3 Theoretical potential herbage production

The theoretical potential herbage production was 6.97 t DM ha^{-1} yr^{-1} in 9 yr old oil palm plantation and 4.55 t DM ha^{-1} yr^{-1} in the 12 yr old oil palm plantation. When only the area available for grazing and leaf production were considered, the theoretical potential production was 4.53 t DM ha^{-1} yr^{-1} (total DM) and 2.45 t DM ha^{-1} yr^{-1} (leaf DM) in the 9 yr old oil palm plantation and 2.95 t DM ha^{-1} yr^{-1} (total DM) and 1.59 t DM ha^{-1} yr^{-1} (leaf DM) in the 12 yr old oil palm plantation.

6.4 Discussion

6.4.1 Current status of system and implications for beef production

6.4.1.1 Annual herbage demand and production

The reported herbage accumulation in 9–12 yr old oil palm plantations in West Malaysia is generally 400–800 kg DM ha^{-1} yr^{-1}. In one 3–4 yr un-weeded oil palm plantation, a production of 3 t DM ha^{-1} yr^{-1} was reported, while in another case 5.5–9.5 t DM ha^{-1} yr^{-1} was reported but markedly lower values of 400–800 kg DM ha^{-1} yr^{-1} were reported for a plantation that was 6–7 years old (Chen, 1990; Chen et al., 1991, as cited in Hassan, 2001). In another study, production was reported to remain at 400–800 kg DM ha^{-1} yr^{-1} for the next 20 years from year 7 (Jalaludin and Halim, 1998). By contrast, (i) the estimated annual herbage accumulation of 6.5 t DM ha^{-1} yr^{-1} for 9OP1/9OP2, based on the cutting experiment, and 3.4 t DM ha^{-1} yr^{-1} for 12OP; (ii) the theoretical potential herbage production based on light availability (4.53 and 2.95 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 12OP, respectively); and (iii) the herbage accumulation estimate (as herbage eaten) from MEB of 2.0–2.4 t DM ha^{-1} yr^{-1} for 9OP1/9OP2 and 1.42–1.68 t DM ha^{-1} yr^{-1} for 12OP) indicated that herbage DM yield for beef production on 9 yr old and 12 yr old oil palm plantations (or OPIC farms) for oil palm plantations of similar age were all higher than these published values. Moreover, the higher herbage supply as herbage eaten estimated using MEB in this study is slightly higher or similar to the value of 1.5–2.0 t DM ha^{-1} yr^{-1} recorded by Hassan et al. (2004) from cutting experiment for a much younger (5 years old) oil palm plantation operating OPIC farming system.

Herbage supply as herbage harvested by cattle grazing in the oil palm plantation, as determined by MEB is only half of the theoretical potential herbage production based on assumed light penetration. Data from the cutting experiment are higher than those from MEB or theoretical potential production. The difference between the results from the MEB calculations and the cutting experiment could be due to a number of factors including: cattle only grazing the leaf, cattle refusing some patches of the herbage, or inconsistent grazing pressure. Leaf is preferred by cattle (Chacon and Stobbs, 1976) probably because it is more nutritious than stem and dead material (Lambert and Litherland, 2000), or possibly also because it tends to be mainly in the upper horizon of the sward, and is therefore grazed first. In fact, when only leaf DM is considered, the difference between the results of the MEB and, for example, the cutting experiment is smaller (1.3–1.7 t DM ha^{-1} yr^{-1} for 12OP and 0.6–0.9 t DM ha^{-1} yr^{-1} for 9OP1/9OP2). From another perspective, the MEB provides a reasonable estimate of operational herbage production in the system. Another factor contributing to the difference is herbage rejection; cattle are reported to reject forage near their faeces for more than a month (Dohi et al., 1991) and thus expected to graze less herbage during the next grazing event. This dung-avoidance behaviour was observed in this study (Appendix 6.4) despite the grazing rotation being as long as 60 d. Another possible factor influencing the relativity between cutting yield and other yield measures is the harvesting of herbage to ground level when cutting, while grazing leaves residual herbage. This interpretation of the data is also supported by comments made to the cattle farm manager (*pers. comm.*) by the oil palm management group, advising that 9OP1 and 9OP2 were not satisfactorily clear of undergrowth.

Comparing the data of herbage production reported by other authors (e.g., Chen, 1990; Chen et al., 1991, Jalaludin and Halim, 1998) with those reported in this study, it can be rationalised that herbage production between plantations of similar oil palm age can differ. Hence, in terms of OPIC farm management, there is a risk of farmers adopting a stocking rate inappropriate to their own site if the estimate of herbage production in this study (based on the MEB or cutting), for example, is used directly for farm system configuration planning on other OPIC farms in Sabah. The difference in herbage production between oil palm plantations is attributed to a range of factors including differences in micro-ecological conditions, whether cattle or herbicide are used to control the undergrowth, the fertiliser regime, and extent of disease or insect predation of herbage; but to date the interactions between these factors are not yet studied in detail, and are thus less understood. For example, the low herbage production in a mature oil palm plantation will always be primarily explained by the reduced amount of understorey light, linked to canopy closure with palm age, and soil nutrient content (Dahlan et al., 1993; Subtropen, 2003). However, the interaction between solar radiation, oil palm age, and soil nutrient level is complex; soil condition has been reported to delay oil palm frond expansion and thus the reduction of understorey light (Subtropen, 2003).

6.4.1.2 Seasonality of herbage demand and production

Based on the MEB results, herbage supply in the system is expected to be aseasonal, because the calculated intra-annual fluctuations of monthly herbage demand on the farms (see Figure 6.1) are much smaller (minimum monthly average growth rate 40%–70% of maximum) than those observed in temperate pastures like the ones studied in Chapter 3 (minimum typically <20% maximum) and also because those intra-annual demand fluctuations observed in Figure 6.1 are largely attributable to the movement of cattle between the farms belonging to the company (see Figure 6.2). Reasons for stock transfer between farms include weaning, transfer out to other farms or to feedlots for finishing, rather than as a result of management response to seasonal change in herbage growth, or on account of a wet or dry period. This interpretation of the data is also supported by the fact that the typical weather in Sabah is aseasonal (see Thomas et al., 1976a–d) and that the farms studied did not report a problem of herbage production associated with dry and wet periods. As noted earlier (Section 6.3.2.1), these are the factors that were considered as the reasons to annualise the monthly herbage production data obtained in August and September 2014.

The conclusion about seasonality or aseasonality of herbage harvested is relevant to interpretation of herbage accumulation data from cutting. If it can be assumed that herbage accumulation is aseasonal and that there are not major changes in standing herbage mass through the year, then the herbage accumulation data determined by cutting in the months of August and September can be used to infer the annual herbage production, and values so obtained were 6.10 t DM ha^{-1} yr^{-1} for

9OP1/9OP2 and 2.14 t DM ha^{-1} yr^{-1} for 12OP on the farms studied. The extent of seasonality of herbage production could of course be investigated by a cutting experiment of 12 months or 2 yr duration, but the required absence from New Zealand within the term of the PhD study was not feasible.

Elsewhere in tropical areas, seasonality of herbage production has been reported. At Gowa, South Sulawesi Indonesia, for example, herbage supply fluctuates with dry and wet seasons (Bulo et al., 1994). A similar trend is also reported on OPIC farms in the northeastern region of West Malaysia (e.g., Hassan et al., 2004).

6.4.1.3 Herbage demand during calving and weaning

Under the present farm system operation there was no seasonal spike of herbage demand on the farms during calving and weaning. Superficially, this indicates that calving and weaning were sufficiently spread that they did not create any spike of herbage demand, however a second possibility is that a spike in demand could have been masked by a fall in animal body weight. Further research would be needed to determine if this is the case. It would be expected, however, that if the calving rate were higher than the present rate (33%–40%), then the monthly herbage consumption would be increased by lactation and calf-weight-gain energy demand following any periods of concentrated calving. Assuming higher calving rates do occur in future system, then some aspect of the system will need to be modified. For example, stocking rate could be lowered accordingly to avoid feed deficit and poor growth of cattle.

6.4.1.4 Herbage ME and CP

The average herbage ME on 9OP1/9PO2 and 12OP (8.3–8.5 MJ ME kg DM^{-1}) meets only the minimum requirements for efficient animal production, but the CP (15%–16%) is more than sufficient. As stated earlier in Chapters 4 (Section 4.4.2.1) and 5 (Section 5.4.1.1), the minimum ME of herbage for animal production is reported to be 8 MJ kg DM^{-1} (Smeaton, 2003) and for CP is 6%–8% (Humphreys, 1991). Average herbage ME on 9OP1/9PO2 and 12OP are at the lower end of the range reported for oil palm plantations in Malaysia. The CP is at the upper range. Herbage ME in oil palm plantations in West Malaysia are reported to be 7–10 MJ kg DM^{-1} (Lane and Mustapha, 1983; Dahlan et al., 1993) and CP is reported to be 11%–16%, but sometimes the ME and CP can be as low as 4.6 MJ kg DM^{-1} and 8%, respectively (Dahlan et al., 1993; Wattanachant et al., 1998), that is, lower than values observed in the present study.

In addition to low carbohydrate levels of forage under low light conditions (Samarakoon et al., 1990; Dahlan et al., 1993), the change in functional species composition especially the absence of legumes could also affect forage ME per kg DM in oil palm plantations. Broadleaved plants are more nutritious than grasses (Dahlan et al., 1993). Hence, herbage in older oil palm plantations is expected to be of lower ME due to the depletion of broadleaved species and the low production of carbohydrate (by most species) associated with low light intensity at ground level (Dahlan et al., 1993). Light intensity factors, therefore, may explain the low herbage ME on the farms studied. Herbage on the farms contained lower numbers of broadleaved species (2–8 species, Table 6.6) compared with species numbers reported for other oil palm plantations in Malaysia (e.g., 29–60 species: Chen, 1990; Dahlan et al., 1993).

Nitrogen application, horizontal transfer of N by soil water movement and N uptake by herbage may explain the high herbage CP on the farms studied. In oil palm plantations, N fertiliser is applied on the bare soil in a circle of about 2 m radius around the palm base. However, displacement from that area is common especially during the rainy season (Bah et al., 2014), and this leads to the fertiliser being unintentionally applied to adjacent herbage. N application improves herbage CP (Minson, 1967; Chin, 1995) and total N of tropical grasses increases linearly with incremental supply of N (Johnson et al., 2001). Since N application in mature commercial oil palm plantations (>5 years old) in Malaysia is reported to be 110–185 kg ha^{-1} yr^{-1} (Kee et al., 1995), the low soil N reported for the farms studied (see Section 6.2.1.1) must arise from a combination of high N uptake rate by the oil palms and undergrowth, and rainfall-related leaching through the soil profile.

6.4.1.5 Feed conversion efficiency

The variation in FCE between the subsystems and the most efficient monthly FCE within subsystems (72.3 kg DM kg LWG^{-1} for 9OP1 in April, 28.8 kg DM kg LWG^{-1} for 9OP2 in June, and 27.5 kg DM kg LWG^{-1} for 12OP in May) appear to be largely a reflection of the numbers of rapidly growing young calves (calves have a higher percentage of total energy for gain compared with adult cattle) in a particular system at a time. On the farms studied, the bulls were farmed together with the cows throughout the year. Thus, calving occurred almost every month on 9OP1, although relatively, more calves were born in the March–May period (13–17 calves mo^{-1}), September (10 calves mo^{-1}) and October (17 calves mo^{-1}) compared to the monthly average (8 calves mo^{-1}). Thus, the high calving and weaning rates in March improved the FCE on the cow-calf farm (9OP1) in April, and the arrival of young calves on 9OP2 and 12OP in March improved FCE on these farms in May and June (the weight gain of calves or young cattle increases FCE). The higher calving rate in September and October, however, was not coincident with weaning (i.e., thus stocking rate is still high), and perhaps because of that, there was no FCE improvement in November. On the farms, weaning was carried out mainly in March (43 calves) and July (49 calves), with a small number in November (7 calves). The FCE of 9OP2 (weaner bulls) was higher than that of 9OP1 (breeding herd) because in 9OP1, more energy is partitioned to body maintenance especially by the breeding cows, rather than to growth.

Other factors, however, likely to have an effect on the FCE of the OPIC system, such as, N application and herbage nutritive value as well as rainfall. Studies carried out on cut-and-carry feedlot (Chapter 4) and grazing cattle (Chapter 5) farms indicated that N application following rainfall improved FCE (except when *S. sphacelata* 'Kazungula' pasture was being grazed), and this tactical approach to improving response to N fertiliser could also be relevant for OPIC farms. However, a difference between the former and the latter farms is the N is applied to the oil palms and not to the herbage, which means the effect of N application on the herbage in OPIC farms is indirect. The relationship between N application, rainfall and FCE, however, could not be specifically explored in this study, as the relevant data had not been recorded by the OPIC farms.

Based on the FCE data, the cow-calf system of the OPIC farming system (9OP1: FCE = 94.0 kg DM kg LWG^{-1}) is two times less efficient than that of the grazing cattle farming system in Sabah (Brahman Cow-Calf Unit: FCE = 45.3 kg DM kg LWG^{-1}; Brahman was the breed used on the OPIC farms; Table 5.3, Chapter 5). The marked difference in FCE between the cow-calf subsystems is not the result of differences in cattle breed, because in both subsystems, the cattle are of Brahman breed imported from Australia. One likely reason for the differences is in the cow-calf subsystem of the grazing system, the cattle were also fed with concentrate (PKC) of higher ME content (>9.5 MJ ME kg DM^{-1}) than the herbage and thus, had a better growth. Ibrahim et al. (1987) reported for cattle in Sabah that the growth was only 390 g hd^{-1} d^{-1} when feeding solely on herbage, but this improved to 580 g hd^{-1} d^{-1} when supplemented with PKC. As noted in Section 6.2.1.1, the average daily gain of cattle in the OPIC system was reported to be 368 g hd^{-1} d^{-1} from birth to weaning (average 10 mo) and 242 g hd^{-1} d^{-1} from weaning to 24 months, which is in line with the growth reported by Ibrahim et al. (1987) for cattle that feed solely on herbage. As a comparison, the average daily gain for the cattle in the cow-calf subsystem of the grazing system (Appendix 5.2) was 691 g hd^{-1} d^{-1} from birth to weaning (average 8 mo) and 216 g hd^{-1} d^{-1} from weaning to 20 months. Other possible reasons for the differences in FCE between the subsystems are as stated earlier, factors such as N application and herbage nutritive value, as well as rainfall.

The interpretation of the FCE results for the OPIC cow-calf and grazing cow-calf subsystems would also require consideration of other factors, especially operational costs. Regardless, of the FCE attained, the OPIC cow-calf subsystem studied (and generally, OPIC cattle farming system) requires no expenditure to build and maintain fences and to purchase fertiliser and feed supplement. The fertiliser use in the subsystem occurs in the course of normal oil palm production. The beef production is obtained from herbage that would otherwise be a nuisance or would need to be controlled by herbicide at extra cost but with no return to the oil palm company. A systematic comparison here of cost-return and FCE between these subsystems in Sabah is infeasible, as the present study is not designed for that purpose and no analysis of this type has been carried out in the past. The economic benefit of OPIC farming system is reported in an analysis for OPIC farms in Johor, Malaysia where the study indicated that cattle integration reduced the total cost of oil palm production by 9% (Gabdo and Ismail, 2013). Specifically, the study estimated that cattle integration reduced the cost of weeding from RM568 ha^{-1} yr^{-1} to RM33 ha^{-1} yr^{-1}, that is, a saving or a return of RM535 ha^{-1} yr^{-1} to the plantation owners. In contrast, for the Brahman cow-calf grazing system studied in Chapter 5, weeding cost (herbicide purchase) was RM61 ha^{-1} yr^{-1} (or RM21,048 yr^{-1}), fertiliser cost was RM19 ha^{-1} yr^{-1}, and supplement cost was 46 ha^{-1} yr^{-1}, that is, overall RM126 ha^{-1} yr^{-1}. If a very crude comparison is made considering just the FCE and weeding as well as fertiliser and supplement costs, the grazing system appears to be still RM0.42 more profitable per kg beef produced compared to the OPIC system. The FCE for the grazing and OPIC cow-calf subsystems (as stated earlier) was, respectively, 45.3 and 94.0 kg DM kg LWG^{-1}; the feed harvested for the grazing subsystem was 5.78 t DM ha^{-1} yr^{-1} and that for the OPIC subsystem was 2.2 t DM ha^{-1} yr^{-1}, which means 127.6 kg beef ha^{-1} yr^{-1} was produced in the grazing subsystem and 23.4 kg beef ha^{-1} yr^{-1} in the OPIC subsystem; while the associated production cost of the same subsystems was, respectively, RM0.99 and RM1.41 per kg beef produced. Considering this comparison of beef production cost, the benefit of OPIC cow-calf subsystem appears to be in reducing the oil palm production cost rather than the beef production cost. This finding indicates that there would be merit in further study of the economics of the OPIC and grazing cow-calf subsystems from the perspective of cost of increasing the beef production in Sabah.

6.4.2 Implications for future system design

In the oil palm industry, the palms are the main crop, and the OPIC farming system provides understorey vegetation control in the plantations, which otherwise has to be achieved through hand weeding and/or the use of herbicides at a cost, while producing beef as a by-product (Chen, 1990; Devendra and Thomas, 2002; Azizol and Norlizan, 2004). The management of the plantations will always have a focus on improvement of fruit and oil yield. For this reason, the use of supplement as feed for the cattle in the OPIC system is seen as an additional cost and is typically not favoured by plantation managers in Sabah. This interpretation of managers' attitude to supplement use is supported by the fact that none of the three farms studied used supplement to establish successful OPIC farms. It has to be noted, however, that the OPIC cow-calf subsystem is also used to supply calves to cut-and-carry feedlot cattle farming system (can be owned by the same oil palm company), and in the latter, supplement will be used to improve the growth of the cattle and the profit of the enterprise. If it could be shown that tactical use of supplement in OPIC system could increase the income from the cattle grazing operation by more than the cost of the supplement, presumably attitudes could be changed, but at this stage the necessary evidence to advocate the use of supplement to improve the beef production of OPIC farming system in Sabah is lacking.

The above analysis of OPIC farming systems in Sabah shows that the objectives of beef production and undergrowth control are not conflicting, but rather complementary, with the successful introduction of an OPIC eliminating a portion of the production cost and delivering a secondary income source. In terms of vegetation control, the data indicate that herbage consumption in 9 yr old oil palm plantations could be intensified, as herbage production in these plantations is still higher than 2 t DM ha^{-1} yr^{-1} and in addition the oil palm manager commented that the ground vegetation in the plantations is not sufficiently controlled. In terms of beef production, the intensification of herbage consumption in those plantations by cattle would indirectly improve beef production of the system. Another consideration is taking advantage of the seasonal uniformity of herbage supply by organising the calving and weaning events any time of the year to avoid a spike of feed demand. This flexibility, however, would no longer be applicable once the cow performance is improved.

The intensification of herbage consumption and adjustment of calving and weaning events in the system have to be organised adaptively, as it is almost certain that the FCE gains arising from optimal stocking rate (i.e., from an optimal match of animal body weight to herbage availability) also apply in OPIC farming system. It is clear that because of canopy closure and light reduction as palms mature (Dahlan et al. 1993), over the life of a plantation, stocking rate needs to be progressively reduced, but it also appears that local factors (such as, N application, soil conditions, and rainfall) affect the precise time course of reduction in light and herbage accumulation. Moreover, because temporary fencing is used, paddock sizes are determined ‘roughly’ by daily estimation of the area required and so stocking rate optimisation will need to be adjusted accordingly, something that is more difficult than in permanently fenced grazing systems. For the same reasons, an analysis of past system configurations to identify an optimal stocking rate for future use will not be realistic for OPIC farming system. Therefore, the optimal stocking rate for palms of a particular age would need to be determined on a case-by-case basis, taking account of those local factors. Perhaps, a CSR-type statistic of animal liveweight per unit of production will be useful for farmers and extension officers in Sabah to explore how to lift the performance of OPIC farming system (as was demonstrated for the cut-and-carry feedlot and grazing cattle farming systems in Chapter 4 and 5, respectively). A CSR calculated for the OPIC cow-calf system (9OP1), for example, is 89 kg LWT t DM^{-1} (if the feed offered is taken as the average feed harvested in the system, which is 2.2 t DM ha^{-1} yr^{-1}, plus a 15% allowance for non-utilisation), or a stocking rate of approximately 231 kg animal LWT ha^{-1}. The CSR for near-optimal stocking for the grazing system was found to be 94 kg LWT t DM^{-1} (Chapter 5), and it was estimated to be 96 kg LWT t DM^{-1} for the feedlot system (Chapter 4). Comparing these three CSRs, it appears that the CSR of the OPIC cow-calf subsystem is lower, indicating that the subsystem might be understocked. In grazing management, one of the common problems with understocking is that low grazing pressure leads to poor herbage quality. Again, as noted in Chapter 4 and 5, further evaluation is needed to establish the optimal value of this CSR index for a OPIC farming system in Sabah.

6.4.3 Further studies

During the course of this study, some important topics for future study to further improve understanding and management of OPIC farming system were identified. These include, among others, investigation of:

(i) A body condition scoring technique to reduce the time cost of assessing liveweight and growth of the cattle;

(ii) Feed profiles of the OPIC farming system in Sabah with oil palms younger than 9 years old, for example 3 yr and 6 yr old oil palms (if there are farms with suitable data available for study), and add the results to those obtained in the present study to obtain a more comprehensive herbage productivity trajectory with palm age for the Sabah environment;

(iii) A CSR-type statistic to define optimal stocking rate for each point in the herbage production-decline trajectory;

(iv) A 12-month measurement cycle for herbage accumulation from cutting data and the comparison of the results with the modelled feed demand to identify any feed surplus and deficit periods that might have been undetected in this study;

(v) The response of herbage production and nutritive value to N application in oil palm plantation, considering that the grazing rotation can be scheduled to take advantage of the effect of run-off N fertiliser on herbage growth;

(vi) The relationship between FCE and fertiliser application as well as rainfall in the system and the approach to improve the FCE;

(vii) The effect of animal manure on herbage non-utilization; and

(viii) A way to improve the reproductive performance of the cow to lift calving percentage. Although genetic factors contribute to poor calving percentage, it is also not known whether the low calving rate in the system is due to a loss of the calf during pregnancy or a long calving-to-mating interval. To date, the approach used to increase calving rate is a practice of all year round mating. Artificial insemination may be difficult in this system considering that the cattle are farmed semi-wild.

The sequence for the proposed work is as numbered above. Development of a body condition scoring technique to reduce the time cost of assessing liveweight and growth of the cattle is important to be the first study because a routine weighing of cattle liveweight is difficult to carry out for the system since the cattle are farmed semi-wild and this technique is a key for successful implementation of items (ii) to (vii). Item (viii) is important as a long-term project and can be initiated together with items (i) to (vii).

6.5 Conclusions

Based on the data analyses in this chapter, the following conclusion can be made:

- A 9 yr old oil palm plantation can still supply 2.0–2.4 t DM ha^{-1} yr^{-1} of herbage and a 12 yr old oil palm plantation, 1.4–1.7 t DM ha^{-1} yr^{-1}, for beef production. These values are higher than those previously reported in Malaysia for oil palm plantations.
- The production of herbage in the system is aseasonal, although it is expected to decrease gradually with the age of the oil palms.
- The animal production of the system was also constrained by marginal ME value of herbage (8.3–8.5 MJ ME kg DM^{-1}), despite the value being higher than values previously reported in OPIC system. The CP value (15%–16%) of the herbage, however, was considered sufficient to support higher levels of animal production.
- In current practice, calving in the system is distributed throughout the year, and there was no seasonal spike of feed demand linked to calving and lactation observed in the data. Even so, the data indicated that FCE was low for a month where more new calves were born but fewer calves from previous year birth were weaned; thus, a study is required to identify the best way to coordinate both calving and weaning events so that stocking rate relative to herbage growth is optimal and percentage of feed translated to weight gain is high.
- It is important to configure the system for optimal FCE to improve beef production, and to use a CSR-type statistic as a tool to define the optimal stocking rate for each point in the herbage-production-decline trajectory. However, for that to be possible, the time trajectory of the OPIC understorey herbage production needs to be fully understood first.

Chapter 7

General Discussion

7.1 Introduction

The main goal of this study was to explore the patterns of feed demand and supply and performance of current beef cattle farming systems in Sabah using a MEB methodology developed in New Zealand and to recommend from the results the future focus of the systems to support the evolution and expansion of the beef industry. Sabah has permanent grassland (21,698 ha) and oil palm plantation (1.511 million ha of which 1.36 million ha are mature plantations where cattle can be integrated) that could be used for beef cattle farming. There are also government schemes available to assist, especially, rural farmers to start beef cattle farming (Awang Salleh, 1991; DVSAI, 2008, 2009). However, it has been reported that between 1974 and 2012, the sufficiency of beef production in Sabah had decreased from 95% (Awang Salleh, 1991) to only 4% (calculated from the beef production and consumption statistics reported by DVSAI, 2014). With the widening gap between demand and local supply, beef has needed to be imported. In 2012, RM125 million was spent to import beef from India, Australia and New Zealand compared to only RM35 million was spent in 2003 (DVSAI, 2014). Based on the local retail price of beef in 2012 (RM24 kg^{-1}) and the quantity of beef imported (9,835 t) in the same year, increasing the local beef production to meet the local beef demand could inject RM236 million into the domestic economy with a corresponding saving in import costs. This earning power would have a great impact on financial status of farmers, especially those participating in the government poverty mitigation projects.

Beef cattle farming is important for food production and socio-economic development in Sabah. However, over the past decades little information has been available on beef cattle farming activities, especially feed profiles of the farming systems for extension personnel to use to assist local farmers to improve the beef production of their farms. This problem is exacerbated also by a lack of analytical tools to capture the system details. Therefore, in this study, after a methodology development phase in New Zealand (Chapter 3), the feed demand and supply patterns and performance of three different beef production systems in Sabah were analysed: cut-and-carry feedlot cattle farming system (Chapter 4), grazing cattle farming system (Chapter 5), and oil palm integrated cattle (OPIC) farming system (Chapter 6) – to capture the system characteristics and to identify potential future development of the systems that could facilitate the improvement of beef production in Sabah.

7.2 Insight from the methodology development

7.2.1 Insight from New Zealand North Island hill country farms (Class IV)

Over the 1980–2010 period, the data indicated that as a result of changes in farm system configuration moving towards high feed conversion efficiency and associated gains in performance, especially improvement of reproductive performance, change in animal stock classes on farm to facilitate lifting of sale weight of animals sold for meat, or addition of weight to purchased stock for resale, New Zealand farmers managed to improve FCE of their farms by 20%–30%. New Zealand farmers have also further improved their terms of trade over the study period by increases in farm size (Table 3.1), in addition to increased productivity per ha (Table 3.5). Interestingly, the FCE (kg DM kg (sheep+cattle carcasse)$^{-1}$) has increased (Table 3.4), against the trend of reducing pasture production.

The decrease in modelled herbage production and in herbage harvested on New Zealand farms detected in this study was an unexpected finding that will be of interest and concern to farmers in the study region. Since the early 1980s feed harvested on New Zealand (Class IV) sheep and beef cattle farms has decreased by 13%. This finding is in parallel with the decline in herbage production (12%) as indicated by the GROW model using relevant weather data during 1980–2010. The decrease in pasture production appears to be associated with a trend towards warmer and drier summers in recent years, and this conclusion is supported by a similar long-term downward trend in the pasture growth index calculated by NIWA from aggregated weather data and reported by NZX (NZXAGRI, 2012) (Appendix 3.6). There could also be other factors contributing to the trend of declining pasture production, such as, increased pasture utilisation (estimated to be 83%–95% on the case farms in this study), which over time without pasture renewal can weaken the regrowth potential of the pasture.

The identification of the trend of declining pasture production in the New Zealand systems also provides an alternative perspective to some other discussions currently taking place in the industry. For example, complaint about perceived reduced persistence of new forage grass cultivars is not uncommon at farmer meetings. It may be that the perceived poor performance of new pasture sowings mentioned by some farmers is not because of genetic factors but because of climate change. The new cultivars may actually have contributed markedly in maintaining the herbage supply in the system during the challenging climatic conditions, but without the awareness of the climate change issue, the new cultivar is presumed to be the problem.

Linking the scenario in New Zealand to that in Sabah, farmers in Sabah could also use the approaches taken by farmers in New Zealand, considering that "improvement of reproductive performance, change in animal stock classes on farm to facilitate lifting of sale weight of animals sold for meat, or addition of weight to purchased stock for resale" are not climatic-related factors but managerial skill factors. Since those factors have helped farmers in New Zealand despite declining pasture production, they could be even more effective when applied in Sabah where rainfall is higher (provided that fertiliser application is sufficient and leaching is comparatively low). It is expected, however, that the low nutritive quality of the tropical pasture would still be one of the constraints faced by farmers in Sabah, even if they could emulate the approaches applied by farmers in New Zealand. Relevant to this discussion is also a caution for farmers in Sabah that the success story of the above factors in New Zealand is attributed to farming sheep in the systems (together with cattle) where twin lambs are a common occurrence. This means an increased supply of animals for replacement and sale. In the same systems, the calving percentage over the past 30 years was in fact only 80%–86%. This calving percentage is much higher than that in Sabah, but the time required for the work to lift reproductive performance to that level appears to be longer.

It is also relevant to mention here that there is a suggestion from some quarters in Sabah to discontinue subsidies to farmers to push them to lift agricultural production including beef production. This issue is not directly investigated in this study, but there should be a discussion over that suggestion before it could be applied in Sabah. It is noted that pastoral production in New Zealand survived well on removal of subsidies in the 1980s (Section 3.4.1). However, one point observed during the literature review of this study is that there is a lack of understanding from some authorities in Sabah that many farmers in New Zealand were already advanced in farming skills (e.g., the three case farms studied in Chapter 3) when the farming subsidies were discontinued and thus a majority of them were able to continue the farming without the subsidies, though adjustment did occur.

7.2.2 Insight from MEB application in Sabah

The MEB methodology is useful not only as a farm management tool as it is recommended in New Zealand but also as an extension tool to transfer a farming technology to other pastoral systems. It is indirectly a farming education tool. The strength of the technique is demonstrated through all the chapters in this study. The tool allows the energy flow from the feed to be linked to the energy demand of the animals. In this way any farming system manipulation that affects the feed in terms of growth, availability or nutritive value can then be interpreted from the animal perspective (provided that the liveweights of animals are measured or assessed in some way such as body condition scoring) to evaluate the effectiveness and weaknesses of the farming system configurations used. In the same way, the technique is also expected to allow the evaluation of conceptual suggestion about feed planning to improve the farming system. It is also cost effective, although at times it uses considerable professional time to carry out the calculation.

As was the case in this study, where the author gained excellent insight about the systems studied, MEB can be an extension tool for farmers in Sabah. For that purpose, an instruction manual on how to capture and understand a farming system using MEB has to be prepared for the farmers or agricultural extension officers, detailing the essential data to be collected and analysed for a better interpretation of the results. The production of the manual should also be part of the task of the institutions that teach the tools. The manual has to be provided to the students who take animal production courses to enhance their learning experience. Secondly, establishment of specific farms to demonstrate the practical application of MEB in Sabah are required for farmers to learn (hands-on) about objective-oriented feed planning.

Parker (2010) provided three ways to use feed profile analysis (and MEB) that can also be used by farmers in Sabah:

(i) To assess feed sufficiency when the production cycle unfolds (present time application);

(ii) To assess the comparative advantage of different livestock policies (forecasting); and

(iii) To aid in the investigation of tactical options to improve the performance of the system (e.g., forecasting the effect of fertiliser application on herbage growth, animal growth and farm profitability).

Another use of the tools in New Zealand, which was also an outcome in the present study, is for farm consultants and extension officers to understand the farming activities of the farmers and to use the understanding to communicate with the farmers about the way to improve farm performance. A new way to use the tools, elucidated in the present study is to identify efficient historical farm system configurations (especially optimum stocking rate) for future replication and refinement. This new way of using MEB echoes the statement from the farmers studied in New Zealand (see Chapter 3) about the importance of identifying the successful approach for farming their own land. They had identified the effective tactics for farming their land many years before and only maintained that approach, with slight modification to suit the conditions of a particular year, to keep the farms productive.

The MEB revealed viable options to improve the productivity of the systems in Sabah, by providing information for identification of existing local efficient farming systems for further refinement, avoiding the risks associated with attempting to directly transplant established pastoral systems of New Zealand to Sabah and of applying a trial-and-error approach when determining farming system configuration. It has to be noted, however, that the present study was successful because of the quality animal data supplied by the case farms, in particular the government farms, and because of other information also included in the analysis (herbage dry matter yield, feed nutritive value, fertiliser application, rainfall, and soil data on levels of major plant nutrients) to enhance the interpretation of the results from the budgeting. If this study is to be repeated in other tropical areas, those factors have to be considered to attain a meaningful interpretation of the results.

7.3 Recommendations for future focus of the beef cattle production systems in Sabah

7.3.1 Cut-and-carry feedlot and grazing cattle farming systems

7.3.1.1 Configuration of current systems for optimal FCE as a first step

Based on the data of feed demand and supply patterns and performance of the cut-and-carry feedlot (Chapter 4) and grazing systems (Chapter 5), the future focus in order to improve the productivity of these systems is to produce efficient farm system configurations that suit the conditions of the current systems. At present there are low numbers of calves born, and the herbage is of low nutritive value, with low herbage production as a result of soil acidity, low soil nutrient content, and because of the invasion of non-sown species (native grass). Recent modelling work carried out in Malaysia (Abdulla et al., 2016) also indicated that it is important for the local farmers to be sufficiently trained in feed efficiency management to meet the beef self-sufficiency level set by the country.

It is suggested for the systems in Sabah that the first step towards configuring the current systems for optimal FCE is by using the configuration of efficient systems in the past identified in Chapter 4 and Chapter 5 as the template to refine future farming systems. At current pasture production levels in Sabah, optimal FCE is achieved at a stocking rate of approximately 994 kg animal LWT ha^{-1} (or approximately a CSR = 96 kg LWT t DM^{-1}) for the cut-and-carry feedlot system and 506 kg animal LWT ha^{-1} (or a CSR = 94 kg LWT t DM^{-1}) for the grazing system.

The reasons for the recommendation to configure the current systems for optimal FCE as a first step are:

(a) Some lessons from New Zealand systems

Theoretically, Cooper (1970) estimated that based on 3% conversion efficiency of light in Singapore, potential herbage production in the tropics is 49 t DM ha^{-1} yr^{-1}; while recorded experimental plot yields with high fertiliser have reached 48.8 t DM ha^{-1} yr^{-1} for *P. maximum* and 84.7 t DM ha^{-1} yr^{-1} for *Pennisetum purpureum* Schumach. For Sabah, however, considering the economic reality of farming, the needs of society, and the possibility of environmental damage through over intensification of agriculture, for practical purposes, an efficient system is more realistic, rather than a system that aims to achieve and utilise the theoretical herbage production. Focusing on efficient systems has been demonstrated to be more viable, based on operation of the New Zealand systems in the past 30 years.

As noted in Chapter 3, the pastoral systems in New Zealand have become highly evolved, as farmers continually apply new technology and new ideas to maintain and improve farm productivity to meet not only changing customer demands, but also the needs of society. In this operating context, the primary aim has become that farming remain economic. As such the systems have evolved to focus on system efficiency rather than on producing and utilising the theoretical maximum production of herbage in New Zealand. Cooper (1970) estimated that the theoretical maximum herbage production for Wellington, New Zealand would be 37 t DM ha^{-1} yr^{-1} and cited a highest recorded yield in New Zealand of 26.6 t DM ha^{-1} yr^{-1} at Te Awa, near Feilding. In contrast to this, the data in Chapter 3 indicated that herbage harvested on New Zealand sheep and beef cattle farms (national average) is much less than the theoretical herbage production and declining. Herbage harvested on the farms studied as determined by MEB was 7.43 t DM ha^{-1} yr^{-1} in 1980–81 and only 5.76 t DM ha^{-1} yr^{-1} in 2010–11. Also herbage supply (based on GROW model calculations using weather data) had decreased from 9.64 t DM ha^{-1} yr^{-1} to 8.70 t DM ha^{-1} yr^{-1} (partly due to an apparent climate change effect) and the total animal stock units per ha had been reduced by 20% (Table 3.1). Even so, with the advances in animal genetics the evolution of farm system configurations over the past quarter century focusing on efficiency gain, New Zealand farmers (national average) are now using 21%–28% less feed to produce one kg of product compared with the situation 30 years ago.

(b) Low cow reproductive performance

In situations of low animal reproduction, farmers have limited option to modify the age class and composition of animals to improve farm productivity (Brookes et al., 1998). The present beef cattle industry in Sabah is small with a calving rate of lower than 50% (DVSAI, 2008; see also Chapter 5). Thus, if increasing the herbage production were the first step, there will be insufficient animals to graze the herbage.

It is expected that improving the calving percentage in the systems, for example to 70% or 80%, would markedly increase the beef production in Sabah. However, to set this as the first step to improve the system is difficult to attain immediately. Even in New Zealand (as stated earlier), over the past 30 years (1980 to 2010), the calving percentage was only 80%–86% and in fact, 6% lower in recent years than historically (Table 3.1). Many of the beef cattle in New Zealand come from the dairy industry. Thus, for the case in Sabah, improving the cow reproductive performance is viewed as a long-term and continuous target rather than an immediate step.

(c) FCE versus increasing herbage production and consumption

High herbage production and consumption per ha (Table 5.2) did not lead to high FCE (Table 5.3). Hence, increasing herbage production and consumption does not necessarily lead to high animal production. On the other hand, high feed consumption could lead to over grazing. In the grazing system, for example, the Brahman Bull Unit in 2013 (Table 5.2) showed high herbage consumption but poor animal growth (Table 5.1).

(d) Advantage of unseasonal herbage supply

The data did not indicate seasonality of herbage supply, and with twice-a-year calving the system feed demand profile is still comparatively 'flat'. Hence, attention to increasing herbage production in a particular season is a minor priority. At some areas in Sabah, however, marked dry periods event occur (see Figure 2.11). In those areas, tactical use of supplement (see Section 7.3.1.3 below) and reserved rainwater would be applicable. During ENSO events there might also be a concern over effect of weather (dry and wet periods) on herbage productivity in Sabah, but to date there is no data on this topic and thus further study is required to gain an insight on the extent to which ENSO affects herbage productivity on beef cattle farms in Sabah.

(b) Directing a greater proportion of system energy intake to animal growth

System performance can be improved from adjustment by feed planning, such that energy intake is used more for the growth of the animals rather than for maintenance, and not necessarily from improvement of herbage production. The data from the grazing system (Chapter 5) indicated that a system of high FCE does not necessarily occur at maximum herbage production. For example, the average FCE of the Heifer Unit over the 6 yr period studied was 40.6 kg DM kg LWG^{-1}, which was the highest among the grazing units studied. Even so, the heifers were found to have used more than 80% of the feed energy for body maintenance, which means only 20% was used for other metabolic activities including growth. At that low allocation of energy for growth, to achieve the aim of having the heifers mate and calve before reaching 3 years of age is unlikely to be achieved.

7.3.1.2 Development of a pasture husbandry package as a second step

The second step after FCE optimisation of the current systems is to evolve pasture management over time to achieve a herbage nutritive value of at least 9–10 MJ ME kg DM^{-1} energy content and 13%–16% CP content. This can be done by development of a pasture husbandry package to define fertiliser application regime, and grazing cycle for increasing pasture productivity towards the potential herbage dry matter yield (14–20 t DM ha^{-1} yr^{-1}), ME (9–10 MJ ME kg DM^{-1}), and CP (14%–16%) at harvesting (for the cut-and-carry feedlot system) and grazing (for the grazing system). Important factors to be considered are types, rates and timing of fertiliser application, and intensity (amount and frequency) and timing of cutting or grazing rotation, and herbage nutritive value (Chin, 1995). Components of the pasture husbandry package will be (i) to define the fertiliser application schedule to avoid herbage toxicity to the cattle, especially when *S. sphacelata* ‘Kazungula’ is used; (ii) to assign paddock(s) to the grazing units in such a way as to avoid paddocks of different species with different growth rate and grazing interval requirements being in the same unit; and (iii) to monitor forage nutritive value but at the same time to minimise the cost of unnecessary chemical analyses, and thus development of assessments that can be made on farm such as visual pasture quality and animal body condition scores would be essential in the package.

The rationale for these recommendations is as follows:

(a) Annual herbage supply

The operational herbage productivity in the three systems studied (i.e. herbage harvested) is presently lower than the potential herbage production, as discussed above. Hence, if increasing the herbage production is to be the first step, there will be significant costs incurred (e.g., pasture renovation, and high fertiliser input). By comparison with optimal FCE as a first step, a much smaller cost increment will be expected to occur because the systems would be operated as they are at present, except that the stocking rate would be adjusted to levels previously found to be optimal, for example, 994 kg animal LWT ha^{-1} (or approximately a CSR = 96 kg LWT t DM^{-1}) for the cut-and-carry feedlot system and 506 kg animal LWT ha^{-1} (or a CSR = 94 kg LWT t DM^{-1}) for the grazing system.

(b) Herbage nutritive value

As stated earlier, if optimal FCE is the first step, attained by adjusting stocking rate, the system can be operated as at present, and thus there is less need to make the investment and changes needed to improve herbage nutritive value. Nutritive value of herbage in all systems studied (7.7–8.5 MJ ME kg DM^{-1} and 9%–14% CP) was similar to, or lower than the minimum feed ME (8 MJ ME kg DM^{-1}) and CP (8%) requirements for efficient animal production suggested by other authors (i.e., Smeaton, 2003; Humphreys, 1991). Although there is a trend for herbage ME (8.3–9.4 MJ ME kg DM^{-1}) and CP (10%–13%) to be slightly higher after fertiliser application by the case farm during the herbage cutting experiment, a method to improve herbage nutritive value with consistent results is so far elusive in Sabah.

7.3.1.3 Revision of the use of feed supplement as a third step

As part of the first and second steps stated just above, revision of feed supplement use in the systems is necessary either to eliminate the supplement, or to use it tactically to achieve the intended animal production target. If feed supplements are to be used, batches of the feed should be tested before purchase for quality assurance purposes.

(a) Elimination option

Cost is the first reason to review and consider eliminating the use of feed supplements. The manager of the cut-and-carry feedlot and grazing farms studied stated that the current cost of PKC (RM700–800 or sometime RM500–600 per tonne), the main component of the feed, is considered high by local standards. International buyers also purchase a majority of the PKC production. The production was 663,621 tonnes in 2008, 629,911 tonnes in 2012, and 665,985 tonnes in 2015 (MPOB, 2009, 2013, 2016). That production was almost all exported (>90%), based on a comparison of the production and export of PKC by Sabah in 2008 and 2012 (MPOB, 2009, 2012; DOA, 2009, 2012a). Avoidance of higher feed costs would be one consideration in future systems.

The second point for review with respect to present feed supplement use is whether diet quality enhancement can be achieved without it. Currently, the quantity of supplement used in the systems is not substantial: 0.85–1.80 t DM ha^{-1} yr^{-1} as herbage equivalent in the cut-and-carry feedlot system (Section 4.3.2.1), and less in the grazing system (Section 5.3.1.1). If herbage production and nutritive value can be improved (perhaps in part through change in fertiliser application policy; Chin, 1995), the need for regular supplementation would be reduced or perhaps eliminated. A third reason to review supplement use is the inconsistent nutritive value of the presently used feed supplements. The ME (9.5–11.5 MJ ME kg DM^{-1}) and CP (13%–16%) contents of the feed supplement and PKC tested in this study were variable. This could wrongly lead farm managers to rely on feed supplement to improve the growth of the cattle when in fact with some batches of supplement, expected benefits were not achieved because the feed had poor nutritive value.

(b) Tactical use option

Feed supplement, however, could contribute markedly to the growth of cattle in Sabah (see Ibrahim et al., 1987) especially for confined cattle where *ad libitum* feeding of herbage is difficult to maintain, especially during rainy periods partly because of the rejection of damp herbage by the cattle. Hence, where animal performance gains could be achieved the value of which exceeded the supplement cost, feed supplement could be used tactically to avoid marked cattle liveweight loss (eliminate or reduce occurrence of ME_{LWL}), to support compensatory growth (in the feedlot system), to improve body conditions of cows during lactation and mating to increase conception rate (in the grazing system), and to shift system energy allocation by feed planning such that energy intake is used more for the growth of animal. In New Zealand the role of supplements is to meet the feed requirement of the animals when it exceeds the herbage yield or when a much higher animal production is targeted (De Ruiter et al., 2007). However, if feed supplements are to be used in Sabah, every batch of the feed has to be tested before purchase for nutritive value assurance, in which case another concern is the cost to carry out the test.

7.3.2 Oil palm integrated cattle farming system

Proposing the optimisation pathway for this system is difficult until the feed profile is fully understood as herbage production and nutritive value in this system decrease with oil palm age. In addition, as stated in the last paragraph of Section 2.1.4.2, introduction of improved grass variety or legume in OPIC pastures >5 years old has little potential to lift the feed production, because of poor dry matter production of pasture under low light condition. Forage planting in oil palm plantations also introduces (i) competition with the oil palms for nutrients and (ii) an additional workload for the plantation staff to manage the pasture. In some plantations in Indonesia, it has been reported that there are trials to sacrifice several rows of oil palms per ha to create pastureland for the cattle to meet their potential feed requirements, but the manager of the farms included in this study is less convinced about using this approach.

In this situation of declining herbage productivity with time, a decision to re-implement a previously efficient farm system configuration would not lead to a higher animal production. Intuitively, a dynamic system optimisation approach could be suitable for this system, where the optimisation of beef production is planned for the whole plantation by taking account of current oil palm age and the replanting program on the plantation, and the grazing management is coordinated between the different sections of the plantation with strong emphasis on matching the management with the herbage–oil palm age relationship. The author, however, is not aware if there is research on beef production in oil palm plantations that takes into account the feed profiles of the system from year 3 to year 15. Considering that the needed information remains still scarce, identification of the optimization pathway for the OPIC farming system in Sabah is suggested as a topic for future research with the initial target to carry out a feed profile analysis in 3 yr and 6 yr old oil palm plantations and where the results are combined with the results from in this study to elucidate the trajectory for pasture and animal production of this system for the period from 3 to 15 years after planting.

In brief, the analyses reported in Chapter 6 indicated that herbage production on the OPIC farms studied was higher than commonly reported, and there is a need to carry out component research on (i) a CSR-type statistic to define optimal stocking rate for OPIC farming system (as this was found to be applicable for the system); (ii) the effect of manure on herbage non-utilization; (iii) the herbage production and nutritive value responses to oil palm fertiliser application, considering that the grazing rotation can be scheduled to take advantage of the fertiliser effect on herbage growth; (iv) the monthly herbage production by cutting experiment and the comparison of the results with that of the modelled feed demand to identify any feed surplus and deficit periods that might have been undetected in this study; (v) the relationship between FCE and fertiliser application, as well as rainfall effects on the fertiliser response; and (vi) the establishment of a body condition scoring technique for this system to ease the assessment of liveweight and growth of the cattle for farmers who do not have scales.

7.3.3 Additional considerations to improve the productivity of the systems in Sabah

7.3.3.1 Addressing fundamental cattle management issues

The data indicated that other minor considerations to improve the productivity of the systems in Sabah include:

(i) Setting up the stocking rate and grazing rotation based on local information on herbage production and nutritive value is necessary especially for the OPIC farming system. When comparing the data in Chapter 6 with other data in literature, it is evident that herbage productivity and nutritive value differ between different plantations of similar oil palm age in Malaysia. Hence, the use of herbage information from other plantations could lead the cattle manager to formulate an inappropriate grazing rotation;

(ii) Maintaining the integrity of the planned system throughout the year (beyond controlling the stocking rate by means of animal number and liveweight) is also important. For example, factors such as poor fence maintenance and re-allocation of land area or animals (in the grazing system) during the production cycle could still decrease FCE of the system by causing either lax- or over-grazing (see Chapter 5);

(iii) Reducing the feed waste and herbage rejection by cattle during rainy period (in the cut-and-carry feedlot system) would achieve production gains. Wet herbage is one of the factors contributing to feed waste reported in the cut-and-carry feedlot system, and an effective procedure to address this problem needs to be established; and

(iv) A notable further issue for attention is to mitigate the reduction of liveweight that currently occurs after weaning.

7.3.3.2 Setting long-term goals of productive animal

Long-term goals for the animal management in beef cattle farming systems in Sabah have not yet been set, and farmers have little clue about them. There is no comparable study available to date. Hence, without losing sight of the need for good feed planning to assist the cattle to achieve their growth potential, and although there is no direct evaluation in this study, it would be reasonable to suggest theoretically some relevant goals for beef cattle performance in Sabah based on the experience from other pastoral systems. Fundamentally, good animal reproduction traits and genetics will play a critical role in the expansion and sustainability of beef production. Based on Morris and Smeaton (2009), some theoretical long-term goals of productive beef cattle (that would be applicable in Sabah especially in future experiments) can be listed as:

(i) The cows attain 90–95 calves weaned per 100 cows mated each year, or indirectly attain >95% calving percentage and survival of calves to weaning (this is also in line with the Third Sabah Agricultural Policy 2015–2024, yet to be published, under a heading "to increase population growth of ruminant");

(ii) The cows in the system calve at 24 months of age, calve every year for 12 or more years, and produce milk sufficient for the female and male calves to grow to weaning at a desirable rate;

(iii) The male calves attain saleable weight in 1.5–2 years and the heifers are ready to mate at 15 months of age; and

(iv) The cattle herd improves in genetic potential from one generation to the next. The study of the strategies to achieve these long-term goals has to be initiated by the relevant authorities in Sabah through workshops and research.

7.3.3.3 Integration of different animals in the same systems

If herbage production were increased as a first step (given that financial support is available for that purpose), the other option to better utilise the herbage produced would be to introduce another class of animal on the farm, for example, goats. This option is similar to the case in New Zealand where sheep and beef cattle are usually farmed together (see Chapter 3).

7.4 Implication of the recommendations for livestock production policy in Sabah

High FCE leads to low feed input-high meat output and profitable livestock production (Thornton, 2010). In this study, the practical first step to improve the beef cattle production in Sabah was found to be to determine stocking rate for an optimal FCE. "To configure especially the stocking rate of the current animal production systems for optimal FCE" should thus be incorporated as one of the strategic objectives of the Sabah Agricultural Policy. Specifically, it should become Objective 13 under the present strategic goals, "ensuring sustainability", of the policy. The common suggestion by farmers and authorities in Sabah to improve beef (or dairy) production is to increase the animal population. While this suggestion is reasonable when the farms in Sabah are under stocked, based on experience in New Zealand (see Chapter 3), improving the productivity per unit area at lower stocking rate is likely to be more profitable and environmentally friendly rather than increasing the number of animal per unit area. This is because about 70% or more of the feed energy will be spent for body maintenance (see Section 5.3.1.5), which means for large population, more feed will be required just to maintain the animals, and not to produce. In that situation, sustainability of food supply in terms of beef production is doubted.

Presently, none of the strategic objectives of the agricultural policy in Sabah has emphasized or outlined adjustment of farm system configuration especially stocking rate for optimal FCE as a way to improve livestock or at least ruminant production. In the Strategic Plan of the Third Sabah Agricultural Policy, there are three strategic goals outlined to transform the livestock industry: increasing food security and income, strengthening productivity growth and competitiveness, and ensuring sustainability (Sabah Agricultural Policy 2015–2024, yet to be published). Under these strategic goals there are 23 more strategic objectives outlined. Yet, in the whole 113 pages of Strategic Plan, the word "efficiency" is used only 9 times in sections dealing with fishery and aquaculture, fruit, vegetable and mushroom, economic crop, and agro-based industries. No mention of "efficiency" occurs in sections on the livestock industry and specifically under ruminant production. Moreover, the use of "efficiency" in the Strategic Plan is also not in the context of "feed conversion efficiency".

Similarly, "To develop a pasture husbandry package" is also not one of the strategic objectives of the Third Sabah Agricultural Policy. There is, thus, a need for a strategic objective "To develop a livestock feed husbandry package" in the policy, targeted towards reducing the import of corn as a feed for livestock. It is noted in this study that inclusion of corn in the feed for cattle could improve the animal ADG to 0.81 kg hd^{-1} d^{-1} (see Ibrahim et al., 1987), meaning to achieve a higher ADG either corn is used or it is replaced by other comparable local feed in the ration, and this is where development of livestock feed husbandry package is important.

To improve the use of locally available feed resources for livestock production has been included as one of the strategic objectives in the agricultural policy. This objective is relevant to the comment on the use of supplement in this study. PKC is the agricultural by-product in Sabah, suitable for ruminant production, that is produced in greatest volume, but as stated earlier, this product is mostly exported. Based on the analysis in this study, the use of PKC is optional, although it is advantageous to use it to improve the animal ADG and reproductive performance. If the use of PKC for local beef production were increased, it would be in line with the objectives of the policy. In a broader sense, however, any decision over directing that PKC produced be retained for local use requires further evaluation, and in particular a comparison of the financial gain from exporting this product and from using it locally. Anecdotally, many local producers of PKC are said to prefer to export this product due to a better business environment. That is, fast payment and easier logistic management, because there is already a business mechanism established between the producers and foreign buyers, while there is no such mechanism established between the PKC producers and local buyers.

7.5 Conclusions

7.5.1 Main findings

From the series of studies in Sabah presented in this thesis, it can be concluded that for the future beef industry in Sabah to expand and improve in productivity, the first step is to configure current cut-and-carry feedlot and grazing cattle farming systems as well as OPIC system for optimal FCE suitable to the present conditions of the systems (and for that purpose a CSR-type statistic would be useful to determine the appropriate stocking rate), and the second step is to develop a pasture husbandry package to define fertiliser application regime, and harvesting or grazing cycle for increasing pasture productivity towards the potential herbage dry matter yield (14–20 kg DM ha^{-1} yr^{-1}), ME (9–10 MJ ME kg DM^{-1}), and CP (14%–16%) at harvesting (for cut-and-carry feedlot system) or grazing (for grazing system). Proposing a dry matter production target for the pasture husbandry package for OPIC farming system, however, is difficult until the time trajectory of the feed profile of the system is fully understood as herbage production and nutritive value in this system decrease with oil palm age. At the same time, the use of feed supplement in the beef production systems in Sabah can be evaluated for cost reduction or tactical use to improve the growth or nutrition of the cattle especially during reproduction for the breeding animals.

7.5.2 Limitations of the study and suggestions for further work

While the tasks proposed for implementation in Sabah (Sections 4.4.3, 5.4.2, 6.4.2, 6.4.3, and 7.3) are implemented, a few other tasks (arranged based on priority) also need to be carried out to mitigate factors that potentially limit the application of animal MEB used in this study:

- Using MEB to help farmers in Sabah to improve the productivity of their farms and to gain further insight on its practicality. The system configuration suggested in this study (see Sections 4.4.3 and 5.4.2) can be used as the template to begin the extension initiative;
- Conducting more comparisons between the intakes predicted by animal MEB and observed in feeding experiments. In this study, both approaches were found to provide a similar estimate of animal energy requirements. However, the comparison was constrained by small sample number, short experimental period, and a limited range of parameters observed in the experiment;

- Measuring the annual and monthly herbage production in the three studied systems in Sabah using cutting experiments and comparing the results with those from the animal MEB;
- Assessing the monthly herbage nutritive value;
- Repeating the analysis in Chapter 6 on an OPIC farming system with oil palms of younger than 9 years old, for example 3 yr and 6 yr old oil palm plantations (if there are farms available for study), so that the results can be combined with those obtained in the present study to draw the trajectory of feed profiles of OPIC farming system in Sabah for 3 yr to 12 yr old oil palm plantations; and
- Carrying out an experiment on herbage dry matter intake (DMI) of cattle under feedlot and grazing condition (following the method suggested by CSIRO, 2007) to generate more information on DMI in Eq. 4.1 (see Section 2.2.4).

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Appendices

Appendix 2.1 Potential grazing area in Sabah (ha).

Residency	Gazetted area for grazing	Improved pasture	Fenced lalang (*Imperata cylindrica*)	Natural grassland suited for grazing	Natural grassland moderately suited for grazing	Other Natural grassland	Total potential grazing area
West coast and Kudat	10514	1420	1210	10864	18067	64169	106244
Interior	1722			2667	9070*	16545	30004
Sandakan				8563		13500	22063
Tawau		2747		4805	5088	4234	16874
Total (ha)	12236	4167	1210	26899	32225	98448	175185

*Within forest area. Source: extracted from Thomas *et al*. (1976a–d).

Appendix 2.2 Major facilities, projects and support centres for livestock production in Sabah.

No.	Facility	Function
1.	Beef cattle breeding centre: (a) Stesen Pembiakan Ternakan, mile 16, Tawau (SPT Tawau); (b-c) Pusat Pembanyakan Ternakan Wario I and II; (d) Pusat Pembanyakan Ternakan Timbang Menggaris; and (e) Pusat Menternak Lembu Dara Semporna	Carry out beef cattle breeding and research; facilitate training; receive calf from contract farmers; and provide milk collection facility for nearby smallholder dairy farmers.
2.	Dairy cattle breeding centre: Stesen Pembiakan Ternakan Sebrang, Keningau (SPT Sebrang).	Carry out dairy cattle breeding and research; facilitate training; provide milk collection facility for nearby smallholder dairy farmers; provide facility to acclimatise imported dairy cattle; and produce beef as secondary product.
3.	Projek Bioteknologi	Obtain semen of dairy and beef cattle bulls for local use; carry out a selection of bull sires; and provide training on artificial insemination.
4.	Projek Pembangunan Padang Ragut	Establish pastureland and provide training on management and production of pasture.
5.	Projek Ternakan Pekebun Kecil	Supply beef cattle and assist smallholder farmers to develop their farms.
6.	Projek Lembu Tenusu	Increase local fresh milk production for local use.
7.	Extension Program and Outreach Research	Improve nutritive value of local feed; conduct research to exploit farm condition for ruminant production; intensify the use of local agro-based protein; and improve livestock production through strategic nutrition.
8.	Pusat Pengeluaran Makanan Ternakan, Lok Kawi	Produce high quality feed at lower cost and carry out research and training on feed and feed processing.
9.	Projek Ekonomi dan Epidemiologi Veterinary	Record and analyse disease outbreak; plan and monitor disease prevention and eradication program; and certify the quality of imported livestock product.
10.	Pusat Latihan Menternak Bantayan, Tuaran	Train and transfer skill on modern farming technique to DVSAI staff and livestock farmers.
11.	Veterinary Diagnostic Laboratory, Livestock Quarantine, and Abattoir Facilities (centralized)	Carry out disease prevention, control and treatment program.
12.	DeVetSa	Provide one-stop online support for livestock farmers to expand their business.

Source: extracted from DVSAI (2008).

Appendix 2.3 Some advantages and challenges facing the beef and dairy cattle farming sector in Sabah including land, cattle breed, productivity, feed, labour, technology, farm management, and market.

Factors	Advantages	Challenges
Grazing area	Potential grazing area is 175,185 ha as identified by Thomas et al. (1976a–d). Sabah has 1.54M ha oil palm plantations.	Officially gazetted grazing area is so far only 21,698 ha (Awang Salleh, 1991). Many potential grazing areas could have been used for oil palm plantations. Approximately, 72.31% of the agriculture land has been used especially for palm oil production (DOA, 2004–2010).
Cattle breed and population	Choice of breed is available: Brahman, Bali, Bali crossbreed, Droughtmaster, and Friesian crossbreeds. Beef cattle are increasing. Dairy cattle are increasing.	Calving rate is low. Breed reported elsewhere in Malaysia as less productive breed (e.g., Droughtmaster) is still used, although it is being phased out on some farms. The reasons for low calving rate have not yet been thoroughly studied and addressed. Slaughter rate is lowering.
Product	Quality for local market is expected to be acceptable, as complaint is nil. Sabah is free from any serious livestock disease. Sabah could become a centre for production of 'halal' beef and milk.	Compliance to quality for export is unknown; published study on this topic is not available. Low production of beef and milk. Expansion to cater international market beyond Brunei is slow. Although Sabah is safe from any serious livestock diseases, bacterial contamination of milk is still high.
Feed	Formula and production technique are available.	Current published evaluation on feed quality is not available. Quantity is insufficient and assessment of local feed resources is not available. Publication on relationship between feed and cattle growth is not available. Work has to be done to compile, understand, and publish cattle growth data from the farmers and the breeding stations of the DVSAI. Publication on energy and feed requirements of cattle is not available. Production cost is high.
Labour	Family business: labour shortage is not a serious problem.	Could be a hobby business. Succession plan to maintain the business is unknown. Professional manpower is limited.
Technology	Breeding centres, Diagnostic lab, and sperm production centre are available.	Milk chiller is limited.
Farm management	Farming subsidy and training support are available. Environmental problem is not an issue. Health care services are available.	Assessment of effectiveness of outreach program and training is not available. Characters of successful farmers have never been outlined and learnt. Future of cattle farming has never been properly addressed. Evaluation of farm soil fertility (Chew, 1991) is limited. Analysis of economics of cattle farming (Chew, 1991) is out dated. Twenty-two farmers withdrew due to the high production cost and insufficient of good quality feed (DVSAI, 2008); study to overcome the problems faced by the farmers is not available.
Market	Local demand is high both in Sabah (DVSAI, 2014) and in Malaysia.	Demand is not consistent throughout the year. Consumption per capita tends to decline, probably as a response to high beef price (Assis et al., 2015). Diversification of products has not been evaluated; current products are fresh beef and fresh milk. The farming has not been directed to meet the demand of imported beef-based or dairy-based product.

Source: extracted and analysed from DVSAI (2008, 2009 and 2014), except where the source is indicated in the text.

Appendix 3.1 Liveweight by stock class in 1980–81/1985–86 and 2010–11[a] used in the model to calculate metabolic energy requirements of animals for North Island (Class IV) sheep and beef cattle farms in New Zealand.

Stock class	kg per head											
	J	A	S	O	N	D	J	F	M	A	M	J
MA ewe	52	53	55	56	56	57	59	60	59	59	60	55
	(55)	(56)	(58)	(59)	(59)	(60)	(62)	(63)	(62)	(62)	(63)	(58)
2-tooth ewe	48	49	51	54	56	58	59	60	59	59	60	55
	(50)	(51)	(53)	(56)	(58)	(60)	(61)	(62)	(61)	(61)	(62)	(57)
Wet hogget	42	43	46	49	51	52	55	56	56	56	56	55
	(43)	(44)	(47)	(50)	(52)	(53)	(56)	(57)	(57)	(57)	(57)	(56)
Dry hogget	36	37	41	44	47	52	55	56	56	56	56	55
	(37)	(38)	(42)	(45)	(48)	(53)	(56)	(57)	(57)	(57)	(57)	(56)
Lamb	0.66	3.12	5	9	13	17	23	25	28	30	32	34
(replacement)			(6)	(10)	(14)	(18)	(24)	(26)	(29)	(31)	(33)	(35)
Lamb (finishing)	0.66	3.12	5	9	13	17	23	25	28	30	32	34
			(6)	(15)	(23)	(27)	(33)	(35)	(38)	(40)	(42)	(44)
Foetus	0.66	3.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.07
Wether or Ram	0.66	3.12	5	9	13	17	23	29	35	38	40	41
lamb			(6)	(15)	(23)	(27)	(33)	(39)	(45)	(48)	(51)	(51)
Wether or Ram	43	45	46	47	51	55	59	60	61	63	65	66
hogget	(45)	(47)	(48)	(49)	(53)	(57)	(61)	(62)	(63)	(65)	(67)	(68)
Wether or Ram	65	65	65	66	66	67	69	70	70	70	71	71
	(68)	(68)	(68)	(69)	(69)	(70)	(72)	(73)	(73)	(73)	(74)	(74)
Heifer calf				34	48	59	80	130	175	179	193	208
R1–R2yr heifer	223	237	252	266	281	296	310	325	339	354	369	383
R2–R3yr heifer	392	376	354	331	340	354	389	408	408	415	422	430
Beef cow	435	454	472	488	504	520	529	537	515	515	515	515
Steer calf				35	52	69	85	101	118	134	150	178
				(46)	(80)	(97)	(113)	(129)	(146)	(162)	(178)	(206)
R1–R2yr steer	207	225	247	270	294	318	351	381	372	363	354	368
	(235)	(253)	(275)	(298)	(322)	(346)	(379)	(409)	(400)	(391)	(382)	(396)
R2–R3yr steer	362	383	388	450	482	514	533	529	525	522	552	582
	(390)	(411)	(416)	(478)	(510)	(542)	(561)	(557)	(553)	(550)	(580)	(610)
Steer	612	621	631	640	640	640	640	640	640	640	640	640
	(640)	(649)	(659)	(668)	(668)	(668)	(668)	(668)	(668)	(668)	(668)	(668)
Bull calf				30	52	73	95	121	147	171	182	192
R1–R2yr bull	200	224	228	228	265	314	364	381	398	415	432	449
R2–R3yr bull	466	483	500	517	534	551	568	582	612	621	631	640
Bull	640	640	640	640	640	640	640	640	640	640	640	640

[a] In parentheses – included only if different from that in 1980–81, as suggested by the farmer of Farm B.

Sheep: Foetus to lamb birth for single lamb (Koong et al., 1975). Wet hogget and replacement (Baker et al., 1979). Lamb at birth to weaning, dry hogget, replacement hogget, 2-tooth ewe, and MA ewe (Parker, 1986; Geenty, 1979). Wether and Ram; 3–16 months (Baker et al., 1979). Adult ram or wether is assumed to be 10 kg heavier than a MA ewe of similar age.

Cattle: Steer or bull calf at birth to weaning (Everitt et al., 1980). R1–R3yr steers (Barton, 1975). Heifer calf at birth to weaning and R2yr–R3yr heifers (Anderson et al., 1981). R3yr heifer and beef cows (Nicoll, 1979). Bull calf to 15–20 month old (McRae, 1985; McRae, 1987). Bull of 20–32 month old (Farm A's 1985/86 record). R3yr steer and much older bull (Farm A's 1999/00 record).

Liveweight data are rounded to nearest values and are omitted from the table if they are not applicable in the model. Information was verified again by the farmers of Farms A and B before use.

Appendix 3.2 Energy equations and constants used in the model to calculate metabolic energy requirements of animals for North Island (Class IV) sheep and beef cattle farms in New Zealand.

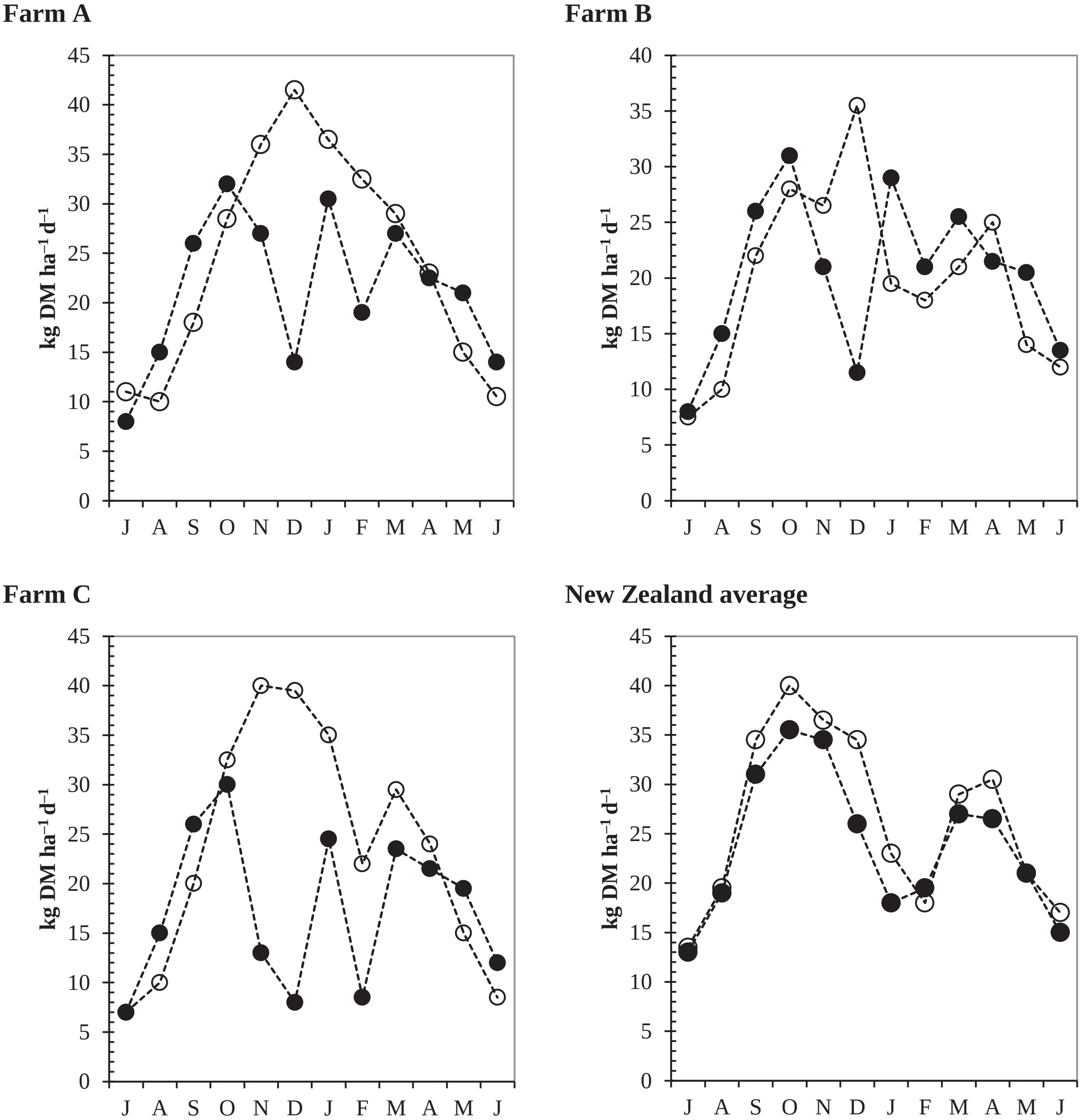
Energy requirement	Equation	Description and note
Total energy requirements (MJ d^{-1})	ME_M+ME_{G+}+ME_{G-}+ME_P+ME_L	General equations. Energy requirement for grazing activity is accounted for using the metabolic coefficient = *a*.
ME_M: Body maintenance (MJ d^{-1})	$a \times$ liveweight$^{0.75}$	a = 0.52 (sheep) a = 0.56 (breeding ram) a = 0.66 (cattle)
ME_{G+}: Gaining weight (MJ d^{-1})	$b \times$ liveweight gained (kg d^{-1})	b = 55 (sheep) b = 55 (cattle, except for adult bulls or steers) b = 70 (adult bulls or steers)
ME_{G-}: Losing weight (MJ d^{-1})	$c \times$ liveweight lost (kg d^{-1})	c = 20 (sheep) c = 25 (cattle, except adult bulls or steers) c = 40 (adult bulls or steers)
ME_P: Pregnancy (MJ d^{-1})	Sheep: ME_M+ME_{G+} of sheep foetus. Equation for foetus growth is as follows (Koong et al., 1975): $W = 0.000103e^{0.613N+(0.128-0.00038T)T}$	W = Liveweight N = Number of foetus T = Day of pregnancy
	Cattle: 4.6, 12.3, 21.8, 37.4 and 23.4 MJ ME hd^{-1} d^{-1}.	Fixed at those amounts for the last five months of pregnancy.
ME_L: Lactation (MJ d^{-1})	ME_M+ME_G of lamb and calf until weaning.	a = 0.45 (female lamb), 0.50 (male lamb) a = 0.65 (female calf), 0.72 (male calf) b = as in Table 5 (lamb) and Table 12 (calf) of Nicol and Brookes (2007).

Appendix 3.3 Herbage metabolisable energy content used in the model to calculate metabolic energy requirements of animals for North Island (Class IV) sheep and beef cattle farming systems in New Zealand.

Stock	MJ ME kg DM^{-1}												$\bar{x}$
	J	A	S	O	N	D	J	F	M	A	M	J	
Sheep[a]	11.1	11.4	11.7	11.4	10.97	10.15	9.4	9.3	9.3	10.4	10.7	10.9	10.5
Cattle	9.67	10.1	9.83	10.52	10.19	8.92	7.79	7.53	7.83	8.05	8.36	9.17	8.95
Sheep[b]	11.8	11.2	10.8	11.0	10.7	10.7	10.2	10.7	11.5	11.6	12.0	12.2	11.2
Cattle	10.3	9.91	9.07	10.15	9.94	9.41	8.46	8.61	9.68	8.98	9.37	10.3	9.51
% [c]	12.9	11.5	16.0	7.7	7.1	12.1	17.1	19.5	15.8	22.6	21.9	15.9	15.0

[a] McRae (1987).
[b] Machado et al. (2005).
[c] ME of herbage for finishing cattle was reduced at this percentage.

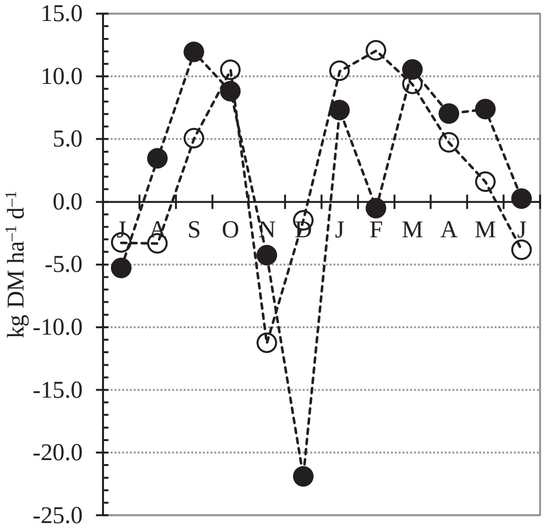
Appendix 3.4 **Pasture growth in 1980–81/85–86 (○) and 2010–11 (●) calculated using GROW model based on statistics for an average farm and actual data for Farms A, B and C of North Island (Class IV) sheep and beef cattle farming systems in New Zealand.**



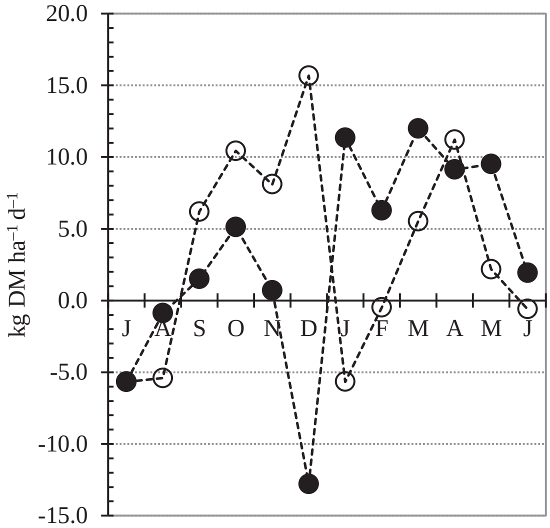
Appendix 3.5 Feed balance (pasture supply minus feed demand) in 1980–81/85–86 (○) and 2010–11 (●) for the average farm and Farms A, B and C of North Island (Class IV) sheep and beef cattle farming systems in New Zealand.

The figures were obtained by first calculating the feed demand for the average farm and Farms A, B, and C using MEB and second deducting the respective feed demand from the relevant pasture supply (see Appendix 3.4) calculated using GROW model.

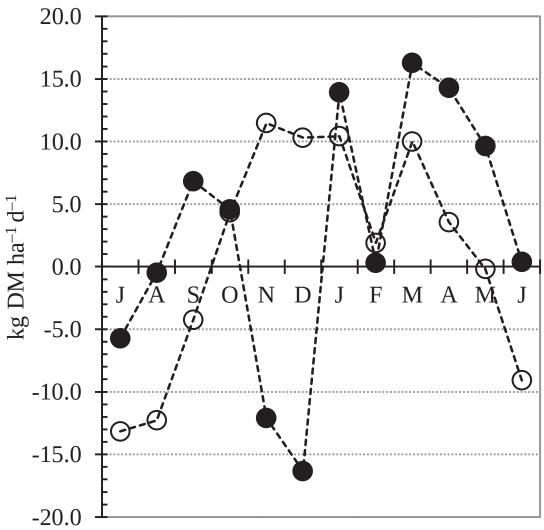
Farm A



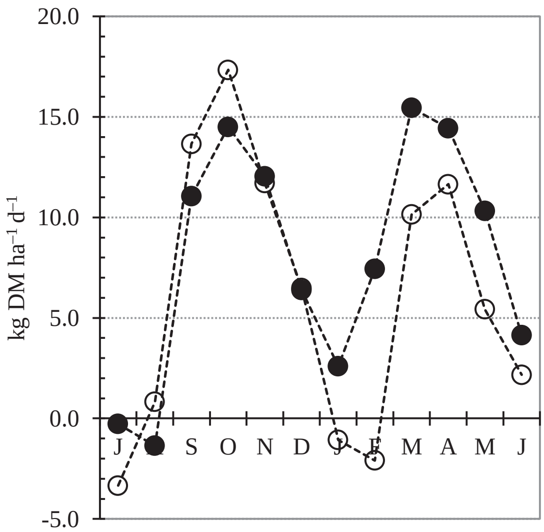
Farm B



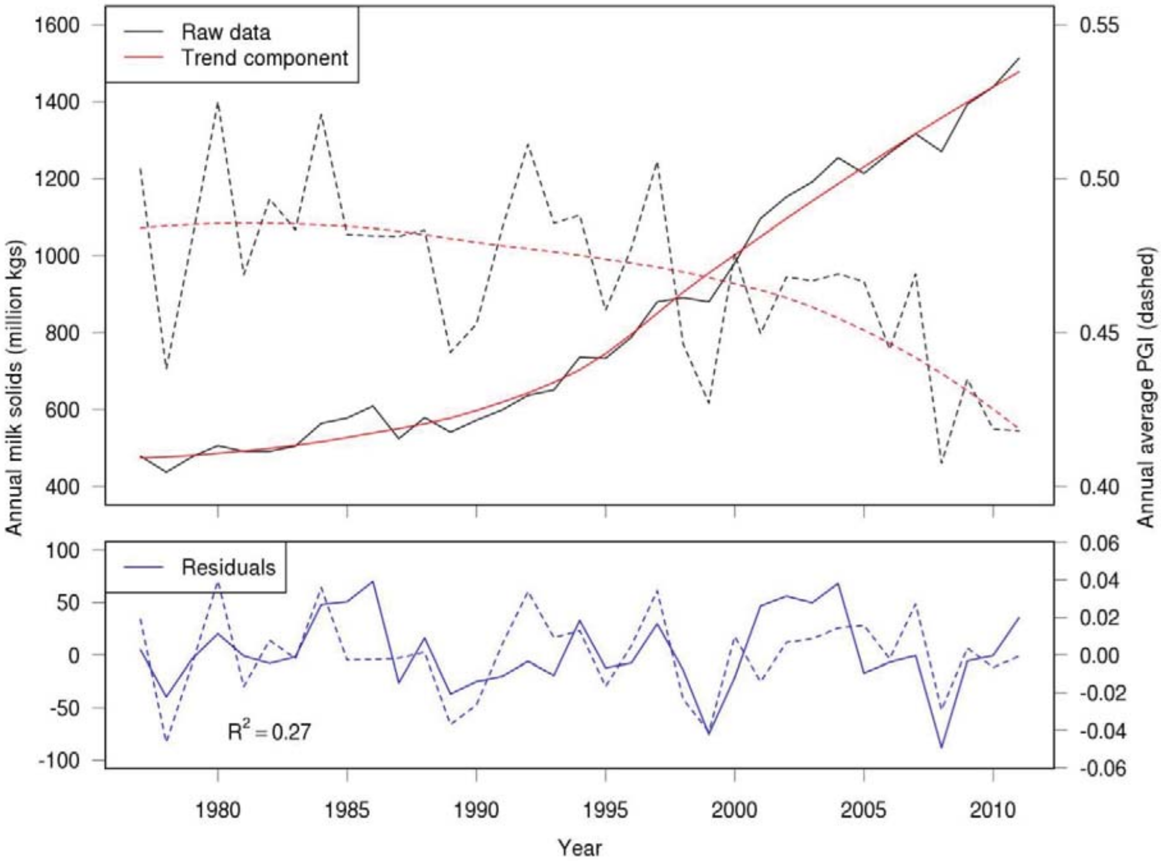
Farm C



New Zealand average



Appendix 3.6 Annual average Pasture Growth Index (black dashed line with trend line in red) for New Zealand from 1977–2010.



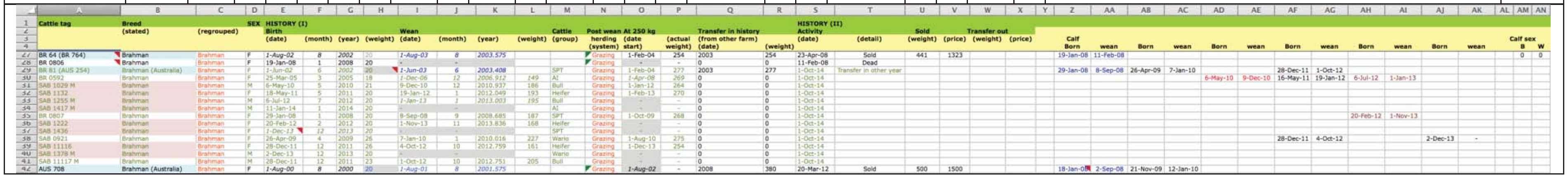
Source: NZXAGRI (2012)

"The **national pasture growth index (PGI: dashed black line)** has a more stable long-term trend, although there has been significant downward movement in the past decade. The low PGI over the last few years is due mainly to drier that normal conditions." – NIWA (NZXAGRI, 2012)

Appendix 3.7 Softcopy (in CD) of sample of MEB spreadsheet used to capture North Island (Class IV) sheep and beef cattle farming systems in New Zealand.

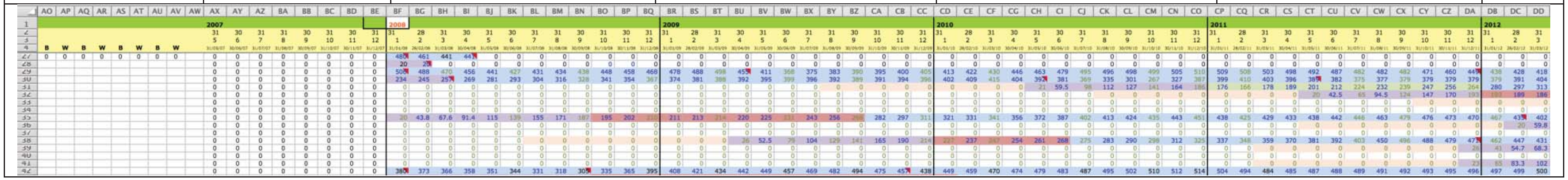
Appendix 4.1 Sample of key information and animal data used in MEB for cut-and-carry feedlot, grazing and oil palm integrated cattle farming systems in Sabah.

Cattle identification number	Breed	Group	Sex	Birth date	mo	yr	LWT	Wean date	mo	yr	LWT	Cattle unit	Grazing/Feedlot	Date at 250 kg	Actual LWT at 250 kg	Transfer in history	LWT	Current activity (date)	Sold, transfer out, died (+reason), treatment	Sold LWT	(Price)	Transfer out LWT	(Estimate price)	Calving history of cow (Calf birth and wean date)	Calf sex



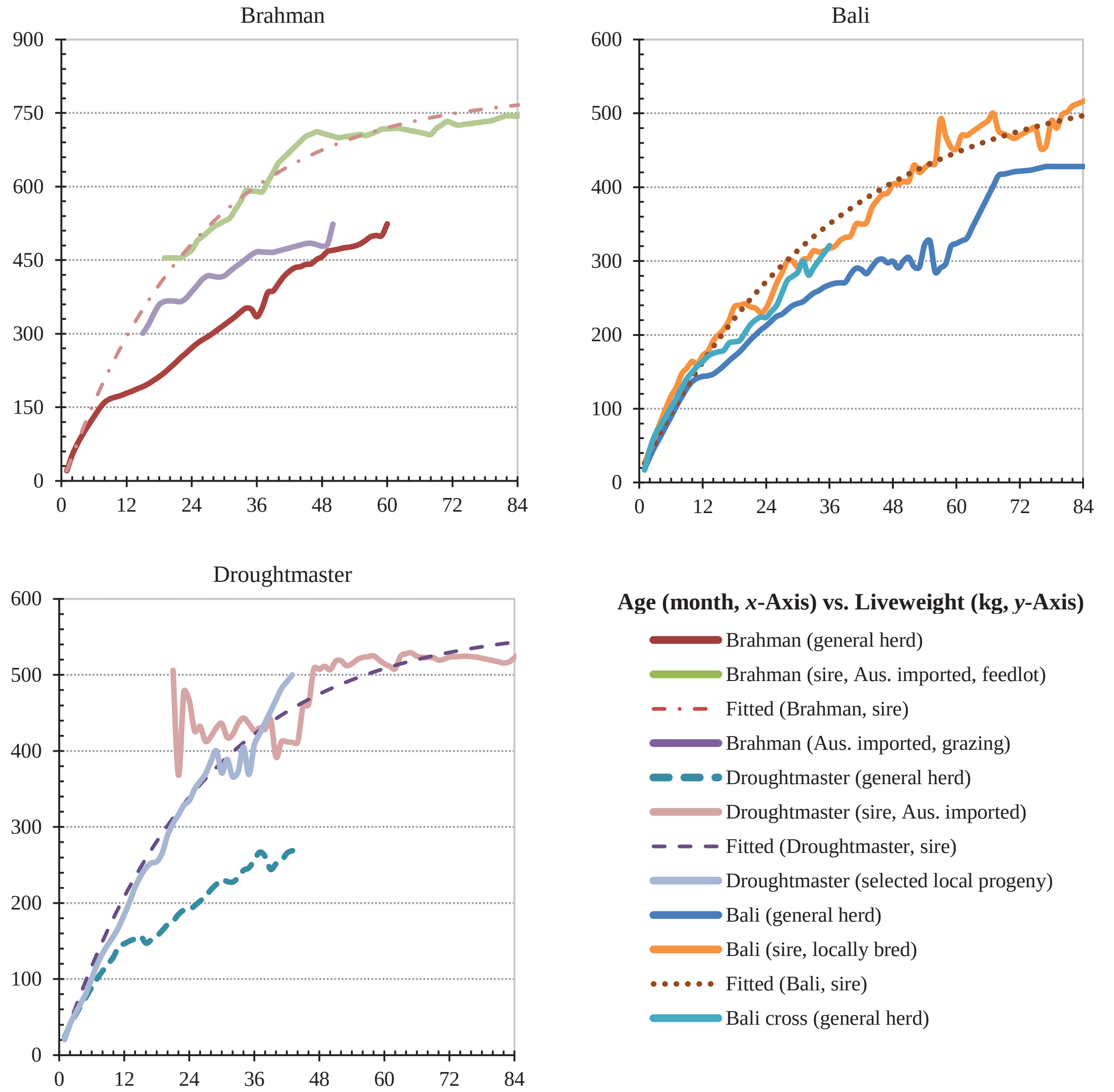
(Appendix 4.1 Continued)

Calf sex	Year, month, number of day, date, LWT	Year, month, number of day, date, LWT	Year, month, number of day, date, LWT	Year, month, number of day, date, LWT	Year, month, number of day, date, LWT	Year, month, number of day, date, LWT



Data were entered from column A until column DZ (104 columns) and from row 1 until row 1379 of the Microsoft®Excel spreadsheet. Some additional information (e.g., sold, price) was included for other purposes in the future.

Appendix 4.2 Samples of liveweight trajectories (kg mo^{-1}) of entire male cattle in cut-and-carry Brahman, Bali and Droughtmaster feedlots at SPT Tawau, Sabah.



Note: Bulls arrive in the feedlots at 145–155 kg (decided by weight rather than by age). Brahman (Grazing) is for comparison. Brahman (general herd) returns to grazing system once >250 kg liveweight: the growth data are displayed for comparison. The weaning effect is indicated by the deviation of growth trajectory once the bulls arrived in the feedlot (starting at 145–155 kg liveweight). The fitted growth curves are displayed for comparison. The growth data before weaning represent the growth of the calves while with the cows in grazing system. The average number of cattle observed per point (per month) to generate the growth data was 78 for Brahman, 48 for Bali, 4 for Bali crossbred, and 56 for Droughtmaster.

Appendix 4.3 Equations, calculation set up, and assumptions used in calculation of metabolic energy requirements of animal in cut-and-carry feedlot, grazing and oil palm integrated cattle farming systems in Sabah.

App. 4.3.1 Equations

The animal metabolic energy calculations were carried out using Microsoft®Excel. The equations were adapted from CSIRO (2007) and Nicol and Brookes (2007). The key equations were:

Eq. 1 $\mathbf{ME_{TOTAL} = ME_{BASALMETABOLISM}+ME_{GAIN}+ME_{GRAZE}+ME_{PREGNANCY}+ME_{LACTATION}}$

(i) Energy requirement for body maintenance

Eq. 2 $M_{BASALMETABOLISM}$ = (Species*sex*0.28*EXP(–0.03*Age)*LWT^0.75)/k_m

(ii) Energy requirement for liveweight gain in addition to $M_{BASALMETABOLISM}$

Eq. 3.1 ME_{GAIN} = 1.1*((0.92*LWG)*((6.7+(((920*LWG)/(4*(SRW^0.75)))–1))+(20.3–(((920*LWG)/(4*(SRW^0.75)))–1))/(1+EXP(–6*((LWT/SRW)-0.4)))))/k_g

Calculation of dietary ME spared from liveweight loss:

Eq. 3.2 ME_{LWL} = 1.1*((0.92*LWL)*((6.7+(((920*LWL)/(4*(SRW^0.75)))–1))+(20.3–(((920*LWL)/(4*(SRW^0.75)))–1))/(1+EXP(–6*((LWT/SRW)-0.4)))))/k_g

Eq. 3.2.1 ME_{LWLRNL} = ME_{LWL}*0.80

Eq. 3.2.2 ME_{LWLRL} = ME_{LWL}*0.84

Eq. 3.2.1.1 ME_{LWL} as dietary ME spared = ME_{LWL}*0.80/k_m

Eq. 3.2.2.1 ME_{LWL} as dietary ME spared = ME_{LWL}*0.84/k_l

(iii) Energy requirement for grazing activity in addition to $M_{BASALMETABOLISM}$

Eq. 4 ME_{GRAZE} = $ME_{CHEW+RUMINATE}$+ME_{MOVE}+$ME_{ACTIVITY}$

Eq. 4.1 $ME_{CHEW+RUMINATE}$ = LWT*((Species*DM intake*(0.9–Digestibility))/k_m

DM Intake = Potential DM intake (I)*Relative ingestibility (RQ)*Relative availability (F)

Eq. 4.1.1 I = 0.025*SRW*Z*(1.7–Z)*Correction factor; Where Z = N/SRW; N = SRW–(SRW–BirthWT)*EXP(–0.35*Age*SRW^–0.27); and Correction factor = 1.0, or (LWT/N)*(1.5–(LWT/N))/0.5 if LWT/N >1.0

Eq. 4.1.2 RQ = 1–1.7*(max((0.8–(1–P_{legume})*0.16)–Digestibility,0.0))

Eq. 4.1.3 F = E*T = (1.0–EXP(–b*B))*(1.0+c*EXP(–d*B^2))

Eq. 4.2 ME_{MOVE} = (0.0039*LWT*(SR/5)/((0.057*GF)+0.16))/k_m

Eq. 4.3 $ME_{ACTIVITY}$ = LWT*((0.008216)+(0.0448))/k_m

(iv) Energy requirement for pregnancy in addition to $M_{BASALMETABOLISM}$

Eq. 5 $ME_{PREGNANCY}$ = (BirthWT/40)*EXP(349.222–349.164*EXP(–0.0000576*Days))*0.0201*EXP(–0.0000576*Days)/k_p

(v) Energy requirement for lactation (calculated based on calf liveweight from birth to weaning) in addition to $M_{BASALMETABOLISM}$

Eq. 6 $ME_{LACTATION}$ = (Eq. 2)+(Eq. 3.1)+(Eq. 4)

App. 4.3.2 Calculation set up

(a) Cut and carry feedlot system

Age was taken as age in years in the month the calculation was carried. LWT was the liveweight of the animal in kilogram every month. Species was 1.2 (*Bos indicus*) for beef cattle and 1.3 (*Bos indicus* × *Bos taurus*) for dairy crossbred cattle. Sex was 1.0 (female) and 1.15 (entire male). M/D was herbage ME, that is, 8.5 MJ ME kg DM^{-1}. M/D of feed concentrate was 10.5 MJ ME kg DM^{-1}. M/D was obtained by chemical analysis. k_m was M/D*0.02+0.5, that is, 0.67. k_g was M/D*0.042+0.006, that is, 0.363. LWG was the liveweight gain of the animal every month. LWL was the liveweight loss of the animal every month. SRW was the standard reference weight (kg) of Brahman (M: 850, F: 550), Bali (M: 550, F: 400), Bali crossbred (M: 480, F: 380), and Droughtmaster and dairy crossbreed (M: 770, F: 550). The SRW were assigned based on the highest liveweight records by sex observed for the breeds in the long-term liveweight data kept by the studied farm. It has to be noted that information on green forage is not required for this system.

(b) Grazing system

Age, LWT, species and sex were defined in the same way as those of cut-and-carry feedlot system. M/D of herbage was 8.3 MJ ME kg DM^{-1}, and that of feed concentrate was 9.5 MJ ME kg DM^{-1}. M/D was obtained by chemical analysis. k_m was M/D*0.02+0.5, that is, 0.666. k_g was M/D*0.042+0.006, that is, 0.355. k_l was M/D*0.02+0.4, that is, 0.566. LWG, SRW, and LWL were also defined in the same way as those of cut-and-carry feedlot system. Herbage digestibility was calculated as M/D ÷ 15.088. SR was current stocking rate as cattle number per ha. GF was the amount of green forage as tonnes dry matter per ha and this was determined by the herbage cutting experiments: 1.46, 1.06, 1.33, 1.33, and 1.59 t DM ha^{-1} for the Brahman Cow-calf, Bali Cow-calf, Droughtmaster Cow-calf, heifer and Brahman Bull Units, respectively. The days for the $ME_{PREGNANCY}$ were days since conception; the information of birth date and pregnancy test was used as the guide to estimate the conception, taking 274 days as a gestation period. The k_p for pregnancy was

0.133. The energy requirement for lactation was based on the energy requirements of the calves for body maintenance, growth and grazing activity. In this study, records of calf liveweight were available for that calculation to be possible.

(c) OPIC farming system

Age, LWT and sex were defined in the same way as those of grazing system. Species was 1.2 (*Bos indicus*); the cattle were all Brahman. M/D of herbage was 8.5 MJ ME kg DM^{-1}. M/D was obtained by chemical analysis. It has to be noted that feed supplement was not used in this system. k_m was M/D*0.02+0.5, that is, 0.67. k_g was M/D*0.042+0.006, that is, 0.363. k_l was M/D*0.02+0.4, that is, 0.57. LWG, LWL and SRW (for Brahman only) were defined as those of grazing system. SRW were assigned based on the highest liveweight records by sex observed for the breeds in the long-term liveweight data kept by the government farm in the same district of the OPIC farms. Herbage digestibility was calculated as M/D ÷ 15.088. SR was current stocking rate as cattle number per ha. GF was the amount of green forage as tonnes dry matter per ha and this was determined by the herbage cutting experiments: 1.383 for 9OP1/9OP2 and 0.768 for 12OP. The set up for calculation of energy for pregnancy and lactation is similar to that of grazing system. The liveweight data of calf used were obtained from the government farm in the same district of the OPIC farms.

App. 4.3.3 Assumptions

(a) Cut and carry feedlot system

(i) Herbage ME of 8.5 MJ ME kg DM^{-1} and feed concentrate ME of 10.5 MJ ME kg DM^{-1} were assumed to be consistent throughout the feed budgeting calculations. (ii) As noted earlier, information on green forage is not required for this system. (iii) Waste was assumed 15% for herbage and 18% of feed concentrate; the values were obtained from the feeding experiment. (iv) The energy allowance for body heat maintenance and heat effect on energy requirements were assumed zero, because the ambient temperature on the farm was higher than the lower critical temperature but lower than the upper critical temperature where energy for body thermoregulation would be required. (v) The effect of parasite load on energy requirements was not accounted for because there was no evidence the cattle had parasite problem.

(b) Grazing system

(i) Herbage ME of 8.3 MJ ME kg DM^{-1} and feed concentrate ME of 10.5 MJ ME kg DM^{-1} were assumed consistent throughout the feed budgeting calculations. (ii) Amount of green forage was also assumed consistent (as stated for grazing system above) throughout the feed budgeting calculations. (iii) Based on the information given by the farm, feed supplement waste was 5%. (iv–v) The assumptions were similar to those of cut-and-carry feedlot. (vi) Slope in Eq. 4.2 was given an index of 1.5, that is, moderately steep in the sense of Nicol and Brookes (2007). This is because farm has a gently undulating topography. (vii) Since little is known about grazing behaviour of the cattle on the farm, the cattle were assumed to have walked 3.15 km horizontal distance and 1.6 km vertical distance a day to graze in Eq. 4.3. The horizontal distance was a middle point of the 6.3 km maximum distance reported by CSIRO (2007), and the vertical distance was a middle point of the horizontal distance.

(c) OPIC farming system

(i) Herbage ME of 8.5 MJ ME kg DM^{-1} was assumed consistent throughout the feed budgeting calculations. (ii) Amount of green forage was also assumed consistent (as stated for OPIC farming system above) throughout the feed budgeting calculations. (iii) As noted earlier, feed supplement was not used in this system. (iv–vii) The assumptions were similar to those of grazing system.

Appendix 4.4 Animal energy intake comparison between the metabolic energy model and a feeding experiment at SPT Tawau, Sabah.

	Weaner bull	Heifer	Bull
Age (yr)	1.1±0.1	1.0±0.7	1.6±0.6
Initial liveweight (kg hd^{-1})	231.6±20.9	203.4±38.3	309.8±28.7
Liveweight gain (kg hd^{-1} d^{-1})	0.93±0.43	0.38±1.22	1.23±1.01
Feed fed (*S. sphacelata* 'Kazungula', kg hd^{-1} d^{-1})	20±0	30.6±0	30.6±0
Feed fed (PKC, kg hd^{-1} d^{-1})	3±0	3±0	3±0
DM intake (*S. sphacelata* 'Kazungula', kg DM hd^{-1} d^{-1})	3.97±1.20	5.22±0.50	8.41±0.47
DM intake (PKC, kg DM hd^{-1} d^{-1})	1.93±0.50	0.53±0.36	0.98±0.90
% DM intake over liveweight	2.5	4.2	3.0
M/D (*S. sphacelata* 'Kazungula', MJ ME kg DM^{-1})	8.2	8.2	8.2
M/D (PKC for this trial, MJ ME kg DM^{-1})	10.5	10.5	10.5
A. ME intake estimate from the feeding experiment (MJ ME hd^{-1} d^{-1})	**61.0±15.1**	**49.1±7.9**	**81.5±13.3**
B. ME requirement estimate from the modelling (MJ ME hd^{-1} d^{-1})	0.563 × 231.6^0.75 + 0.93 × 35.43 = **66.37**	0.491 × 203.4^0.75 + 0.38 × 45.66 = **43.80**	0.555 × 309.8^0.75 + 1.23 × 42.0 = **92.62**
Difference: B – A (MJ ME hd^{-1} d^{-1})	5.37	–5.30	11.12

Appendix 4.5 Feed demand and supply of cut-and-carry Brahman, Bali and Droughtmaster feedlots at SPT Tawau, Sabah (2008–2013): (a) annual and (b) monthly.

(a) **t DM ha^{-1} yr^{-1}**	08	09	10	11	12	13	$\bar{x}$	SD	CV %
Herbage:									
Brahman	1.79	3.16	2.55	2.85	4.20	4.28	3.14	0.97	31
Bali	1.28	1.68	1.59	1.72	2.30	1.85	1.74	0.33	19
Droughtmaster	1.16	1.76	2.10	1.78	0.92	0.34	1.34	0.66	49
Concentrate:									
Brahman	0.69	0.85	1.04	1.03	1.04	0.57	0.87	0.21	24
Bali	0.56	0.75	0.73	0.53	0.45	0.22	0.54	0.19	36
Droughtmaster	0.50	0.62	0.60	0.45	0.13	0.03	0.39	0.25	64
Total	5.98	8.82	8.61	8.35	9.03	7.30	8.02	1.17	6

(b) **kg DM ha^{-1} d^{-1}**	J	F	M	A	M	J	J	A	S	O	N	D	$\bar{x}$	SD	CV %
Herbage:															
Brahman	8.95	8.70	8.39	7.67	7.77	7.43	8.71	7.97	8.93	8.78	9.32	10.5	8.60	0.85	10
Bali	4.72	4.35	4.53	4.67	4.51	4.29	5.03	4.63	5.01	4.74	5.15	5.48	4.76	0.35	7
Droughtmaster	3.48	3.49	3.54	3.97	4.58	3.30	3.63	4.46	4.36	3.26	3.06	3.05	3.68	0.54	15
Concentrate:															
Brahman	2.10	2.34	2.51	2.62	2.10	2.77	2.58	2.82	2.44	2.69	2.13	1.48	2.38	0.38	16
Bali	1.16	1.36	1.56	1.65	1.39	1.81	1.51	1.74	1.57	1.75	1.36	0.85	1.48	0.27	19
Droughtmaster	0.73	0.91	1.12	1.20	1.01	1.44	1.15	1.35	1.18	1.24	1.00	0.44	1.06	0.27	26
Total	21.1	21.2	21.6	21.8	21.4	21.0	22.6	23.0	23.5	22.5	22.0	21.8	22.0	0.78	4

Total feed demand and supply per feedlot is equal to herbage + concentrate. Sum of feed demand and supply (annual or monthly) of all feedlots is equal to the average feed demand and supply per ha (annual or monthly) of the cut-and-carry feedlot system because the feedlots shared the same cut-and-carry paddocks or effective area.

Appendix 4.6 Dry matter yield of herbage and nutritive value of feeds used in cut-and-carry Brahman, Bali and Droughtmaster feedlots at SPT Tawau, Sabah (±SD).

	B. decumbens		**B. decumbens*		**S. sphacelata* 'Kazungula'		Feed Supplement[A]
Day before cutting	15 d	2 d	14	1 d	7	1 d	–
DM (kg DM ha^{-1})	1350±64	2240±304	2011±242	1859±227	544±90	1068±228	–
GDM (kg DM ha^{-1})	1151±54	1911±259	1715±206	1585±194	463.6±77	673.3±202	–
LDM (kg DM ha^{-1})	709±34	1177±160	1057±127	977±119	286±48	415±125	–
CP (N × 6.25%)	8.8±0.2	10.9±2.8	8.4±0.2	8.5±0.7	12.4±0.9	11.5±0.5	13.9±2.1
ME (MJ ME kg DM^{-1})	7.7±0.02	8.5±0.9	7.9±0.2	7.7±0.04	8.2±1.5	7.8±0.7	11.5±2.8

GDM: Green DM. LDM: Leaf DM. [A] Average including unpublished results from previous test carried out by Livestock Feed Processing Centre, Lok Kawi (DVSAI). *Comparison: the results were obtained from samples collected on the grazing paddocks; the day refers to day before grazing.

Appendix 4.7 Feed conversion efficiency (FCE) of cut-and-carry Brahman, Bali and Droughtmaster feedlots at SPT Tawau, Sabah (2008–2013): (a) annual and (b) monthly.

(a) kg DM kg LWG^{-1}	08	09	10	11	12	13	$\overline{x}$	SD	CV %
Overall	25.3	21.4	20.4	25.3	22.8	29.1	24.1	3.2	13
Brahman	24.4	20.1	22.9	31.8	24.6	39.3	27.2	7.1	26
Bali	32.5	26.8	27.6	32.2	28.1	24.8	28.7	3.1	11
Droughtmaster	22.6	24.3	20.6	23.8	22.1	14.7	21.3	3.5	17

(b) kg DM kg LWG^{-1}	J	F	M	A	M	J	J	A	S	O	N	D	$\overline{x}$	SD	CV %
Overall	26.9	25.9	25.1	22.1	22.7	28.3	21.6	20.0	23.9	24.0	26.0	22.5	24.1	2.4	10
Brahman	37.6	34.1	28.8	26.5	25.0	27.0	22.7	23.1	23.7	23.3	27.8	26.4	27.2	4.6	17
Bali	25.9	28.5	30.9	28.0	29.5	37.2	21.1	24.1	36.4	25.9	25.2	31.2	28.7	4.8	17
Droughtmaster	19.6	24.4	19.3	15.4	19.9	27.4	20.1	14.3	18.1	27.8	30.2	19.6	21.3	5.0	23

Note that when data for the three feedlots were calculated altogether as single feedlot (overall), the FCE was slightly different because the combined kg LWG was different from that of each feedlot. LWG: liveweight gain.

Appendix 4.8 ME$_{LWL}$ (energy associated with weight loss as herbage equivalent) of cut-and-carry Brahman, Bali and Droughtmaster feedlots at SPT Tawau, Sabah (2008–2013): (a) annual and (b) monthly.

(a) **t DM ha^{-1} yr^{-1}**	08	09	10	11	12	13	$\bar{x}$	SD	CV %
Brahman	0.07	0.25	0.20	0.25	0.21	0.39	0.23	0.10	44
Bali	0.17	0.12	0.21	0.34	0.51	0.12	0.24	0.15	63
Droughtmaster	0.07	0.10	0.39	0.08	0.06	0.00	0.12	0.14	120

(b) **kg DM ha^{-1} d^{-1}**	J	F	M	A	M	J	J	A	S	O	N	D	$\bar{x}$	SD	CV %
Brahman	0.84	0.90	0.79	0.54	0.57	0.61	0.46	0.38	0.49	0.47	0.79	0.78	0.64	0.17	27
Bali	0.48	0.60	0.81	0.80	0.49	0.90	0.67	0.57	0.88	0.45	0.74	0.58	0.66	0.16	24
Droughtmaster	0.32	0.44	0.45	0.19	0.26	0.34	0.45	0.27	0.29	0.36	0.15	0.31	0.32	0.10	31

Sum of ME$_{LWL}$ (annual or monthly) of all feedlots is equal to the average ME$_{LWL}$ per ha (annual or monthly) of the cut-and-carry feedlot system because the feedlots shared the same cut-and-carry paddocks or effective area.

Appendix 5.1 Soil sample analyses

The samples were analysed for moisture content (%MC), pH, total nitrogen (TN), available phosphorus (AP), and exchangeable cations (potassium (K), calcium (Ca), and magnesium (Mg)). The protocols are described in Majalap and Chu (1992)[1]. Summary of the methods used are as follows.

(a) Sample preparation

The samples arrived in plastic bags in 4 batches at different times. All with grasses still firmly attached to the soils, indicating that they were sampled from grass lawns. The samples looked fresh and still moist. To make the work of separating the grasses from the soils a bit easier, the samples were transferred to trays and placed in a lab dryer (40ºC) to dry. Drying was maintained until the soil sample weights became quite consistent (about 5 days to a week depending on the initial conditions of the samples). The grass and roots were then removed and the dried soils ground with a porcelain mortar and pestle to pass through a 2-mm sieve. These were stored in plastic containers pending analysis. For the analysis of TN, a portion of each sample was further ground to pass through a 100-mesh (212-μm) sieve.

(b) Physical and chemical analyses

For the determination of moisture content, a subsample was taken from each sample and dried at 105ºC to constant weight. This step was used to adjust the sample dry weight to oven-dried weight. pH was measured using a pH meter with a combination glass-calomel electrode in a soil water suspension (1:2.5 ratio of soil to deionised water) after shaking overnight at 100 rpm on an orbital shaker followed by standing for 30 min (Landon 1984)[2]. To determine TN, the soil was digested following the Kjeldahl digestion method described by Bremmer (1965)[3] on a Labconco Rapidigest block digestor and the digest measured for nitrogen content on a Burkard SFA2 auto-analyser (UK). Extraction of soil available P followed the method of Bray and Kurtz (1945)[4] and the P contents in the extract were determined using the molybdenum-blue method described in Anderson and Ingram (1993)[5] and read at 880nm on the HITACHI UV-VIS spectrophotometer (Japan). For the determination of Ca, Mg, and K, the soil was leached with 1M ammonium acetate (Gillman et al. 1983, Thomas 1982)[6] [7] and the leachate analyzed for Ca, Mg and K on a GBC 932 atomic absorption spectrometer (Australia).

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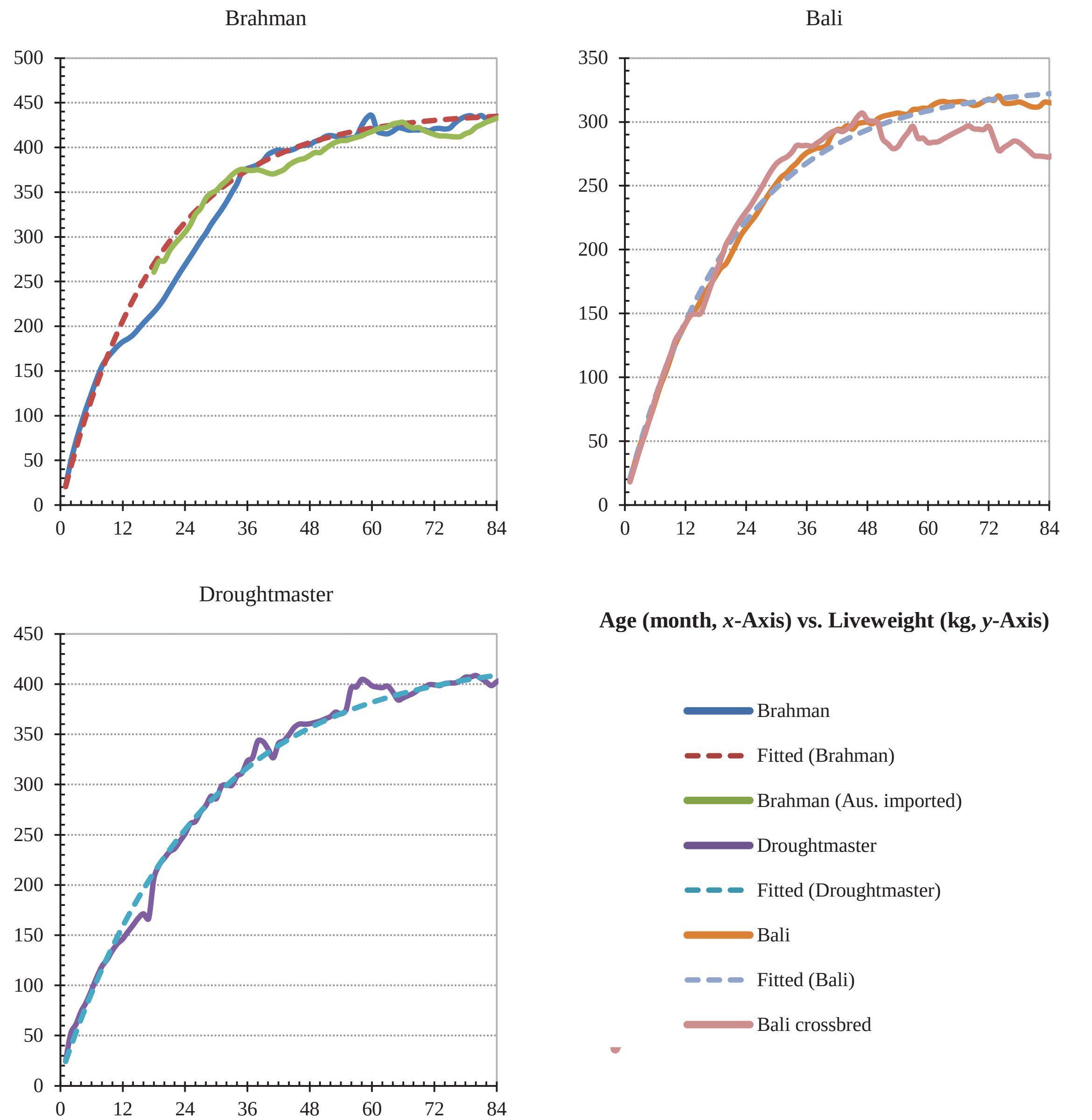
Appendix 5.2 Liveweight and age of Brahman, Droughtmaster and Bali cattle at SPT Tawau, Sabah at birth, weaning, mating and first calving (±SD).

	Brahman			**Droughtmaster**			**Bali**		
	Overall	Female	Male	Overall	Female	Male	Overall	Female	Male
Calf birth weight (kg)	20.3±2.0	20.2±2.2	20.4±1.9	23.1±4.5	23.1±4.1	23.0±4.7	17.5±1.6	17.6±1.6	17.5±1.5
Calf weight at dam mating (kg)	113.7±37.4	122.1±37.7	104.3±35.0	97.3±35.9	97.8±36.9	97.1±36.4	70.7±35.3	63.0±29.0	75.6±38.3
Calf age at dam mating (mo)	4.3±2.3	4.8±2.5	3.8±1.8	6.7±3.8	7.3±3.9	6.3±3.9	4.3±4.2	3.7±2.6	4.6±4.9
Calf weight at weaning (kg)	179.9±27.4	180.6±25.3	179.1±29.9	164.5±15.6	162.0±18.1	166.8±12.9	162.3±16.1	162.0±18.3	162.6±13.0
Calf age at 150 kg or weaning (mo)	7.7±1.0	7.9±1.1	7.5±0.8	10.2±2.2	10.7±3.0	9.8±1.0	11.0±2.0	12.1±2.1	10.0±1.3
Calf actual weight at 250 kg	256.6±6.0	255.7±5.4	257.7±6.5	259.4±9.9	261.6±11.4	257.2±9.3	255.5±5.8	253.6±3.6	257.3±6.5
Calf age at 250 kg (mo)	19.6±4.2	19.8±4.4	19.4±4.1	19.6±4.0	21.9±4.7	17.5±3.0	27.4±5.4	26.4±3.4	28.1±6.4
Heifer weight at first calving (kg)	420.3±59.9			445.1±53.0			302.2±38.1		
Heifer age at first calving (mo)	53.1±24.5			122.3±21.2			59.0±21.3		
Dam weight at calving (kg)	441.4±63.9			468.1±44.4			306.5±33.8		
Dam calving intervals (mo)	19.0±8.1			23.7±11.8			19.5±9.8		
Dam weight at mating (kg)	427.3±53.9	421.1±49.5[a]	434.4±58.2[b]	4443.6±40.8	455.0±52.3[a]	437.6±33.3[b]	306.9±32.6	298.3±26.6[a]	312.3±35.1[b]
Dam weight at calf weaning	411.8±60.2	413.5±58.5[a]	409.7±62.4[b]	467.4±50.9	469.7±53.1[a]	465.6±50.0[b]	303.8±44.0	301.6±42.1[a]	305.6±45.9[b]

[a] If the calf is female
[b] If the calf is male

Appendix 5.3 Samples of liveweight trajectories (kg mo^{-1}) of female cattle in grazing systems at SPT Tawau, Sabah.



Note: The cattle are weaned at 145–155 kg (decided by weight rather than by age). The weaning effect is indicated by the deviation of growth trajectory (starting at 145–155 kg liveweight) especially the Brahman cattle. The fitted growth curves are displayed for comparison. The average number of cattle observed per point (per month) to generate the growth data was 64 for Brahman, 73 for Bali, 9 for Bali crossbred, and 56 for Droughtmaster.

Appendix 5.4 Dry matter yield (±SD) of major grasses and nutritive value (±SD) of the species and feed supplement used as cattle feed at SPT Tawau and on other farms in Sabah.

	B. decumbens								
Day before grazing	14	1	*25^{DG}	*14^{TM}	*1^{TM}	*14^{EN}	*1^{EN}	*16^{CC}	*3^{CC}
Green DM (kg DM ha^{-1})	1715±206	1585±194	971±94	2428±139	1522±178	1703±228	2493±171	1151±54	1911±259
Leaf DM (kg DM ha^{-1})	1057±127	977±119	592±57	1657±95	1039±121	1162±156	1701±117	709±34	1177±160
Crude protein (N × 6.25%)	8.4±0.2	8.5±0.7	9.1±0.9	7.4±1.4	7.9±0.4	7.6±0.8	8.4±1.2	8.8±0.2	10.9±2.8
Energy (MJ ME/kg DM)	7.9±0.2	7.7±0.04	8.0±0.3	7.4±0.3	7.3±0.3	7.7±0.2	7.6±0.2	7.7±0.02	8.5±0.9
	P. maximum 'Guinea'		*D. milanjiana* 'Jarra'		*A. compressus*				
Day before grazing	14	1	14	1	7	1	*14^{TM}	*1^{TM}	
Green DM (kg DM ha^{-1})	762±262	1341±210	359±54	622±208	1275±141	1053±340	686±150	1038±132	
Leaf DM (kg DM ha^{-1})	463±160	816±128	218±33	378±127	776±86	641±207	468±103	709±90	
Crude protein (N × 6.25%)	12.0±1.4	13.7±0.1	15.3±1.9	12.1±1.1	11.8±0.9	11.2±0.8	10.6±1.5	11.7±2.9	
Energy (MJ ME kg DM^{-1})	8.5±0.0	8.9±0.0	7.6±0.1	7.0±0.4	8.7±0.4	7.5±0.3	8.5±0.2	8.4±0.4	
	S. sphacelata 'Kazungula'				PKC	*PKC Mixture			
Day before grazing	7	1	*14^{TM}	*1^{TM}					
Green DM (kg DM ha^{-1})	463.6±77	673.3±202	218±88	427±127	–	–			
Leaf DM (kg DM ha^{-1})	286±48	415±125	148±60	291±87	–	–			
Crude protein (N × 6.25%)	12.4±0.9	11.5±0.5	10.9±0.8	10.0±1.3	16.0±2.4	13.9±2.1			
Energy (MJ ME kg DM^{-1})	8.2±1.5	7.8±0.7	7.9±0.6	7.5±0.1	9.5±2.3	11.5±2.8			

*Comparison. The 14 d and 1 d before grazing are 14 d and 28 d after grazing, and the 7 d and 1 d before grazing are 7 d and 14 d after grazing, respectively.
[DG] 25 d after grazing was started and 3 d before grazing was completed. [TM] Samples from Timbang Menggaris farm at northwestern of Sabah. [EN] Samples from Entilibon farm at central of Sabah.

Appendix 6.1 Average lowest liveweight trajectories (kg mo^{-1}) of Brahman cattle on a government cattle breeding farm located near to 9OP1, 9OP2 and 12OP farms (OPIC farms).

Year	Month 0	1	2	3	4	5	6	7	8	9	10	11
Female												
1	18	32	45	58	71	83	94	106	116	127	137	146
2	155	164	173	181	189	197	204	211	218	225	231	238
3	243	249	255	260	265	270	275	279	284	288	292	296
4	300	303	307	310	314	317	320	323	326	328	331	333
5	336	338	340	343	345	347	349	351	352	354	356	357
6	359	360	362	363	365	366	367	368	369	371	372	373
7	374	375	376	376	377	378	379	380	380	381	382	383
Male												
1	18.5	30	41	52	63	74	84	94	104	114	123	133
2	142	150	159	168	176	184	192	200	207	215	222	229
3	236	243	250	256	263	269	275	281	287	292	298	304
4	309	314	319	324	329	334	339	343	348	352	356	361
5	365	369	373	377	380	384	388	391	395	398	401	405
6	408	411	414	417	420	422	425	428	431	433	436	438
7	441	443	445	448	450	452	454	456	458	460	462	464

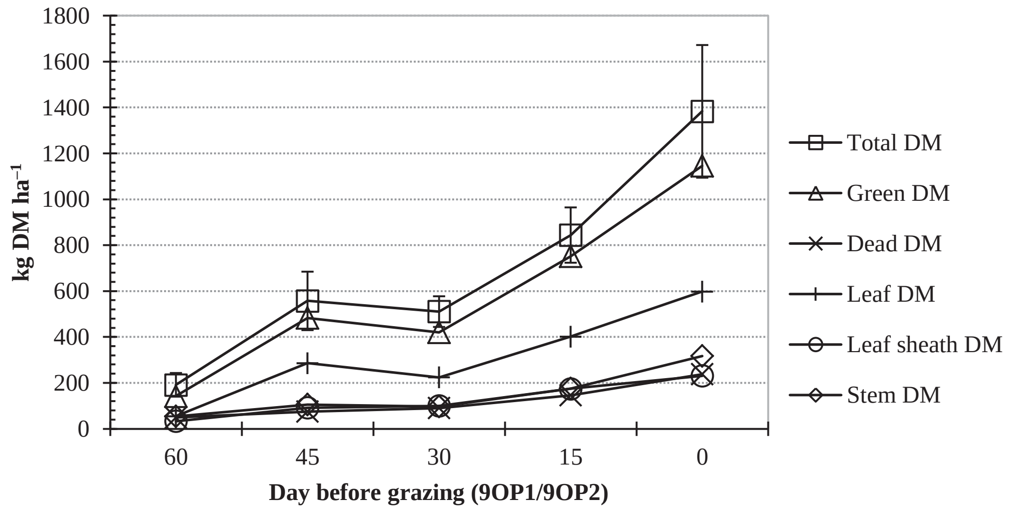
Growth for female is 391.2 g/hd/d from birth to 10 months old and 248.9 g/hd/d from 10 to 24 months old. It is 343.5 and 281.8 g/hd/d for male, respectively.

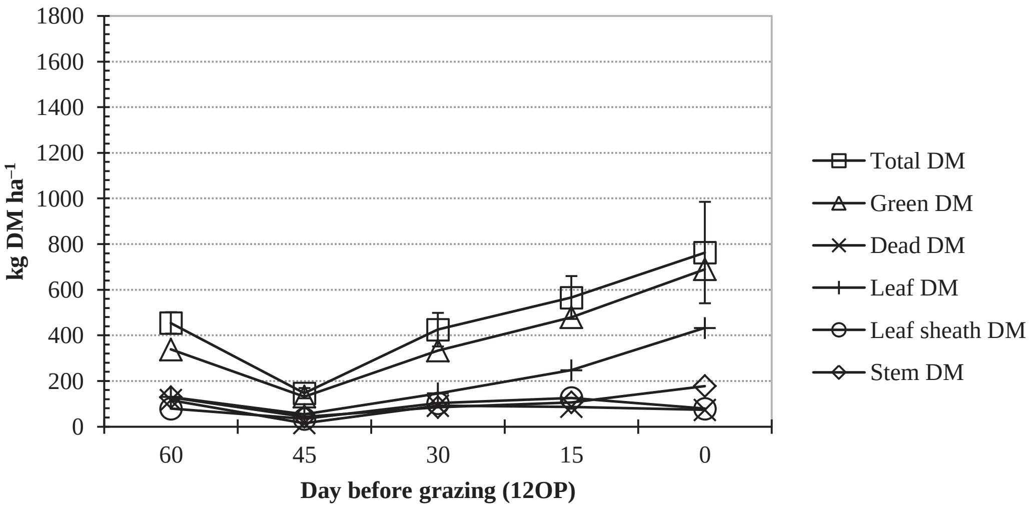
Appendix 6.2 Theoretical potential herbage production in 9 yr and 12 yr old oil palm plantations.

	Value used	Reference	Calculation	
			9 yr old	12 yr old
Daily Short-Wave (SW) radiation (daily energy input) in Sabah (MJ m^{-2} d^{-1})	15.87	Kartini et al. (2015)	15.87	15.87
% Light transmission through oil palm canopy	46 (30[A])	Dahlan et al. (1993)	15.87 × 0.46 = 7.3002	15.87 × 0.30 = 4.761
% Light capture of received light by herbage (average at 8 wk and 4 wk)	51.5	Figure 10 (Wilson and Ludlow, 1990)	7.3002 × 0.515 = 3.759603	4.761 × 0.515 = 2.451915)
% Photon Irradiance (PI) on herbage under shade (total light energy as PAR)	27	Baldocchi et al. (1984)	3.759603 × 0.27 = 1.01509	2.451915 × 0.27 = 0.66202
% PAR light energy conversion to herbage DM	3.5	Cooper (1970)	1.01509 × 0.035 = 0.0355282	0.66202 × 0.035 = 0.0231706
Herbage production a day (kg m^{-2} d^{-1})	18.4	GE, MJ/kg DM (CSIRO, 2007)	0.0355282/18.4 = 0.0019101	0.0231706/18.4 = 0.0012457
Overall production (t DM ha^{-1} yr^{-1})			0.0019101*3650[B] = 6.97	0.0012457*3650[B] = 4.55
Production on grazebale area (t DM ha^{-1} yr^{-1})	65%	Grazeable area: this study (Table 6.2)	6.97 × 0.65 = 4.53	4.55× 0.65 = 2.95
Production as leaf (t DM ha^{-1} yr^{-1})	54%	Leaf before grazing: this study (Table 6.5)	4.53 × 0.54 = 2.45	2.95 × 0.54 = 1.59

[A] For 12 yr oil palm plantation. PAR: photosynthetically active radiation. GE: gross energy. Method used was adapted from Wilson and Ludlow (1990) and Copper (1970). [B] (10^4 × 365/1000 = 3650)

Appendix 6.3 Herbage dry matter per ha on 9OP1, 9OP2 and 12OP farms (OPIC farms) every 15 days during a 60 d grazing interval.





Appendix 6.4 Ungrazed herbage around old manure in 9OP1 (9 yr old oil palm plantation), indicating grazing avoidance.

See red arrow.