Groundnut foliage as feed for Cambodian cattle

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Abstract

This thesis explored smallholder cattle production in Cambodia and investigated the nutritive value of groundnut (*Arachis hypogaea* L.) foliage and/or cassava (*Manihot esculenta*, Crantz) tops as protein supplementation for cattle production.

The majority of households surveyed kept 1-3 cattle and the most common cattle management system was grazing with supplementation. There was shortages in feed resources particularly during the dry season, when mainly rice straw and low quality natural pasture were available. The major constraint to cattle production in the agro-ecological zones of the Great Lake floodplain, Mekong floodplain and Coastal zone was found to be low breed quality, while diseases were identified as the main constraint in the Plateau/Mountainous zone.

Foliage from groundnut, left as crop residues, was examined for its potential as a protein supplement to a basal diet of rice straw and para grass for growing cattle. Increased levels of sun-dried groundnut foliage (DGF) improved total dry matter intake, crude protein digestibility and nitrogen retention in cattle. Daily weight gain was higher on the supplemented diets than on the control diet, but did not differ among levels of supplementation. Supplementation of DGF at levels of 2 or 3 g crude protein per kg body weight increased microbial protein production and the efficiency in microbial crude protein production in cattle.

Responses in rumen fermentation characteristics were investigated in adult cattle using dried cassava tops (DCT) alone or in combination with DGF as a protein supplement to a basal diet of rice straw and para grass. Total dry matter intake increased when animals received diets containing DGF or DGF combined with DCT. However, the diet containing DCT had the lowest digestibility of crude protein and neutral detergent fibre. The ruminal ammonia nitrogen and total volatile fatty acid response increased with all diets containing supplements.

Keywords: apparent digestibility, ammonia nitrogen, daily weight gain, feed intake, microbial crude protein, smallholder cattle production, volatile fatty acids.

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ដើមសណ្តែកដី ប្រើជាចំណីគោ នៅក្នុងប្រទេសកម្ពុជា

សង្ខេបសារណា

និក្ខេបបទនេះ បានធ្វើការស្រាវជ្រាវលើការចិញ្ចឹមគោខ្នាតតូច (ជាលក្ខណៈគ្រួសារ) នៅក្នុងប្រទេសកម្ពុជា និងធ្វើការវាយតម្លៃទៅលើជីវជាតិរបស់ដើមសណ្តែកដីស្ងួត (*Arachis hypogaea* L.) និងចុងដំឡូងមីស្ងួត (*Manihot esculenta*, Crantz) ដើម្បីប្រើជាចំណីបន្ថែមប្រូតេអ៊ីន នៅក្នុងការចិញ្ចឹមគោ។

ភាគច្រើននៃគ្រួសារនៅក្នុងការអង្កេតតាមផ្ទះ មានចិញ្ចឹមគោ ពី ១ ទៅ ៣ក្បាល ហើយប្រព័ន្ធនៃការចិញ្ចឹមដែលអនុវត្តជាទូទៅ គឺការព្រលែងឱ្យដើរស៊ីតាមទីវាល និងផ្តល់ចំណីបន្ថែមនៅពេលត្រឡប់មកផ្ទះវិញ។ កង្វះប្រភពចំណីតែងកើតមាន ជាពិសេសនៅរដូវប្រាំង ដែលនៅពេលនោះមានតែចំបើង និងស្មៅ ដែលមិនសូវសំបូរជីវជាតិ។ ឧបសគ្គចម្បងសំរាប់ការចិញ្ចឹមគោនៃតំបន់ក្បែរត្របរិស្ថាន នៅក្នុងតំបន់លិចទឹកនៃបឹងទន្លេសាប, តំបន់លិចទឹកនៃទន្លេមេគង្គ និងតំបន់ឆ្នេរ ត្រូវបានរកឃើញថាមានការខ្វះខាតពូជល្អៗ ខណៈដែលជំងឺ ត្រូវបានកំណត់ថាជាឧបសគ្គចម្បងនៅក្នុងតំបន់ខ្ពង់រាប និងតំបន់ភ្នំ។

ដើមសណ្តែកដី ដែលនៅសល់ពីការប្រមូលផលគ្រាប់ ត្រូវបានគេពិនិត្យឃើញពីសក្តានុពល ដែលអាចប្រើប្រាស់ជាចំណីបន្ថែមប្រូតេអ៊ីន ទៅលើរបបចំណីគ្រឹះដែលមានចំបើងនិងស្មៅ សម្រាប់ការលូតលាស់របស់សត្វគោ។ ការបង្កើនបរិមាណដើមសណ្តែកដីស្ងួត (DGF) នៅក្នុងរបបចំណី បានជួយបង្កើនបរិមាណចំណីស៊ីចូលសរុបគិតជារូបជាតុស្ងួត បរិមាណប្រូតេអ៊ីន លទ្ធភាពរំលាយ និងការរក្សាទុកអាសូត នៅលើសត្វគោ។ កំនើនទម្ងន់ប្រចាំថ្ងៃ មានការកើនឡើងចំពោះគោដែលបានផ្តល់របបចំណីបន្ថែម គឺខ្ពស់ជាងគោដែលមិនមានផ្តល់ដើមសណ្តែកដីស្ងួត ប៉ុន្តែកំនើននេះ មិនមានភាពខុសគ្នាទៀតទេ ទៅតាមកម្រិតផ្សេងៗនៃបរិមាណចំណីដែលបន្ថែមនោះ។ ការបន្ថែមប្រូតេអ៊ីនពី DGF នៅកម្រិត ២ ឬ ៣ ក្រាមក្នុង ១ គីឡូក្រាម នៃទម្ងន់ខ្លួន បានបង្កើនការផលិតប្រូតេអ៊ីនពីអតិសុខុមប្រាណ និងបង្កើនប្រសិទ្ធភាពក្នុងការផលិតប្រូតេអ៊ីនពីអតិសុខុមប្រាណ នៃសត្វគោ។

ការឆ្លើយតបលើលក្ខណៈនៃល្បើងនៅក្នុងក្រពះសត្វទំពារអៀង ត្រូវបានវាស់វែងតាមរយៈការអង្កេតនៅលើសត្វគោ ដោយប្រើប្រាស់ចុងដំឡូងមីស្ងួត (DCT) តែឯង ឬផ្សំជាមួយ DGF ជាចំណីបន្ថែមប្រូតេអ៊ីន លើរបបចំណីគ្រឹះ ដែលប្រើចំបើង និងស្មៅ។ ចំណីស៊ីចូលសរុបគិតជារូបជាតុស្ងួត មានការកើនឡើងនៅពេលដែលសត្វទទួលបានរបបចំណីដែលមាន DGF ឬ DGF ជាមួយនឹង DCT។ ទោះជាយ៉ាងណាក៏ដោយ របបចំណីដែលមាន DCT មានលទ្ធភាពរំលាយប្រូតេអ៊ី-ន និងជាតិសសៃ NDF ទាបបំផុត។ អាម៉ូញាក់នៃអាសូតនៅក្នុងក្រពះ និងអាស៊ីតខ្លាញ់ល្បើងសរុបក្នុងក្រពះ មានការកើនឡើងលើគ្រប់របបចំណីដែលមានចំណីបន្ថែម។

ពាក្យគន្លឹះ: ការរំលាយជាក់ស្តែង, អាម៉ូញាក់នៃអាសូត, កំនើនទម្ងន់ប្រចាំថ្ងៃ, ចំណីដែលសត្វស៊ីចូល, ប្រូតេអ៊ីនពីអតិ-សុខុមប្រាណ, ការចិញ្ចឹមគោខ្នាតតូច, អាស៊ីតខ្លាញ់ល្បើង។

អាសយដ្ឋានអ្នកនិពន្ធ: ប៉ុក សំកុល, មជ្ឈមណ្ឌលអភិវឌ្ឍន៍ការចិញ្ចឹមសត្វ និងកសិកម្ម (សែលអាហ្វ្រិត), ភ្នំពេញ, កម្ពុ-ជា។ ប្រអប់សំបុត្រ ២៤២៣, ភ្នំពេញ ៣, ប្រទេសកម្ពុជា។

Dedication

To my parents, my wife Sokerya and my sons Sopheanupong and Sopheavisothanak

It always seems impossible until it’s done.
Nelson Mandela

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Samkol, P.*, Sath, K., Patel, M., Windsor, P.A. & Holtenius, K. (2015). Survey of smallholder beef cattle production systems in different agro-ecological zones of Cambodia. *Tropical Animal Health and Production,* 47 (7), pp. 1299-1306.

II Samkol, P.*, Sath, K., Patel, M. & Holtenius, K. (2017). Effects of supplementing different levels of sun-dried groundnut foliage on intake, apparent digestibility and nitrogen metabolism in cattle offered a basal diet of a mixture of rice straw and para grass. *Tropical Animal Health and Production,* 49 (7), pp. 1495-1501.

III Samkol, P.*, Sath, K., Patel, M., Seng, M. & Holtenius, K. Effects of supplementing low quality hay with groundnut foliage and/or cassava tops on feed intake, apparent digestibility and rumen fermentation in crossbred cattle (submitted manuscript)

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* Corresponding author.

The contribution of Pok Samkol to the papers included in this thesis was as follows:

I Formulated some of the research questions, led the research team, was involved in data collection, analysed samples, performed data analyses and wrote the manuscript.

II Planned/prepared the experiment, collected and analysed samples, performed data analyses and wrote the manuscript.

III Planned/prepared the experiment, collected and analysed samples, performed data analyses and wrote the manuscript.

1 Introduction

1.1 Cambodia economy and its growth

Cambodia is situated in Southeast Asia and is the 90^{th} largest nation in the world, with a total area of 181,035 km^2. The country borders Thailand and Laos in the north, Vietnam in the east and southeast and the Gulf of Thailand and mainland Thailand in the west. The climate is monsoonal, with two distinct seasons, a dry season and a wet season. The wet season is usually from May-October, with clouds that bring 75-80% of the annual rainfall, while the dry season is from November-April. January is the coldest month, while April is the warmest. Cambodia is among the poorest countries in the world and long-term economic development remains a challenge due to endemic corruption, limited educational opportunities, income inequality and poor job prospects (CIA, 2017). The population is 15.8 million and it is estimated that about 4 million people live under the poverty line (earn less than USD 1.25 daily) and that 37% of children under 5 years of age suffer from chronic malnutrition (CIA, 2017).

Agriculture, including sub-sectors such as cropping, livestock, forestry and fisheries, is one of the most important sectors, since the majority of the population lives and works in rural areas, with the poverty rate being high and food security status low among the rural poor and landless (Sothorn *et al.*, 2011). However, recent economic growth has reduced the relative contribution of agriculture to Gross Domestic Product (GDP) compared with industry and services (MEF, 2016).

The agriculture sector occupied around 56% of the total employed labour force in 2007 and labour productivity improved by 2% from 1998-2008 (WB, 2009). When the forestry and fisheries sub-sectors are included, agriculture represents the largest employer in Cambodia, with a total of about 4.5 million workers. Among agricultural products, crops represented the largest share of GDP in 2012, followed by fisheries, livestock and forestry (MAFF, 2013) (Figure 1).

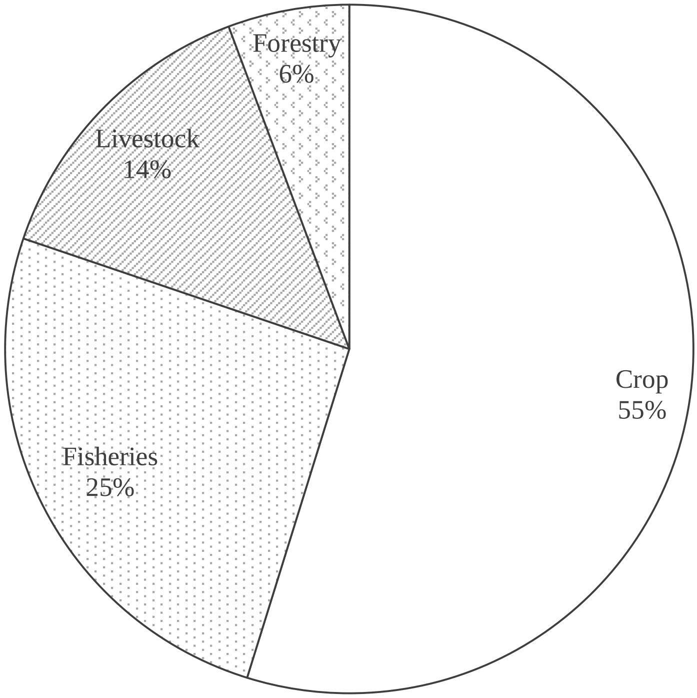

Figure 1. Relative share of gross domestic product (GDP) contributed by different sub-sectors within agriculture in Cambodia, 2012 (MAFF, 2013).

1.2 National policy to support livestock production

The government of Cambodia has decided on a national policy to support livestock production, since it is a strategic step in improving the food security and income of smallholder farmers. This policy covers four types of improvement in the agriculture sector: (i) improved productivity, diversification and commercialisation, (ii) promotion of livestock farming and aquaculture, (iii) land reform and clearance of mines and unexploded ordnance and (iv) sustainable management of natural resources (RCG, 2013). The policy aims to enhance the livelihood of smallholder livestock keepers, where their income and food security are regarded as crucial. The importance of providing a safe and efficient supply of animal products to consumers in urban areas and of exploring potential export markets is also highlighted. Thus, increased growth of the agricultural sector, particularly in livestock, is seen as the key to alleviating the poverty of the rural poor and landless in Cambodia. The government aims to promote livestock farming through increasing production and promoting value chain principles (MAFF, 2015a).

The General Directorate of Animal Health and Production for Cambodia has the goal of strengthening animal health and production services in order to reduce the impact of animal diseases, increase animal production and enhance safe trade (MAFF, 2015b). To control diseases, training programmes for village animal health workers (VAHWs) and private veterinary service operations have been established and animal vaccination programmes have been implemented, with special consideration of smallholder livestock keepers. So far, more than 13,000 VAHWs have been trained to provide animal health advice, monitoring, treatment and vaccination in their respective villages (MAFF, 2013).

1.3 Smallholder cattle production

Cambodia is divided into four agro-ecological zones (AEZs): The Great Lake floodplain (AEZ1), the Mekong floodplain (AEZ2), the Coastal zone (AEZ3) and the Plateau/Mountainous zone (AEZ4) (Phirum *et al.*, 2014) (Figure 2). There are two basic forms of cattle production in Cambodia, lowland and upland production systems, and both are constrained by feed shortages. In lowland areas (AEZ1-3), the land is dominated by rice crops, which imposes significant constraints on the supply of feed for animals. Although there is more land available in upland areas (AEZ4), most of this land is not accessible for cattle production, since the government has ceded it to private companies for development (Harding *et al.*, 2007). The severity of animal feed shortages varies between AEZs, but poor animal nutrition is a general problem. Poor nutrition contributes to a higher incidence of cattle diseases and higher parasite burdens. The major diseases that affect cattle in the region are haemorrhagic septicaemia, foot & mouth disease and blackleg. Other major health problems experienced are internal parasites, ticks and flies (Soun *et al.*, 2006). Apart from health problems, poor nutrition also hampers weight gain, impairs draught performance, reduces fertility and lowers milk production (Copeman & Copland, 2008).

The contribution of cattle to farm income differs between different types of farms. Animals are kept for savings and for maintaining household security by providing emergency finance. Cattle are also used as source of draught power and income and as a form of wealth. The wastes from the animals, *i.e.* manure and urine, are beneficial for rural households, since they mean that less fuels and fertilisers are required to support household and farming operations and that dependency on chemical fertilisers is reduced. These integrated farming systems are common among smallholder families and they contribute to the sustainability of farming operations and minimise the economic risk (Lukefahr & Preston, 1999).

The cattle population in Cambodia has declined slightly in recent decades, from 3.46 million head in 2008 to 3.38 million head in 2012 (MAFF, 2013). This decline is due to a reduction in the use of cattle for draught purposes with the introduction of machinery for land preparation and transportation (Maclean, 1998). The average number of cattle kept by households in Cambodia is 2.89 head (Ashley *et al.*, 2018). The Local Yellow is the most common breed, while other major breeds are Haryana and Brahman (Harding *et al.*, 2007). According to Soun (2003), Haryana cattle were introduced to Cambodia from India in the 1960s, while the Brahman breed was brought in from the Philippines during the 1980s, although its original source was India. Haryana animals are tall and narrow-shouldered, and are therefore good walkers and popular among farmers for draught purposes. Households favour crossbreeds with the local breed due to their good appearance, better draught performance, good walking ability and high market price. Haryana x Local Yellow crossbreed cattle are mainly found in the Mekong floodplain area, where water is available to supply crop production, since they have better draught capacity for farm operations and since crop residues are available as feed. However, proper genetic improvement programmes are lacking, since natural breeding is widely practised by smallholder cattle keepers (Harding *et al.*, 2007).

1.4 Utilisation of local resources as feed for cattle

There is potential to improve the growth and reproductive performance of cattle in Cambodia, leading to a significant economic return if feeds can be used more efficiently (Devendra & Leng, 2011). However, the availability of feeds differs across the AEZs, due to seasonality and land use for crops, which is mostly dependent on market demand (Sath, 2012).

Feed for cattle is based largely on the use of rice straw and other crop residues, in addition to grasses, weeds and shrubs. The feed supply is strongly affected by seasonal availability. In the wet season, cattle are tethered close to the household and fed rice straw supplemented with cut-and-carry native grasses. During the dry season, cut-and-carry grasses are in short supply and cattle are brought to fields and native pastures for grazing during extended periods of time (Sath *et al.*, 2008). Other supplementary feed resources are given at different times of the year. These include forage legumes (*e.g.* groundnut, *Arachis hypogaea* L.), cassava (*Manihot esculenta*, Crantz), leucaena (*Leucaena leucocephala*), rice (*Oryza sativa*) bran, maize (*Zea mays*) stover and banana (*Musa* spp.) stems.

1.4.1 Natural pasture grass

In Cambodia, pasture covers 315,000 hectare (ha) of the land area. The largest natural grasslands are found in AEZ1, where the carrying capacity is about 2.5 adult oxen per ha (Devendra *et al.*, 1997). Weeds and grasses along the roadside, wasteland and fallow cropping land are resources that ruminant keepers usually allow their herds to graze, or plant material can be collected as cut-and-carry for stall feeding. Serey *et al.* (2014) report that most cattle keepers rely mainly on pasture grasses and that the cut-and-carry system is the most common practice almost all year round, with a peak in July-September. The quality (digestible energy, nitrogen (N), mineral content) of grass is considered to be suitable for cattle in the wet season, but the quantity decreases during the dry season due to water shortage (Pen *et al.*, 2013). Thus animals display reduced body weight and compromised reproductive performance during the dry season. Sokerya *et al.* (2007) report that in the dry season grazing cattle lose about 150 g of body weight per day, while Young *et al.* (2014) claim that all types of cattle in Cambodia grazing low quality pasture grass during the dry season have a body score of 'thin'.

1.4.2 Rice straw

Rice straw, a residue from rice production, is used as a feed resource for cattle in Cambodia. About 80% of the Cambodian rural population cultivates rice as their main crop and rice straw is widely used as the basal diet of animals in Southeast Asian countries (Devendra *et al.*, 1997). However, rice straw does not supply enough nutrients, as it has a low crude protein (CP) concentration and a high fibre content. Feeding urea-treated straw supplemented with foliage legumes has been shown to give promising results, as it improves feed intake, apparent digestibility and thus daily weight gain of the animals (Wanapat *et al.*, 2009; Hue *et al.*, 2008; Khang & Wiktorsson, 2006). However, Sath (2012) pointed out that adoption of the technique of treating straw with urea is low due to (i) the cost and availability of urea and the complexity of the treatment process, (ii) lack of knowledge and an appropriate place for treating straw, (iii) lack of labour to perform the work and (iv) lack of capital to invest.

1.4.3 Forage legumes

Forage legumes contain substantial amounts of cell wall contents and are therefore suitable for feeding cattle, due to the capacity of ruminants for microbial digestion of complex carbohydrate fibres (Wilkins, 2000). Furthermore, legumes generally have a relatively high protein content and therefore have great potential to overcome limitations in protein supply. The relatively low rumen solubility of the protein fractions in legumes might confer a further advantage in ruminant feeding, since more of the protein fraction would bypass the rumen and reach the small intestine (Thang, 2010). Protein is generally a limiting nutrient for the growth of young animals and for milk production in the tropical region (Minson, 1990). It has been suggested that an appropriate approach for smallholder farms is to grow legume plants that allow higher yields of protein in the form of leaf biomass as components of their farming systems (Pound *et al.*, 1972). Strategies to efficiently utilise these less conventional feeds are more likely to succeed when the production system matches available local feed resources (Preston & Leng, 1987).

Some legumes contain anti-nutritional substances such as hydrogen cyanide and tannins that reduce voluntary feed intake and apparent digestibility, which limits their use. However, the content of hydrogen cyanide in legume-based material can be reduced by sun-drying (Promkot *et al.*, 2007) or ensiling (Sokerya *et al.*, 2009). Tannins in the feed are reported to decrease voluntary feed intake (Kumar & D'Mello, 1995) and may inhibit the activity of microbial enzymes, resulting in a reduction in ruminal turnover and digestion rate (McDonald *et al.*, 2002; Salawu, 1997). However, feed that contains 2-4% tannins in dry matter (DM) intake appears to be beneficial for host animals, as it protects the protein from microbial attack in the rumen and it thereby passes on to the small intestine (Barry *et al.*, 1986).

In Cambodia, about 8.5 million tonnes of cassava, 0.16 million tonnes of soybean and 0.14 million tonnes of groundnut were produced in 2014 (FAO, 2018). Groundnut is a legume crop that is grown primarily for oilseed production and groundnut foliage has potential to be a valuable feed supplement for cattle, as it is rich in CP (100-180 g/kg DM) and has high organic matter (OM) digestibility (660-770 g/kg) in sheep (Blümmel *et al.*, 2005). When groundnut foliage was used in a study to replace wheat straw in the diet of sheep, it was found that feed intake, apparent digestibility and N retention increased (Khan *et al.*, 2013). Foster *et al.* (2009) showed that DM intake, digestibility and daily microbial N synthesis in sheep fed groundnut hay are similar to those in sheep fed diets containing soybean meal. Cassava foliage is also rich in protein and it is used as a feed supplement for cattle in Cambodia (Sath *et al.*, 2012; Sokerya *et al.*, 2007). Inclusion of sun-dried cassava foliage with straw and grass as the basal diet has been shown to improve feed intake, N retention and body weight of growing cattle, but to decrease digestibility when included at higher levels (Sath *et al.*, 2012).

1.5 Feed intake and digestibility in cattle

Feed intake and digestibility in ruminants are limited by a number of factors: (i) feed factors such as fibre content and inhibitors and (ii) animal factors such as physiological state and sensitivity to feed palatability (Baile & Della-Fera, 1981).

Plant cell walls, which are composed of structural carbohydrates and lignin, constitute a large percentage (35-80%) of plant OM (Jung & Allen, 1995). The cell walls provide structural integrity to the plant and the cell wall content generally increases with increased plant maturity (for reference see Van Soest, 1994). The rumen allows for utilisation of forages through a symbiotic relationship with microorganisms that are able to ferment the polysaccharides in plant cell walls, which are not amenable to mammalian enzymatic hydrolysis (Hungate, 1966). The cell wall content is negatively related to intake by contributing to ruminal fill, since it is slowly degradable and thus passes slowly from the reticulorumen. The relatively low digestibility of the fibre fraction contributes to a general reduction in DM digestibility of high forage diets (Harper & McNeill, 2015). Forage contains stems and leaves, with the stems having lower digestibility than the leaves due to their high proportion of cell wall constituents (Joshi *et al.*, 2010). Lignin is virtually indigestible even for rumen microorganisms (Van Soest, 1994). The lignin content is generally higher in legumes than in grasses (Allen & Mertens, 1988). Another factor reducing intake and digestibility is the content of anti-nutritional compounds such as tannins, as mentioned above.

An adequate level of ammonia nitrogen (NH_3-N) in the rumen to supply N for microbial growth is considered to be crucial for optimal forage digestion by ruminant livestock. The minimum level of ruminal fluid NH_3-N for optimum intake of forage with a low N content and low digestibility in cattle is 200 mg/L, due to the high fibre fraction of the forage (Krebs & Leng, 1984). Silva & Ørskov (1988) showed that when the level of NH_3-N in the rumen is below 200 mg/L, the degradability of barley straw is negatively affected. It is well known that growth of microbial cells in the rumen requires fermentable carbohydrates and N compounds for synthesis of protein and vitamins (Van Soest, 1994).

1.6 Aims of the thesis

The overall objectives of this thesis were to achieve a better understanding of smallholder beef cattle production systems in Cambodia and to investigate the nutritive value of groundnut foliage as a protein supplement in cattle production in Cambodia.

Specific objectives were:

- To better understand the diversity of farm production and the extent to which it contributes to rural household incomes, and to document differences in production systems, feeding practices and constraints to smallholder beef cattle productivity in the different AEZs in Cambodia.

- To evaluate the effects of different levels of dried groundnut foliage inclusion in a basal diet comprising a mixture of rice straw and para grass on feed intake, apparent digestibility, N balance and microbial CP production in growing Cambodian Local Yellow cattle.

- To evaluate the effects on feed intake, apparent digestibility and rumen fermentation characteristics in crossbred cattle fed dried groundnut foliage and/or dried cassava tops to cattle as supplements to diets based on rice straw and para grass.

2 Summary of materials and methods

2.1 Location of the experiments

In Paper I, a survey was conducted in each of the four AEZs in Cambodia. AEZ1-3 have the potential to use crop residues for cattle production, while AEZ4 is sparsely populated and poverty rates are high, but there is potential for cattle production due to availability of forest land and pasture for grazing. Four villages were selected in each of the four provinces of Battambang, Takeo, Kampot and Kampong Speu, representing AEZ1, AEZ2, AEZ3 and AEZ4, respectively (Figure 2). Selection of the villages was based on the following criteria: (i) at least 50% of households kept cattle, (ii) households kept cattle the whole year round and (iii) there was potential to produce agricultural products and by-products suitable for cattle diets.

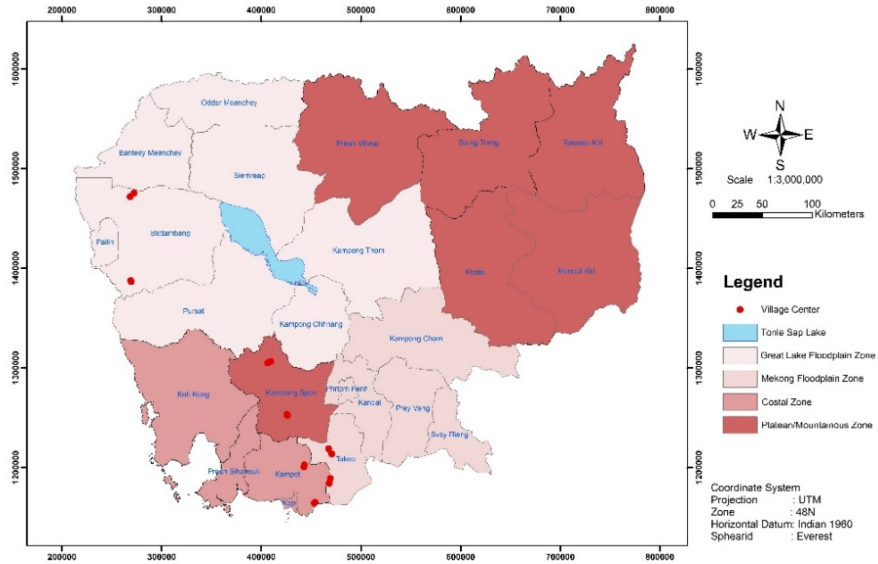

Figure 2. Map of Cambodia showing the main lake Tonle Sap, the four different agro-ecological zones (AEZ, see key) and their constituent provinces and villages selected for the survey (red dots) (ArcGIS).

The study examining the effects of supplementing the diet of cattle with different levels of dried groundnut foliage (Paper II) was carried out at the research farm of the Centre for Livestock and Agriculture Development (CelAgrid). The farm is situated in Phnom Penh (104°53'E; 11°26'N). The minimum and maximum temperature during the study period was 22 °C and 35 °C, respectively, and the minimum and maximum humidity was 44% and 96%, respectively.

The study described in Paper III was performed at the research farm of the Royal University of Agriculture (RUA), located in Phnom Penh. The minimum and maximum temperature during the study period was 20.5 °C and 34.5 °C and the minimum and maximum humidity was 54.0% and 92.5%, respectively.

2.2 Experimental design

In Paper I, 360 households (90 in each AEZ) were interviewed following random selection from a list of smallholder beef cattle keepers provided by village chiefs and VAHWs. The interviews were conducted during April-May 2014. The village representatives were informed about the purpose of the survey and assured that their participation was voluntary and that their identity would be kept confidential. A semi-structured questionnaire was used to interview the household members who take care of the animals. An interview team, comprised of CelAgrid researchers and undergraduate students at RUA, met with representatives from the Office of Animal Health and Production at district and provincial levels and from local authorities.

In Paper II, eight Local Yellow male growing cattle were randomly allocated to a double 4 × 4 Latin square design with four dietary treatments and four periods. The cattle were housed individually in metabolism crates, allowing total urine and faeces collection (Figure 3). Each period consisted of 21 days, including 14 days for adaptation and seven days during which feed refusals, faeces and urine excretion were quantitatively collected.

In Paper III, four adult male crossbred cattle, fitted with rumen fistulas in the dorsal sac, were used in the experiment. The animals were randomly allocated to a single 4 × 4 Latin square design with four dietary treatments and four periods. The cattle were housed individually in pens in a roof-covered area with a concrete floor. Each period consisted of 22 days, including 14 days for adaptation and eight days for sample collection and an in *sacco* study.

Figure 3. Animal confined in metabolism crate for total collection of faeces and urine.

2.3 Feeds and feeding

In Papers II and III, all cattle were offered a basal diet of rice straw *ad libitum* and para grass at a level of 1% of body weight. Fresh water was always freely available during the experiments. In Paper II, the four treatments comprised supplementation with dried groundnut foliage (DGF) at different levels: 0, 1, 2 and 3 g CP per kg body weight, denoted DGF0, DGF1, DGF2 and DGF3, respectively. In Paper III, the four treatments were: (1) Control without supplement, (2) DGF, (3) dried cassava tops (DCT) and (4) DGF+DCT. The supplementary feeds were fed to a level of 2 g CP per kg body weight in treatments (2) and (3) and 1 g CP of each feed per kg body weight in treatment (4).

The rice straw, grown during the dry season, was harvested, dried for 3-5 days and stored in a shed. The para grass was grown as a monoculture, harvested daily and on the next day chopped into 30-40 cm lengths prior to feeding. Groundnut foliage was collected after the groundnuts were harvested, sun-dried for 3-4 days and then chopped into 5-10 cm lengths before storage in hay bags under a roof. In Paper III, cassava foliage was collected at the time of cassava root harvest and the tops were cut to a length of one-quarter of the plant, sun-dried for 3-4 days and chopped to 3-4 cm length. In Paper II, groundnut foliage was fed at 09:00 h and thereafter rice straw and para grass were offered at 17:00 h and 20:00 h, whereas in Paper III all feeds were fed at the same time by dividing them into two equal daily rations offered to the animals at 08:00 h and 16:00 h.

2.4 Data collection

In Paper I, smallholder cattle keepers were questioned about (i) livelihood activities relating to ways to generate income for the households and (ii) cattle production in terms of management system, herd size and composition, breed, feed resources, vaccination, disease outbreaks and constraints. Furthermore, households were asked to rank their various sources of income. Cattle were evaluated for body condition score, recorded on a 1-4 scale, in July-August, 2014. Furthermore, four common types of feeds used for cattle nutrition in all AEZs were collected for determination of nutrient composition. All feeds were collected during feeding of cattle and from three different areas in each AEZ, then chopped, placed in plastic bags and frozen at -20 °C until analysed.

The cattle were weighed in the morning before feeding on two consecutive days at the beginning and the end of each experimental period in Paper II, while in Paper III the animals were weighed at day 1 and day 19. In Paper II, the amounts of feed offered and refused and excretion of faeces and urine were recorded daily. Subsamples of feed offered, feed refused and faeces from each animal were collected daily and kept in plastic bags at -20 °C.

Urine was collected in a plastic bucket containing 250 mL of 10% H_2SO_4 in order to keep the pH below 3.0 (Paper II). The daily urine output was recorded and a 50 mL subsample was stored at -20 °C for seven days prior to total N analysis. The remaining urine was diluted with tap water to a final weight of 20 kg (IAEA, 1997). Subsamples of 100 mL were stored at -20 °C for seven days before analysis of allantoin. The purine derivatives and microbial CP were calculated based on the relationship derived by IAEA (1997).

In Paper III, the amounts of feed offered and refused each day were weighed and recorded from day 15 to day 19. Subsamples were stored in plastic bags at -20 °C in each period. Faeces samples were taken directly from the rectum every morning and evening and stored at -20 °C. On day 20 in each period, fluid was obtained from the ventral sac of the rumen, using a syringe and a tube. Samples of 200 mL were withdrawn at 0, 2, 4 and 6 h post-feeding and transferred to McCartney bottles containing 0.3 mL of 18 M H_2SO_4 to stop the fermentation process. The samples were stored at -20 °C pending analysis for NH_3-N and volatile fatty acids (VFA) concentrations. Starting immediately after collection, rumen fluid pH was measured at 0, 1, 2, 3, 4, 6 and 8 h post feeding with a pH meter (ECpH6, Eutech Instruments Pty Ltd, Singapore).

Dry matter, CP and NDF disappearance were estimated using the nylon bag technique (Ørskov *et al.*, 1980) during the last 2 days of each period (Paper III). Sun-dried para grass was milled to pass through a 2-mm screen and 1.5 g of sample was put in each bag. The samples were removed after 2, 4, 8, 16, 24 or 48 h. After removal, the bags were placed in bucket of cold water to stop fermentation and to wash off feed particles on the outside of the bags and then stored at -20 °C. At the end of all removal times, sample bags were thawed and washed in a domestic washing machine. Thereafter the bags were dried in a fan-forced oven to a constant weight at 65 °C and re-weighed. The residues in each bag were analysed for CP and NDF. The degradation at different time intervals was described by fitting DM, CP and NDF loss values to an exponential equation (Ørskov & McDonald, 1979), while the effective degradability of DM, CP and NDF was calculated as proposed by Yáñez-Ruiz *et al.* (2004).

2.5 Sample analyses

Dry matter analysis was performed by oven-drying at 70 °C for 48 h (Paper I; Pen *et al.*, 2013) and at 105 °C for 16 h (Papers II and III; AOAC, 1990). Analysis of N was performed by the Kjeldahl digestion method and ash content was determined by combustion in a muffle furnace at 550 °C for 4.5 h (Paper I) and at 600 °C for 2 h (Papers II and III) according to AOAC (1990). The crude protein content was calculated as N × 6.25 and the OM content as 100 - % ash. Analysis of NDF was performed using the method previously described for Paper I (AOAC, 1990) and Paper III (Goering & Van Soest, 1970). In Paper II, acid detergent fibre (ADF) analysis was performed according to the procedure of Goering & Van Soest (1970) and allantoin concentration in the urine samples was determined on a spectrophotometer using colorimetry as described by Young & Conway (1942). In Paper III, digestibilities were estimated based on acid insoluble ash (AIA) in feed and faeces samples, as described by Van Keulen & Young (1977). The ammonia nitrogen concentration in rumen fluid was analysed using Kjeldahl distillation (Wagner, 1940). Samples for VFA determination were analysed using high-pressure liquid chromatography (HPLC) according to the method of Andersson & Hedlund (1983).

2.6 Statistical analyses

The statistical analyses in Papers I and II were performed using MINITAB 16.1.1 (Minitab, 2010). In Paper I, data on animal herd size, type and breed, nutrient composition of the feeds and body condition score variables were analysed by the analysis of variance (ANOVA) part of the general linear model (GLM) procedure. Information on livelihood activities, management system and feed resources was managed by cross-tabulation analysis. An ordinal regression was used to estimate the significance level ($P<0.01$) of the mean ranks of different income sources of households. Furthermore, an index was calculated to obtain a ranking of feed availability and production constraints.

In Paper II, ANOVA in the GLM procedure was used to estimate the effects of treatments, with fixed effects of period and treatment and random effects of animal and block included in the model. The treatment least square means (LSMs) were compared using Tukey’s pair-wise comparison method and were considered to differ significantly at a probability level of $P<0.05$ and to represent a tendency at $0.05<P<0.10$.

In Paper III, the statistical analyses were performed using SAS software (version 9.3; SAS Institute Inc., Cary NC, USA). Variables including feed and nutrient intakes, apparent digestibility, rumen degradation and effective degradability of nutrients were analysed using the GLM procedure. The model included the fixed effects of treatment and period and the random effect of animal. Ruminal fermentation characteristics and variables of nutrient losses *in sacco* were analysed by procedure MIXED for repeated measures, using time of sampling/incubation in each experimental unit (animal × treatment) and ‘zero’ time point as covariates. The model included the fixed effects of time, treatment and period, the random effect of animal and interactions between treatment × time and period × time. Least square means were analysed using the LSMEANS/PDIFF option and differences between treatment LSMs were compared by Tukey’s adjustment method and were considered to differ significantly at probability level $P<0.05$.

3 Summary of results

3.1 Chemical composition of the feeds

The nutrient composition of feedstuffs used in this thesis (Papers I-III) is summarised in Table 1. The contents of CP and fibre (DM basis) varied among the feeds used. The crude protein content ranged from 56-214 g/kg DM and the NDF content from 480-735 g/kg DM.

Table 1. *Chemical composition (g/kg DM except for DM, which is on a fresh-weight basis) of the feeds used in Papers I, II and III*

Feeds	Paper	DM	CP	OM	NDF	ADF
Pasture, mainly grazing in fields	I	245	114	891	736	n.a
Cut-and-carry fresh grass	I	205	131	890	678	n.a
Banana stems	I	54	56	841	647	n.a
Rice bran	I	913	83	861	616	n.a
Rice straw	II	938	56	878	708	453
Rice straw	III	894	68	878	650	n.a
Fresh para grass	II	220	135	884	694	442
Fresh para grass	III	197	159	900	623	n.a
Dried groundnut foliage	II	920	126	900	539	465
Dried groundnut foliage	III	898	128	907	480	n.a
Dried cassava tops	III	910	214	905	482	n.a

n.a = not analysed, DM = dry matter, CP = crude protein, OM = organic matter, NDF = neutral detergent fibre, ADF = acid detergent fibre

3.2 Smallholder beef cattle production systems in different AEZs of Cambodia (Paper I)

3.2.1 Smallholder cattle management system

The most common cattle management system identified in the survey in Paper I was grazing natural pasture grass with supplementation by local feeds available on the farms, while a few used full grazing in the mountains or communal lands and full confinement in feed stalls (see Figure 4). Grazing with supplements was most commonly practised in AEZ2 and AEZ4, while full confinement was more common in AEZ1 and AEZ3 than in the other two AEZs. It was common to have breeding cows on the farms, but the type of animals kept differed significantly ($P<0.01$) between the AEZs. In AEZ2, there were more draught animals, while beef cattle were the main type of cattle kept in AEZ1.

There was a significant difference ($P<0.01$) in herd size across AEZs, with larger herds in AEZ4 compared with the other AEZs. The number of breeding cows and calves was also higher in AEZ4 than in the other AEZs (Table 2). Local cattle were more common in AEZ4, while the numbers were significantly lower in AEZ1-3. However, the number of crossbreed cattle did not differ across the AEZs. The majority of households across the AEZs raised 1-3 head, followed by 4-6 head, 7-10 head and more than 10 head.

Figure 4. Cattle grazing on native pasture grass and weeds in agro-ecological zone (AEZ)4.

Table 2. *Least square means (standard error) of cattle herd sizes and composition in agro-ecological zone (AEZ)1, 2, 3 and 4 in Cambodia*

	AEZ			
	1	2	3	4
Herd size and composition:				
Draught animals	0.1 (0.04)^{b}	0.7 (0.10)^{a}	0.3 (0.08)^{b}	0.2 (0.06)^{b}
Breeding bulls	0.01 (0.01)	0.02 (0.02)	0.05 (0.03)	0
Breeding cows	1.9 (0.12)^{ab}	1.6 (0.10)^{b}	1.7 (0.12)^{b}	2.4 (0.17)^{a}
Beef cattle	0.2 (0.06)^{a}	0.04 (0.03)^{b}	0^{b}	0.01 (0.01)^{b}
Adults	0.7 (0.14)^{a}	0.1 (0.05)^{b}	0.1 (0.05)^{b}	0.5 (0.10)^{ab}
Calves	0.9 (0.10)^{b}	0.9 (0.11)^{b}	0.7 (0.09)^{b}	1.6 (0.15)^{a}
Total	3.8 (0.28)^{ab}	3.4 (0.17)^{b}	2.9 (0.16)^{b}	4.8 (0.34)^{a}
Herd breed:				
Local breed	1.3 (0.20)^{b}	1.5 (0.21)^{b}	1.0 (0.16)^{b}	3.2 (0.40)^{a}
Crossed breed	2.5 (0.31)	2.0 (0.22)	1.9 (0.21)	1.6 (0.27)

^{a,b} Mean values within rows with different superscripts are significantly different (P<0.01).

3.2.2 Feed for cattle and body condition score

The majority of cattle households depended mainly on rice straw and grazing pasture. Cut-and-carry grass was commonly fed during the wet season, but showed a shortage in the dry season. Crop residues such as rice straw were mainly used by households in AEZ4 during the wet season. For chemical composition of the feeds, see Table 1.

The body condition score of all types of cattle during the wet season after the interviews were performed was ‘medium’ to ‘fat’, except for lactating cows, which were scored as ‘thin’.

3.2.3 Constraints in cattle production

In AEZ1-3, lack of good quality breeding animals was ranked as the main constraint by the farmers surveyed, followed by lack of good quality feed resources and capital for cattle production In AEZ4, outbreaks of diseases were ranked as the number one constraint, while lack of good quality breeding animals and lack of skills relevant for cattle production were ranked as the second and third most serious constraints by cattle keepers.

3.3 Effect of groundnut foliage on feed intake, digestibility and nitrogen retention (Paper II)

The amount of dried groundnut foliage consumed by cattle in treatments DGF1, DGF2 and DGF3 was lower than planned (representing 86.0, 60.5 and 52.0 % of the allotted supplementation amounts). Dried groundnut foliage comprised 0, 25, 34 and 42% of total DM intake when cattle were offered this material at 0, 1, 2 and 3 g CP per kg body weight. The cattle ate virtually all of their allowance of para grass in all experimental diets. However, rice straw intake decreased ($P<0.001$) as dried groundnut foliage intake increased. Total intake of DM, OM, digestible OM, ash, NDF and ADF improved when dried groundnut foliage intake increased, but the rise levelled off at the two highest levels of dried groundnut foliage inclusion.

Cattle receiving diets supplemented with dried groundnut foliage showed increased ($P<0.001$) CP digestibility and a tendency ($P=0.062$) for improved DM digestibility, but the apparent digestibility of OM, NDF and ADF did not differ among the dietary treatments.

Total nitrogen intake increased with increased intake of N from dried groundnut foliage supplementation. Dried groundnut foliage contributed 0, 30.5, 41.8 and 50.2% of the total N supply in treatment DGF0, DGF1, DGF2 and DGF3, respectively. Higher intake of dried groundnut foliage was also linked with increased urinary and faecal N losses. Nitrogen retention and N utilisation (calculated as percentage of N intake retained) increased with increased dried groundnut foliage inclusion levels, but N utilisation was not significantly different between the diets with dried groundnut foliage inclusion.

3.4 Effect of groundnut foliage on microbial crude protein and weight gain (Paper II)

Animals supplemented with 2 g and 3 g of CP from dried groundnut foliage (DGF2 and DGF3) showed increased urinary allantoin excretion, microbial CP outflow from the rumen and efficiency of microbial CP supply ($P<0.01$). Daily weight gain was increased ($P<0.05$) by the presence of dried groundnut foliage in the diet, but did not differ between diets containing different amounts of dried groundnut foliage.

3.5 Effect of groundnut foliage and/or cassava tops on feed intake and digestibility (Paper III)

Consumption of dried groundnut foliage (DGF), dried cassava tops (DCT) and a combination of the two were lower than planned (51.8, 29.9 and 74.5% of the allotted amounts), which corresponded 1.04, 0.60 and 1.50 g CP per kg body weight, respectively. The animals consumed less para grass fed with a mixture of DGF and DCT compared with DGF and DCT fed separately. Rice straw intake decreased significantly in animals on the feeds supplemented with DGF, DCT and DGF+DCT compared with the control diet. Total intake of DM, OM and CP increased in animals receiving a diet supplemented with DGF and DGF+DCT, while NDF intake was highest in the DGF treatment.

The highest digestibility of DM, OM, CP and NDF was observed when the cattle received DGF or DGF+DCT in their diets, while inclusion of DCT in the diet gave rise to the lowest digestibility of CP and NDF.

3.6 Effect of groundnut foliage and/or cassava tops on rumen fermentation and *in sacco* degradation (Paper III)

Ammonia nitrogen and total VFA concentrations were elevated in the diets supplemented with DGF, DCT or a mixture of DGF and DCT compared with the unsupplemented diet. However, ruminal pH and relative proportions of VFA, including acetic acid (C_2), propionic acid (C_3), butyric acid (C_4) or the C_2:C_3 ratio, were not affected by dietary treatment.

There were no differences between dietary treatments in terms of DM, CP or NDF losses from sun-dried para grass in the nylon bags.

4 General discussion

4.1 Smallholder beef cattle production in Cambodia

Cambodian cattle farming was found to rely mainly on the availability of land for grazing the low quality pasture occurring naturally on communal land and forest land (Paper I). The majority of the 360 households surveyed used grazing with a supplement. These findings are in agreement with results published by Sath *et al.* (2008) based on observations made in AEZ2. The grazing areas for cattle were mainly rice fields, communal land and forest land. During the crop growing season, cattle were usually tethered at home or on the small plot of land near the house, to prevent potential crop damage. The cattle were supplemented after grazing in the field and accommodated in pen constructions under/near the house.

The survey showed that various locally available feeds were supplied to the cattle. This agrees with findings in previous studies performed in AEZ1 (Serey *et al.*, 2014) and AEZ2 (Sath *et al.*, 2008). The feed supply during the wet season, mainly natural pasture and cut-and-carry grass, was sufficient to supply the animals with nutrients, as indicated by their body condition score. All animals except cows with suckling calves were medium-fat to fat, while cows with suckling calves were thin. Milk production places substantial energy demands on the lactating cow and they are therefore particularly vulnerable during the dry period when the feed availability is low.

Almost all households raised cattle for breeding purposes. However, the use of cattle for draught power was higher in AEZ2 and AEZ3, probably due to the small plots of land available for cultivation by households. Serey *et al.* (2014) conducted a survey in AEZ1 and observed that households reared cattle for breeding and growing for sale, rather than for draught power. A reduction in the use of cattle for draught may be due to increased mechanisation of land preparation and high prices for cattle on the market.

Herd sizes in Paper I were similar to those reported by Serey *et al*. (2014). The majority of households kept 1-3 head and herd size was larger in AEZ4. It is possible that scarcity of feed supply and lack of labour prevented the farmers from keeping more animals per household. In a previous study performed in Vietnam, it was shown that the number of cattle raised by each household did not reflect the poverty level, but that it was linked to the availability of feed for the animals and labour for animal management (Huyen *et al*., 2013). Larger herds are associated with larger family size and a lower dependency ratio, *i.e*. the number of people of non-working age relative to the number of people of working age, which creates better conditions for keeping cattle compared with smaller herd size households with restricted availability of feed and provision of labour (Huyen *et al*., 2013). However, in Paper I there were no differences in family size among AEZs, and thus the larger herd size in AEZ4 (Plateau/Mountainous zone) could possibly reflect more available land for grazing along the forests and mountains to provide feed for the cattle. Huyen *et al*. (2013) pointed out that in Vietnam, herd size in the highlands, with access to pasture, is higher than in the lowlands.

In Paper I, households kept crossbred animals rather than animals of the local breed. Similarly, Sath *et al.* (2008) found that crossbred cattle were twice as common as the local breed. Crossbreds, mainly crosses between Haryana and local cattle, were found in areas with availability of feed all year round (Paper I). On the other hand, there were more animals of the local breed in AEZ4, most likely due to the practice of natural breeding within herds. In this practice, cows are inseminated in one of two ways: (i) freely in the field, when mixing with other cattle, either by a poorly castrated male or by a young male that has reached puberty but has not yet been castrated or (ii) by bringing cows to a bull kept for breeding, with a charge per conception depending on the geographical area and quality of the bull (Serey *et al.*, 2014).

The ranking of perceived constraints to animal keeping varied across the AEZs. Major constraints reported in AEZ1-3 were lack of good quality breeding animals, followed by lack of good quality feed resources and capital for cattle production. However, in AEZ4 outbreak of diseases was ranked as the first constraint, while lack of good quality breeding animals and lack of competence in cattle production were ranked as the second and third most serious constraints. These findings differ somewhat from those reported by Serey *et al.* (2014), Pen *et al.* (2010) and Sath *et al.* (2008) in studies in AEZ1 and AEZ2, where the main constraint in cattle production was cattle diseases causing morbidity and mortality and the second most important constraint was shortage of feed. The reason for the different findings could lie in the increased availability of veterinary services at village level offered by VAHWs trained by the General Directorate of Animal Health and Production and also the vaccination programme, which have reduced the disease incidence since the studies cited above were performed.

4.2 Effect of groundnut foliage on apparent digestibility and nitrogen utilisation

Supplementing a basal diet of rice straw and para grass with dried groundnut foliage increased intake of DM and N in Local Yellow cattle. However, intake of rice straw was depressed as the level of dried groundnut foliage increased. Similarly, Sath *et al.* (2012) found that the rice straw intake decreased, while total DM intake increased, with level of dried cassava foliage supplementation. Offering dried groundnut foliage at more than 2 g CP per kg body weight did not give any further enhancement of total DM intake. This is probably because the cattle selected more leaves and other components with high nutritive value and refused the less digestible components at higher dried groundnut foliage inclusions. In Paper II, the animals refused about 50% of the dried groundnut foliage material offered at the highest inclusion rate. Furthermore, NDF intake was higher with dietary dried groundnut foliage inclusion, although that material contained little NDF (see Table 1). This was due to the increased total feed intake and also the enhanced N supply inducing greater rumen microbial fibre degradation.

The body weight gain of cattle was improved by inclusion of dried groundnut foliage in the diet. This improvement probably reflects both a true body weight gain and changes in fill of the gastrointestinal tract in response to the increased total DM intake. The effects in Paper II are similar to those observed by Sath *et al.* (2012) when dried cassava foliage was included as a supplement to the same basal diet. However, supplementation with dried groundnut foliage at levels higher than 2 g CP per kg body weight did not further improve weight gain in the animals, which might suggest that a low energy concentration and inappropriate energy:protein ratio limited further body weight gain. Urinary allantoin excretion, an index of microbial protein supply, increased with increasing dried groundnut foliage supply, although the response appeared to diminish at higher dried groundnut foliage inclusion rates. Furthermore, Paper II showed that inclusion of dried groundnut foliage in the diet improved rumen available N, efficiency of microbial CP supply, microbial CP outflow from the rumen and N utilisation for tissue growth of the animals. These results indicate that the N balance was improved by dried groundnut foliage supplementation. It is of vital importance to increase N supplementation in tropical regions like Cambodia, since the available feeds are generally of poor nutritional quality, with the protein content often being particularly low. The total quantity of groundnuts produced in 2014 was about 140,000 tonnes (FAO, 2018). Assuming that groundnut foliage is 60% of the total plant, this was equivalent to 52,500 tonnes of DM (assuming 25% DM rate) and to about 6,500 tonnes of CP (assuming a CP content of approximately 13%). Thus for cattle, the groundnut foliage produced in Cambodia would contribute about 2 kg of CP per animal on a yearly basis.

4.3 Effect of combining groundnut foliage and cassava tops on apparent digestibility, rumen fermentation and *in sacco* degradation

Inclusion of cassava tops in the diet of ruminants is challenging due to the content of anti-nutritional compounds such as hydrogen cyanide and tannins, which are harmful for the animals. Inclusion of dried cassava tops in a control diet comprising a mixture of rice straw and para grass decreased total DM intake and apparent digestibility in crossbred steers (Paper III). This is in consistent with findings by Thang *et al.* (2010), who used dried cassava foliage as a feed supplement to cattle diets based on urea-treated rice straw and concentrate. It is possible that the reduced intake was caused by secondary compounds. However, sun-drying of cassava usually reduces the content of hydrogen cyanide to levels shown not to be harmful to animals (Promkot *et al*., 2007). Thus it is likely that tannins in the dried cassava tops can explain the reduction in DM intake observed in Paper III. Waghorn (2008) reported that when the tannin level reached 5% of DM, intake and digestibility were reduced due to reduced palatability and decreased rate of digestion in the rumen. The cassava tops used in this study were from a bitter variety that is harvested late to maximise root production, and later harvesting leads to higher concentrations of tannins (Khang *et al*., 2005). The diet supplement containing a combination of dried cassava tops and dried groundnut foliage increased total DM intake and apparent digestibility (Paper III). However, prediction of apparent digestibility was based on the AIA method and there was a large variation in AIA content between the feeds used. Rice straw had a markedly higher content of AIA than the other feed sources. Thus, even a small underestimation of the rice straw intake by the cattle fed combined groundnut foliage-cassava tops would give rise to an overestimation of the digestibility. This drawback with AIA as a method to estimate digestibility has been pointed out by Lee & Hristov (2013).

Inclusion of dried groundnut foliage, dried cassava tops and a combination of both foliages increased ruminal NH_3-N concentration (Paper III). This result could be related to the higher CP intake compared with the control diet. Rumen NH_3-N can be used as source for microbial CP synthesis, provided that carbohydrates and other nutrients required for microbial growth are also available. All diets containing additional foliage increased total VFA concentrations, although the increase was significant only when cattle diet was supplemented with dried groundnut foliage alone. The higher rumen VFA concentration among animals which received dried groundnut foliage presumably reflected higher intake of dietary carbohydrates. The VFA content in the rumen might also be affected by rumen pH. A lower pH gives rise to a higher proportion of undissociated VFA, which in turn facilitates lipophilic diffusion of these undissociated acids (Aschenbach *et al*., 2011). However, rumen pH did not differ between treatments and it is thus reasonable to assume that the variations in rumen fluid VFA concentration were an effect of different rates of VFA production, rather than of varying rates of absorption. Thus the results in Paper III suggest that inclusion of foliage contributed not only N for rumen microbial CP synthesis, but also readily available carbohydrates that improve rumen microbial fermentation and provide ATP for microbial growth. Volatile fatty acids are the main energy substrate for cattle and in Paper III rumen VFA concentration was about 40% higher in animals receiving dried groundnut foliage than in those receiving the control diet, which would theoretically give rise to lower rumen pH in animals fed dried groundnut foliage. However, it is possible that dried groundnut foliage stimulated rumination and thus production of buffering saliva, which counteracted a drop in rumen fluid pH.

The *in sacco* method is the most effective method to study rumen degradation of different feeds available today (Mohamed & Chaudhry, 2008). Rumen losses of DM, CP and NDF from sun-dried para grass incubated in the rumen did not differ between the control diet and the diets containing foliage supplements (Paper III). Moreover, the proportions of the individual VFAs, including C_2, C_3, C_4 and the C_2:C_3 ratio, were not affected by the treatments. These results show that the observed responses in terms of *in vivo* digestibility of these parameters were related to the composition of the feeds, rather than to changes in rumen environment induced by the diets.

5 General conclusions and implications

5.1 Conclusions

- Most smallholder beef cattle keepers in Cambodia use grazing with a supplement and keep 1-3 head per household across the AEZs in the county.

- Feed resources for cattle are abundant in the wet season and there is a shortage during the dry season, when mainly rice straw and low quality natural pasture are available. In addition to feed shortages, cattle production in Cambodia faces major constraints such as lack of good quality breeding animals and outbreaks of diseases.

- Inclusion of groundnut foliage in diets based on rice straw and para grass improves DM intake, CP digestibility, N retention, microbial CP production and body weight gain in local cattle breeds. However, the improvement declines when supplementation reaches a level of 2-3 g CP as dried groundnut foliage per kg body weight.

- Supplementation with groundnut foliage and a mixture of groundnut foliage and cassava tops improves DM intake and apparent digestibility in cattle and increases ruminal NH_3-N and VFA concentrations. Inclusion of cassava tops as a sole supplement reduces intake and apparent digestibility.

5.2 Implications

- Smallholder cattle keepers in Cambodia currently only keep 1-3 head, so increasing the number of animals they keep could be an opportunity for these farmers to improve profitability.

- Lack of suitable cattle breeds and outbreak of diseases are the major constraints on cattle production in Cambodia. There is thus a need for breeding programmes that support natural service by bulls, as well as artificial insemination. Furthermore, disease control efforts are needed to reduce outbreaks of animal diseases. In addition, farmers need to be educated in better care and management of their animals.

- The use of groundnut foliage as a protein supplement to a basal diet of rice straw and para grass improves the nutritional supply of cattle. This is vital in areas where feed supply for animals is limited in both quality and quantity, particularly during the dry season. Thus farmers could collect/store groundnut foliage after harvest as a supplementary feed. The suggested amount is 1 g CP per kg body weight and day in growing cattle.

- Inclusion of cassava tops alone reduces intake and apparent digestibility, but combined with groundnut foliage is an additional feed supplement for better performance of cattle.

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Popular science summary

Cattle production plays a significant role for the economy and food security of smallholder farm families in Cambodia. The cattle contribute draught power and protein-rich food products and the manure can be used as bioenergy and as a plant fertiliser. Furthermore, the cattle serve as a family 'bank'. Demand for animal protein is growing in Southeast Asia with an increasing middle class and improved incomes in several countries in the region. It is thus vital to increase beef production to match this demand. This thesis explored smallholder cattle production in Cambodia and investigated the nutritive value of groundnut foliage as a dietary supplement in cattle production. The majority of smallholder farmers surveyed kept 1-3 cattle. Increasing the number of animals kept can improve family income and secure food supply. According to local farmers, the major constraints on cattle production are lack of good cattle breeds and outbreaks of diseases. Thus, breeding programmes that support natural service and also artificial insemination are required. Disease control work will reduce the incidence of animal diseases. In some areas, availability of feeds is a limiting factor for cattle production, especially during the dry season. The most common cattle management system on the farms surveyed in this thesis was grazing natural pasture grass, supplemented with locally available feeds.

Cambodia produces about 8.5 million tonnes of cassava, 0.16 million tonnes of soybean and 0.14 million tonnes of groundnuts annually. The by-products, foliage, tops *etc*. from these crops could be used as feed supplements with relatively high nutrient values. This thesis showed that dried groundnut foliage supplemented to a basal diet of rice straw and para grass improved dry matter intake, crude protein digestibility and nitrogen retention and increased microbial protein production in growing cattle. Body weight gain was higher when the animals were fed a groundnut foliage supplement compared with a diet without dried groundnut foliage, but did not increase further with increased inclusion level. Positive effects on feed intake were also obtained using diets with a combination of dried groundnut foliage and dried cassava tops fed to adult cattle. However, inclusion of cassava tops alone reduced feed intake and nutrient digestibility.

In conclusion, groundnut foliage can be a valuable feed supplement for cattle, with potential to improve the nutritional status of the animals and in turn improve the income and food security of smallholder families in Cambodia.

សង្ខេបការស្រាវជ្រាវវិទ្យាសាស្ត្រ

ការចិញ្ចឹមគោ បានដើរតួនាទីយ៉ាងសំខាន់ សម្រាប់សេដ្ឋកិច្ច និងសន្តិសុខស្បៀង ដល់កសិករដែលចិញ្ចឹមជាលក្ខណៈគ្រួសារនៅកម្ពុជា។ គោផ្តល់ជាកំលាំងអូសទាញ និងប្រភពចំណីប្រូតេអ៊ីន ហើយលាមករបស់វាអាចប្រើជាជីវថាមពល និងជាជីសំរាប់ដំណាំ។ លើសពីនេះ វាមានតួនាទីជា ″ធនាគារ″ របស់គ្រួសារផងដែរ។ តម្រូវការប្រូតេអ៊ីន ដែលមានប្រភពពីសត្វកំពុងមានការកើនឡើងនៅតំបន់អាស៊ីអាគ្នេយ៍ ដោយសារកំណើនកម្រិតជីវភាពនៃប្រជាជនថ្នាក់កណ្តាល និងកំណើននៃប្រាក់ចំណូលរបស់ប្រជាជន នៅក្នុងប្រទេសជាច្រើននៅក្នុងតំបន់។ ដូច្នេះវាចាំបាច់ណាស់ នៅក្នុងការបង្កើនផលិតកម្មគោសាច់ ដើម្បីបំពេញតម្រូវការនេះ។ និក្ខេបបទនេះ បានស្រាវជ្រាវលើផលិតកម្មគោជាលក្ខណៈគ្រួសារនៅកម្ពុជា និងបានអង្កេតលើតម្លៃនៃអាហារូបត្ថម្ភរបស់ដើមសណ្តែកដីស្ងួត និងចុងដំឡូងមីស្ងួត ដែលប្រើជាចំណីបន្ថែមប្រូតេអ៊ីន សម្រាប់ការចិញ្ចឹមគោ។ ភាគច្រើននៃកសិករដែលបានចូលរួមនៅក្នុងការស្ទង់មតិ មានគោពី ១ ទៅ ៣ក្បាល។ កំនើននៃចំនួនសត្វចិញ្ចឹម អាចបង្កើនប្រាក់ចំណូលគ្រួសារ និងធ្វើឱ្យមាននិរន្តភាពស្បៀង។ តាមរយៈកសិករនៅក្នុងតំបន់សិក្សាបានឱ្យដឹងថា កត្តារាំងស្ទះចម្បងក្នុងផលិតកម្មគោ គឺដោយសារកង្វះពូជគោល្អៗ និងការផ្ទុះឡើងនូវជំងឺឆ្លងនា-នា។ ដូច្នេះ វាទាមទារឱ្យមានការគាំទ្រលើកម្មវិធីបង្កាត់ពូជទាំងបែបធម្មជាតិ និងបែបសិប្បនិម្មិត។ វិធានការត្រួតពិនិត្យ និងទប់ស្កាត់ជំងឺ នឹងជួយកាត់បន្ថយអត្រាផ្ទុះជំងឺនានាផងដែរ។ នៅក្នុងតំបន់ខ្លះ ភាពសំបូរនៃចំណី គឺជាកត្តាដែលកំណត់នៅក្នុងផលិតកម្មគោ ជាពិសេសនៅរដូវប្រាំង។ ប្រព័ន្ធចិញ្ចឹមគោ ដែលមានការនិយមបំផុត នៃការស្រាវជ្រាវនៅក្នុងនិក្ខេបបទនេះ គឺការព្រលែងឱ្យស៊ីតាមវាលស្មៅធម្មជាតិ និងបន្ថែមជាមួយចំណីដែលមាននៅក្នុងតំបន់។

ប្រទេសកម្ពុជាផលិតដំឡូងមីប្រហែល ៨,៥ លានតោន, សណ្តែកសៀង ០,១៦ លានតោន និងសណ្តែកដីចំនួន ០,១៤ លានតោន ជារៀងរាល់ឆ្នាំ។ អនុផលជាស្លឹក (ជាប់ដើម), ចុង (មានស្លឹក) ។ ល។ ពីដំណាំទាំងនេះ អាចប្រើប្រាស់ជាចំណីបន្ថែមដែលមានអាហារូបត្ថម្ភខ្ពស់។ និក្ខេបបទនេះ បានបង្ហាញថា ដើមសណ្តែកដីស្ងួត ផ្តល់បន្ថែមទៅលើរបបចំណីគ្រឹះចំបើង និងស្មៅ បានបង្កើននូវបរិមាណចំណីស៊ីចូលសរុបគិតជារូបធាតុស្ងួត លទ្ធភាពរំលាយប្រូតេអ៊ីន ការរក្សាទុកអាសូតក្នុងខ្លួន

សត្វ និងបង្កើនការផលិតប្រូតេអ៊ីនពីអតិសុខុមប្រាណ នៅលើគោដែលកំពុងលូតលាស់។ កំនើនទម្ងន់ខ្លួនគោ បានកើនឡើងនៅពេលដែលសត្វ ត្រូវបានផ្តល់បន្ថែមដោយដើមសណ្តែកដី ធៀបទៅនឹងរបបចំណីដែលគ្មានការបន្ថែម ប៉ុន្តែគ្មានភាពខុសគ្នាបន្ថែមទៀតក្នុងស្ថិតិសាស្ត្រ ជាមួយនឹងការបន្ថែមកម្រិតដើមសណ្តែកដីស្ងួតលើសពីនេះទេ។ ឥទ្ធិពលជាវិជ្ជមាន នៃបរិមាណចំណីស៊ីចូលនៅលើគោពេញវ័យ ក៏អាចទទួលបានផងដែរ ពីរបបចំណីដែលមានផ្សំដោយដើមសណ្តែកដីស្ងួត និងចុងដំឡូងមីស្ងួត។ ទោះជាយ៉ាងណាក៏ដោយ ការបន្ថែមចុងដំឡូងមី តែមួយមុខ បានកាត់បន្ថយការស៊ីចំណី និងលទ្ធភាពរំលាយនៃអាហាររូបត្ថម្ភ។

ជាសន្និដ្ឋាន ដើមសណ្តែកដី អាចប្រើជាចំណីបន្ថែមដ៏ល្អសម្រាប់សត្វគោ ដែលមានសក្តានុពលក្នុងការលើកកម្ពស់ស្ថានភាពអាហាររូបត្ថម្ភរបស់សត្វ ដែលឈានទៅបង្កើនប្រាក់ចំណូល និងសន្តិសុខស្បៀង ដល់គ្រួសារកសិករខ្នាតតូចនៅកម្ពុជា។

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