Forage Legumes as Feed for Pigs in Smallholder Production Systems in the North of Lao PDR

Production Systems, Forage Biomass Yield and Protein Nutrition

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Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2013

Acta Universitatis agriculturae Sueciae
2013:12

Cover: Smallholder pig production systems in the North of Lao PDR
(photo: Phonepaseuth Phengsavanh)

ISSN 1652-6880
ISBN 978-91-576-7769-3

Print: SLU Service/Repro, Uppsala 2013

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Abstract

This thesis sought to characterise and understand existing smallholder pig production systems in the North of Lao PDR and to investigate the role of forage legumes as alternative protein sources for pigs in smallholder production systems.

A survey found that there were three main pig rearing systems, free-scavenging, semi-scavenging and confinement (enclosures and pens), in the study areas. These systems were managed differently depending on intensity of crop production, farmer ethnicity and reason for keeping pigs. Farmers fed their pigs mainly rice bran, distiller's waste, maize, cassava and green plant materials. The growth performance was poor, with an average daily gain (ADG) of around 100 g. The reproductive performance of sows was low, with an average litter size of 8.3 piglets and piglet mortality around 50%. Other constraints in smallholder systems were disease outbreaks.

An agronomy trial showed that the forage legumes Stylo composite and porcupine joint vetch produced high DM yields, had high contents of crude protein (CP) and had potential to be used as protein sources for pigs in smallholder systems. Harvesting every 45 days produced higher DM yields than other harvesting intervals. The CP content was highest with the shortest harvesting interval, while the opposite was true for the fibre content (CF, ADF and NDF).

Growth trials on the CP requirements of growing local Moo Lath pigs showed that final body weight (BW), ADG, feed intake and feed conversion ratio (FCR) did not improve above a dietary CP level of 181 g kg^{-1} DM for weaner pigs, 132 g kg^{-1} DM for grower pigs and 111 g kg^{-1} DM for finisher pigs. Additional growth trials with Moo Lath pigs showed that replacing soybean CP with forage leaf CP reduced DM and energy intake and ADG, but had no effect on FCR. Increasing the replacement of soybean CP with legume leaf CP had a negative linear effect on DM and energy intake, final BW and ADG, and on all carcass traits except lean meat percentage. Supplementing a traditional diet with soybean meal resulted in higher DM and energy intake, lower FCR and higher final BW and ADG.

Keywords: smallholder pig production, rearing system, feeding system, dry matter yield, harvesting interval, Moo Lath pig, protein requirement, forage legume leaf meal, growth rate, feed intake.

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Dedication

To my parents, my wife Phetsamai, my son (Vira) and daughter (Phonenapha)

Contents

Appendix

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

I Phengsavanh, P., Ogle, B., Stür, W., Frankow-Lindberg, E.B. & Lindberg, J.E. 2011. Smallholder pig rearing systems in Northern Lao PDR. *Asian-Australian Journal of Animal Science* 24 (6): 867-874.

II Phengsavanh, P., Ogle, B., Stür, W., Frankow-Lindberg, B.E. & Lindberg J.E. 2010. Feeding and performance of pigs in smallholder systems in Northern Lao PDR. *Tropical Animal Health and Production* 42, 1627-1733.

III Phengsavanh, P., Frankow-Lindberg, B.E. & Lindberg J.E.2012. Effect of harvesting interval on yield and chemical composition of five tropical forage legumes. *Grassland Science*. (Accepted).

IV Phengsavanh, P. & Lindberg, J.E. 2012. Effects of dietary protein levels on growth performance and feed intake in indigenous Moo Lath pigs in Lao PDR. (Submitted).

V Phengsavanh, P. & Lindberg, J.E. 2012. Effect of replacing soybean protein with protein from porcupine joint vetch (Aeschynomene histrix BRA 9690) and stylo (Stylosanthes guianensis Composite) leaf meal on growth performance of indigenous pigs in Lao PDR. (Submitted).

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Abbreviations

ADB	Asian Development Bank
ADF	Acid detergent fibre
ADG	Average daily gain
CF	Crude fibre
CFI	Crude fibre intake
CP	Crude protein
CPI	Crude protein intake
CSF	Classical swine fever
DLF	Department of Livestock and Fisheries
DE	Digestible energy
DF	Dietary fibre
DFI	Daily feed intake
DM	Dry matter
DMI	Dry matter intake
EAA	Essential amino acids
FCR	Feed conversion rate
FMD	Foot and mouth disease
GE	Gross energy
ME	Metabolisable energy
MEI	Metabolisable energy intake
MJ	Mega joule
NDF	Neutral detergent fibre
NE	Net energy
NSC	National statistic centre
NSP	Non-starch polysaccharides
UNDP	United Nation for Development Programme

1 Introduction

Lao PDR is located in South East Asia and has a population of around 6.1 million people (ADB, 2010). Lao PDR is an agricultural country with 77% of the population living in rural areas and engaging in irrigated and rain-fed agricultural production systems (NSC, 2012). In these systems, the main activity is rice production and the production of annual crops such as maize, cassava and legumes. In all areas, livestock is an integral part of agricultural systems, providing food and opportunities for saving, insurance, asset accumulation and maintaining social customs (Phengvichith, 2007).

The Northern part of Lao PDR is the region with the highest poverty rate in the country, particularly in remote mountainous areas where farmers earn less than 1 US dollar per day. Shifting cultivation is the main agricultural practice in the region, which results in low productivity, increasing land degradation and land scarcity. In general, poverty is a major challenge to the Northern region and the country, with Lao PDR being placed lowest of all South East Asian countries in the UN Human Development Index (UNDP, 2006).

Farmers engaged in shifting cultivation usually produce food for their family and if there is any surplus they sell it. However, farmers in this agricultural system are always faced with problems of land degradation and low yield. As a result, most of these farmers have food (especially rice) shortages for 2-6 months each year (Phengsavanh and Phimphachanhvongsod, 2007). The only option for farmers to cope with rice shortage is to keep livestock as a form of capital accumulation that can be used for sale when there is a rice shortage. Given the potential of livestock production to alleviate poverty and reduce shifting cultivation, the Lao government has given the highest priority in its rural development strategy to improving livestock production systems (Government Report, 2004).

Livestock production is extremely important in Lao PDR, with about 90% of all farm households raising one or more livestock species. This livestock production is almost totally smallholder farming, providing a vital component of livelihood security (Horne, 1998). In 2010, agriculture accounted for 29% of GDP. Products from livestock and fisheries accounted for 10% and more than 95% of these were produced by smallholder farms (Government Report, 2010). The main animals kept are cattle, buffaloes, pigs and poultry. Livestock plays a significant role as a protein source, for sacrifice in traditional ceremonies and as a source of household income (Phengsavanh, 2000). Buffaloes and cattle are kept as capital accumulation or saving, and are sold when farmers need a large amount of cash. Pigs are raised mainly as income generation. Pigs can be sold when cash is needed for buying rice and other food, for paying school fees or if a household member needs medical attention (Phengsavanh & Stür, 2006). Apart from this, pigs are also important in cultural activities as they are slaughtered for traditional festivals and ceremonies such as weddings, New Year's Eve, well-wishing and other ceremonies (Stür *et al*., 2006). Poultry consists predominantly of chickens, although ducks, geese and turkeys are also raised. As in other developing countries, livestock also provides a broader role in establishing the status of the farmers (Birner, 1999) or as a store of wealth (Sansoucy, 1995).

In smallholder systems, most pigs are raised in traditional low input free and semi-free scavenging systems, where they are allowed to scavenge freely for feed all the year round or after the main crops have been harvested. Farmers feed only small amounts of additional feedstuffs such as rice bran, maize, cassava and weeds that occur naturally on fallow land, forests and along stream banks (Phengsavanh & Stür, 2006). The traditional feed is limited in both quantity and quality, which severely limits productivity in smallholder pig production systems (Thorne, 2005).

There are many options for improving smallholder pig production systems, such as planting forage legumes as a managed crop, which can supply high protein leaf supplements at the time of year when other feeds are in short supply. Many forage legumes have high protein content (18-25%), are excellent sources of minerals, and can be used as supplements to tubers and cereals (Stür *et al*., 2006). Recently, farmers in Northern Lao PDR reported substantial benefits from supplementing pigs with the forage legume *Stylosanthes guianensis* CIAT 184 (Stylo 184). The benefits include labour savings in collecting feed at critical times of the year (savings of 2-3 hours per day during the wet season) and faster pig growth rates (reaching saleable weight 6 months earlier than unsupplemented pigs) (Stür *et al*., 2007). Therefore, there is a need to investigate the production potential and impacts of selected forage legumes for supplementing pigs in smallholder production systems.

The aims of the thesis:

The general objectives of this thesis were:

- To characterise and understand existing smallholder pig production systems.
- To investigate the role of forage legumes as an alternative protein source for pigs in smallholder production systems.

The specific objectives were:

- To characterise rearing and feeding systems in smallholder pig production systems.
- To study the yield and chemical composition of selected forage legumes and to identify species with the potential to improve pig nutrition in smallholder systems.
- To provide a first assessment of the protein requirement of Moo Lath pigs at different growth stages.
- To quantify feed intake and growth performance of native Moo Lath pigs fed a traditional diet based on rice bran and maize without or with supplementation of soybean meal, and diets where soybean meal protein was replaced with legume leaf meal protein.

2 Background

2.1 Smallholder farming systems in Northern Lao PDR

Smallholder agricultural systems in Northern Lao PDR are mixed farming systems including staple and cash crops as well as livestock production. Many production systems are found in the upland and are influenced by ethnic group, population pressure, land availability, soil and topography (Devendra *et al*., 1997). However, shifting cultivation has been the traditional way of farming in the uplands of Northern Lao PDR, as the land is not suitable for arable crops and paddy. The paddy rice cultivation in this region is practised only in valleys and on flat land (Horne, 1998).

The stability of traditional shifting cultivation systems depends on sufficiently long fallow periods to restore the fertility of the soil before cropping (Chazee, 1994). However, an increase in the local population in an area leads to insufficiently long periods under fallow, soil erosion, soil nutrient depletion and weed problems. Therefore, farmers in this area are increasingly facing challenges to maintain food security in the face of soil degradation, low rice yields and government policies to reduce shifting cultivation for environmental protection (Alexander *et al*., 2006).

Various organisations, including government, non-government and international programmes and the private sector, are helping local farmers to find solutions for diminishing shifting cultivation by encouraging them to plant annual and perennial cash crops in pure stands and to develop agro-forestry or plantations of industrial trees (rubber and teak), as well as livestock intensification.

In the uplands of Northern Lao PDR, livestock rearing and cropping activities are integrated, with livestock providing inputs into crop production such as draught power for soil preparation, manure for soil fertilisation and transportation of products. In turn, livestock graze on recently harvested cropped areas or are fed by-products from rice milling as part of their diet (ADB, 2006). Livestock is always an integral part of the assets of most inhabitants, with about 90% of all farm households raising one or more livestock species. The sales of livestock account for more than 50% of cash income in many upland areas of Lao PDR (Hansen, 1998; Stür *et al*., 2002).

Although livestock are very important for the livelihood of upland farmers, animals are mostly still kept in traditional free ranging systems, which rely mainly on feeds that occur naturally in the areas near forest, along streams and on fallow land (Phengsavanh & Stür, 2006). There are a number of constraints in traditional animal production systems. Firstly, the most important factor is animal disease (Devendra *et al*., 1997), which can cause mortality at rates ranging from 50 to 100% depending on the severity of the disease (Phengsavanh & Phimphachanhvongsod, 2007). Secondly, animal performance is limited by nutritional factors, which vary depending on species. In general, availability of feed in the wet season is not a problem for ruminants, but quantity and quality in the dry season and efficiency of use are the constraints. For non-ruminants, protein feeds are in limited supply and increasing their availability is a major challenge (Phiewvankham, 2011). The lack of feed results in very poor animal production.

Since upland households are dependent on livestock raising, the opportunities for improving productivity, and thereby the sustainability of upland livelihoods, are apparent in terms of improving feeding and management technologies (ADB, 2006). To date, there have been numerous national and donor-assisted projects working with livestock production in the uplands of Lao PDR. These projects have focused on feed improvement for ruminant and monogastric animals, establishing a better health service and vaccination delivery systems at district and provincial levels, and intensifying traditional production systems to be more market-orientated.

2.2 Characteristics of pig production systems in Northern Lao PDR

Pigs are one of the most important livestock species raised by smallholder farmers in Lao PRD. In 2011, there were about 2.6 million pigs in Lao PDR (DLF, 2011), and approximately 85% of these were kept in traditional smallholder systems, mainly in the mountainous regions of the country (Thorne, 2005).

Farmers mainly keep native breeds, as the local people prefer pork from native breeds to pork from imported (exotic) breeds. The common native breeds in the country are Moo Hmong, Moo Lath, Moo Chith and Moo Deng. Moo Hmong and Moo Lath are the most common pig breeds in the North of Lao PDR (Sounthilath, 2005). These two native breeds are either completely black in colour or black with white spots. The mature weight of Moo Lath and Moo Hmong is very similar and ranges from 80 to 120 kg (Wilson, 2007). The local breeds are high-fat pigs. Pig fat is the main fat used for cooking in remote areas and the local pigs provide plenty of fat for this purpose. Moreover, local breeds have many positive attributes such as being hardy and able to survive on relatively poor feed resources (Phengsavanh & Stür, 2006). They are well adapted to scavenge part of their nutritional needs in free-range conditions but growth rates tend to be very low in extensive management conditions, with pigs often taking 15 months to reach a weight of 40-50 kg (Kennard, 1996)

The pig feeding systems are closely aligned with the cropping systems, available resources and traditional knowledge of smallholder farmers, who have developed production systems for pigs using locally available materials, such as green plants, leftover rice and kitchen waste (Kumaresan *et al*., 2007).

The traditional feeds used for feeding pigs in Northern Lao PDR are mainly a mix of planted feeds (cassava and maize), green leaves that are available in the local areas and agricultural by-products (rice bran, leaves and tops of crops). The availability of these feeds varies throughout the year, depending mainly on the seasonality during the year and agricultural practices in the area.

Pig feeding appears to be closely related to the ethnicity of the pig producer. In Lao-Tai villages, where many farmers grow paddy rice for sale, pig feed is based on rice bran as the main feed source, which is fed together with a small amount of green feed. Green feed or vegetable matter is traditionally collected from forest margins and fallow fields and includes *Colocasia esculenta*, *Alocasia macrorrhiza*, *Crassocephalum crepidioides*, *Morus papyrifera* leaves and several other herbs depending on local availability (Thorne, 2005; Phengsavanh & Stür, 2006). Farmers in some Lao-Tai villages also feed distillery waste from making rice wine and spirits, and in some cases broken rice. In all situations the main feed ingredient is rice bran of varying quality. Many small rice mills are not able to effectively separate rice husks from the bran, resulting in a lower-quality product with reduced protein and high fibre content. Rice bran tends to be available for most of the year except for a short period in July to September before the new rice is harvested (Phengsavanh & Stür, 2006).

In Hmong-Mien and Mon-Khmer villages farmers grow rice in shifting cultivation and the yield is always lower than for paddy rice, so they have less rice bran available for feeding to pigs and poultry than Lao-Tai households. In addition to rice, households in these villages grow maize and cassava as a feed for pigs. These are not fed throughout the year but are related to availability. Cassava roots are fed during the rainy season from May to September, maize during the dry season and rice bran throughout the year as long as it is available. Green feeds are similar to those used by Lao-Tai farmers, but there tends to be a larger range of herbs that are used at different times of the year (Phengsavanh & Stür, 2006).

The high labour demand for collecting and preparing feed is another main problem in smallholder pig production systems (Stür *et al*., 2002). Many women spend up to three hours per day collecting and preparing feed for pigs. Feed shortage, both in quantity and quality, severely limits productivity (slow growth rate of approximately 100 g per day) in smallholder pig production systems (Thorne, 2005; Phengsavanh & Stür, 2008).

2.3 Forage legume foliage – an alternative protein source for pigs in smallholder production systems

Protein is the most limiting factor for tropical pig production (Ocampo *et al*., 2005; Leterme *et al*., 2005a and b). To overcome this problem, there are many options such as using commercial concentrates, agro-industrial by-products or agro-forestry-based foods (Makkar, 1993).

The use of commercial concentrates and industrial by-products is not common among smallholder farmers in the uplands of Lao PDR because of the high cost of the feed, the difficulty of transportation and the low economic return. However, numerous reports have shown that legume foliage and other fodder leaves, particularly in the form of leaf meal, can be included in the diet and improve the growth rate of pigs. However, in order to maximise the growth of pigs, the appropriate level of legume leaf meal inclusion in the diet should be determined. Halimani *et al*. (2005) reported that inclusion of leguminous leaf meal at a low level (100 g kg^{-1} of overall diets) increases the feed intake and growth rate of growing pigs. This can probably be explained by the high crude protein and essential amino acid content in leguminous leaf meal (Halimani *et al*., 2005), resulting in improved crude protein and amino acid supply (Lindberg & Cortova, 1995). For instance, the essential amino acid profile of leucaena leaf meal is reported to be similar to that of soybean meal (Phuc & Lindberg, 2001). Moreover, feeding leguminous forage at low levels of inclusion may increase the total tract digestibility of nutrients. Lindberg & Cortova (1995) reported that lucerne leaf meal appears to have potential as a feed for pigs because of its relatively high total tract digestibility of nutrients and energy. All these factors can have positive effects on the performance of growing pigs. However, there are reports indicating that both feed intake and digestibility may decrease markedly with increasing inclusion of forage leaf meal in the diet due to high fibre content (Ly *et al*., 1998; Lindberg & Andersson, 1998).

Each individual feed source is different in fibre content and in proportions of fibre components such as hemicellulose, cellulose and lignin (Bach Knudsen 2001), of which hemicellulose has the highest digestibility (Dierick *et al*., 1989). The diet digestibility depends on both the fibre content in the diet and the composition of the fibre (Lindberg & Cortova, 1995). In addition, fibre utilisation is affected by the age of the pig, as this interacts with the digestive processes and there is a gradual adaptation over time to exposure to fibre-rich diets (Wenk, 2001). Intake of fibre can stimulate the development of the microbiota in the hindgut, where fermentation of undigested organic matter from the small intestine takes place. This results in production of volatile fatty acids that provide energy to the animal. Therefore, the ability of the pig to digest dietary fibre varies with its age or live weight (Noblet & Goff, 2001). Consequently, adult growing pigs and sows have higher digestibility of fibrous components as well as other dietary components and energy than young pigs (Le Goff *et al*., 2002; 2003).

It has been shown that addition of legume leaf meal (leucaena and Stylo leaf meal) to the diet of local Moo Lath pigs, at a level up to 20%, can result in a growth rate of up to 350 g day^{-1}, compared with100 g day^{-1}on a traditional diet (Stür *et al*., 2007; Phengsavanh and Phommaly, 2010; Phengsavanh *et al*., 2010b). However, there is also a need to consider other criteria used by farmers when selecting forage legumes, such as the ease of planting and harvesting, plant re-growth capacity after harvest and forage palatability to pigs (Stür *et al*., 2008). All these criteria must be fulfilled for wide adoption of forage legumes by farmers.

2.4 Energy and protein requirements of native Moo Lath pigs

Energy requirements are expressed on different bases, such as digestible energy (DE), metabolisable energy (ME) and net energy (NE) (Noblet, 2007).

Digestible energy is the proportion of gross energy in the feed remaining after digestion and can be estimated from the difference between energy in food ingested and energy in faeces voided (Adesehinwa, 2008). The ME content of a feed is the difference between DE and energy losses in urine and gases. Noblet *et al*. (1994a) reported that the average energy loss in methane is around 0.4% of DE intake in growing pigs. Noblet & Shi (1993) reported that in sows fed at maintenance level, methane production is around 1.5% of DE and it can reach around 3.0% of DE with high fibre diets (Le Goff *et al*., 2002b). NE is defined as ME minus the heat increment associated with metabolic utilisation of ME and the energy cost of ingestion, digestion and some physical activities (Noblet & Henry, 1993; Noblet *et al*., 1994a).

The DE values for separate feedstuffs are assumed to be additive when included in a diet and the ratio of ME to DE is assumed not to change very much (Farrell, 1978; Morgan & Whittemore, 1982 *cit*. NRC 1998). However, the quality and quantity of protein in the diet is reported to affect the relationship between ME and DE (den Hartog & Verstegen, 1984). The ME decreases if protein is of poor quality and if excess protein is ingested. This is because the amino acids are not used for protein synthesis, but are catabolised and used as a source of energy, and the excess nitrogen is excreted as urea (NRC, 1998). Therefore, good diet formulation requires that a balance is attained between the crude protein (CP) and energy content in the diet (Longe, 1988). According to Cole (1984), the energy content of the diet generally controls the amount of feed consumed under *ad libitum* feeding conditions, and pigs will compensate for a decrease or increase in the nutrient density of the diet by increasing or decreasing their feed intake to normalise energy intake. However, voluntary feed intake may vary considerably from day to day and among individual pigs (Frank *et al*., 1983).

Net energy is the most accurate system available for energy evaluation of pig feed (Noblet & Champion, 2003; Noblet & Milgen, 2004). In this system, faecal, urinary and gaseous losses of energy are accounted for and, in addition, the system accounts for losses in energy as heat (Noblet, 2006). Therefore, NE is the energy retained by the animal, which can be used for productive purposes such as protein and fat deposition (Ewan, 2001; Moehn *et al*., 2005). The NE system is particularly useful when considering alternative ingredients to maize and soybean meal (Nehring & Haenlein, 1973). The energy value of protein or fibrous feeds will be overestimated when expressed on a DE or ME basis, while fat or starch sources are underestimated in a DE system (Noblet *et al*., 2003a; Noblet, 2006).

Dietary protein supply is one of the major factors influencing the productivity of pigs. Good quality protein provides the 10 essential amino acids (EAA) required for normal body function in the amounts and proportions necessary for the particular needs of the pig (Adesehinwa & Ogunmodede, 1995). Amino acids are critical nutrients required by all classes of pigs for physiological processes, maintenance, growth, gestation and lactation (Fashina, 1991). Therefore, supplementation of the diet with amino acids to enhance the quality of the dietary protein is common practice, particularly in the poultry and pig industries (Buttery & Mello, 1994). However, incorrect amino acid supply gives poor pig performance, as the absorbed amino acid pattern is not ideal for optimal protein deposition (Henry, 1988; Chiba *et al*., 1991). The capacity of the diet to provide sufficient EAA and nitrogen for the synthesis of non-essential amino acids (NEAA) determines the adequacy of the dietary protein level (NRC, 1998). Thus, a nutritionally balanced ration is needed for optimal pig performance.

Bender (1975) reported that lower levels of dietary protein are required to maximise growth and efficiency of gain for a protein source with a well-balanced amino acid profile. Therefore, protein quality becomes synonymous with amino acid balance. The amino acid requirements decrease as the pig becomes heavier, which means that the requirements are greatest during the rapidly growing stages of young animals (Conrad, 1984). The changes in the rate of growth and body composition form the basis for recommending different dietary protein levels to meet the amino acid requirements during the life of pigs (Fanimo, 1991).

There are strong and well-established relationships between the requirement for amino acids in relation to energy and amino acids are only utilised and deposited as protein if there is sufficient energy available. However, the optimal ratio of EAA to energy is not the same for each genotype and depends on the maximum amount of lipids that must be deposited per gram of protein. Pigs can only deposit protein optimally if sufficient lipid is deposited too. This minimal amount of dietary energy per unit of dietary protein is less for a lean type of pig than for an obese type (Campbell *et al*., 1984, 1985). Results presented by Yen *et al*. (1986) and Campbell *et al*. (1988) suggest a requirement of 0.80 and 0.71 g lysine per MJ DE, respectively, for female pigs. Chiba *et al*. (1991) suggested 0.72 g of lysine per MJ DE. Bikker *et al*. (1994b) reported that the optimum ileal digestible lysine to energy ratio (g per MJ DE) for average daily gain (ADG) and for minimal gain per feed is about 0.57, while that for maximum protein deposition is about 0.62.

Unfortunately, there is little information on the energy and protein requirements of local pig breeds in Lao PDR, such as the Moo Lath pig. Therefore, in common practice the protein and EAA levels recommended by the National Research Council (NRC, 1998) are used. However, these recommendations should only be used as a guideline for the formulation of diets for pigs of local breeds, as they are derived from data on exotic pig breeds kept under quite different conditions to pigs in Lao PDR. Previous studies on the protein requirements of native pigs in Vietnam and Italy (Ly *et al*., 2003;

Pham *et al*., 2010; Sirtori *et al*., 2010) showed that the NRC protein recommendations were too high for native pigs. Moreover, it is important to avoid excess protein in the diet, since this will be counterproductive for growth and feeding efficiency (Hansen & Lewis, 1993; Barea *et al*., 2006).

Based on our present knowledge of the performance traits of native Lao pigs, such as the Moo Lath breed, they can be assumed to require less dietary CP than exotic (*e.g*. European) breeds. Thus, it is of great interest and practical relevance to establish suitable levels of CP in the diet of native Lao pigs.

3 Summary of materials and methods

3.1 Location of study areas

The studies reported in Papers I and II were carried out in five Northern provinces of Lao PDR. The Northern region is characterised as mountainous and is home to many ethnic groups, which are classified according to similarity of culture and dialect into four main groups: Lao-Tai, Mon-Khmer, Hmong-Mien and Tibeto-Burman. The agricultural production systems are mainly shifting cultivation upland farming systems, with small areas of lowland paddy rice along the valleys.

One agronomy trial (Paper III) and two feeding trials (Papers IV and V) were conducted at the Livestock Research Centre (18°15´N, 102°27´E) of the National Agriculture and Forestry Research Institute (NAFRI) about 40 km north of Vientiane, Lao PDR, at an altitude of 202 m asl. The experimental soil was a sandy loam, with 66% sand, 21% loam and 13% clay (0-20 cm). The main chemical characteristics of the experimental soil were: pH 5.2; 1.45% organic matter; 0.03% N; 13.3 mg P kg^{-1}; 360 mg K kg^{-1}; 780 mg Ca kg^{-1} and 320 mg Mg kg^{-1}. The climate is tropical monsoon, with a dry season from November to April and a wet season from May to October. Mean annual rainfall in the study area is 1660±300 mm, 95% of which occurs from May to October, with a peak in August to September. The mean maximum temperature ranges from 23.5 to 31.3°C and the mean minimum temperature from 16.4 to 24.9°C.

3.2 Experimental design (Papers I-V)

The survey on pig rearing systems and feeding and performance of pigs in Papers I and II used two methods to collect primary information. These were farmers' group meetings and a household survey using a semi-structured questionnaire. The focus group meetings were designed to obtain general information about the main agricultural and livestock activities and detailed information about the pig production systems practised by farmers in the village, and to discuss issues associated with these pig production systems. The information from the focus group meetings was used to complement and corroborate farmers' responses in the individual interviews. The interviews with individual farmers were used to collect details on the management, productivity, problems and benefits of raising pigs. This information, gathered through face-to-face interviews using a semi-structured questionnaire, was followed by probing questions to gain a deeper understanding of the issues.

In Paper III (the agronomy trial), a 5 x 3 x 2 factorial (species/varieties, harvesting intervals and seasons) randomised complete block design with four replicates was used. Five forage legumes (*Aeschynomene histrix* BRA 9690, *Canavalia brasiliensis* CIAT 17009, *Stylosanthes guianensis* CIAT 184, *Stylosanthes guianensis* Composite and *Vigna unguiculata* CIAT 1088-4) were evaluated in the trial. Three harvesting interval treatments were applied (harvesting every 21, 30 or 45 days). Data were collected over one wet and one dry season. The plot size was 1 m x 1 m.

In Paper IV, three growth experiments (weaner, grower and finisher) were carried out. In each experiment, a group of six pigs was allocated to each of five experimental diets according to a completely randomised design. The treatments were based on different levels of dietary crude protein content for weaners, growers and finishers, respectively. The duration of the experiments was 63 days for weaners, 47 days for growers and 42 days for finishers.

The forage legume feeding experiment in Paper V was arranged according to a completely randomised design. A group of six pigs was assigned to each of eight experimental diets, which were based on the two control diets (traditional diet with and without soybean meal) and different amounts of two forage legume leaf meals that replaced soybean meal CP in the six remaining diets at the levels 1/3, 2/3 and 3/3. The duration of the experiment was 73 days, with 14 days extra for adaptation to the diets and pens.

3.3 Survey on rearing and feeding systems in smallholder pig production: Selection of provinces, district, village and farmers (Papers I and II)

The selection of provinces was based on the importance of pig production in each province. All Northern provinces were ranked according to the total number of pigs, and the five provinces with the highest pig populations were selected for the survey.

In each of the five selected provinces, one district was selected from the list of all districts, based on the same criterion as for the selection of province. In the selected districts, all villages were grouped in clusters based on market accessibility, defined in terms of time needed to travel from the village to the district market. Villages were then grouped as: (1) less than 1 hour, (2) 1 to 3 hours (3) more than 3 hours from the district market by car. Next, a transect was randomly selected from those radiating out from each district town. Along this transect, two villages within each of the three clusters were randomly selected for the survey. In total, six villages within each of the five districts were included in the survey. In each survey village, 10 households, or a minimum of 10% of pig rearing farmers in the village, were randomly selected for group meetings and individual interviews to ensure a representative sample. In total 341 respondents were interviewed. These included 110 Lao-Tai (Laoloum, Taidam and Leu), 113 Mon-Khmer (Khmu and Pai), 78 Hmong-Mien and 40 Tibeto-Burman (Ikor and Phounoi) households.

3.4 Agronomy study: Planting materials and management (Paper III)

The experimental area was ploughed twice at the end of April 2009 and again at the end of May 2009 to control weeds. The land was then harrowed with a disc harrow. The experimental plots were prepared by hand, using a hoe to break large soil particles before planting.

Each plot was sown manually on 6 June 2009, and had five rows with 25 cm spacing between rows. The sowing rate was 4 kg ha^{-1}, or 5 g per 10-m row length. One main weeding was carried out 3 weeks after planting and the following weedings were carried out after each harvest occasion. The weeding was done manually. Cattle manure (9.7% N, 1.9% P and 12.6% K) was applied once after the first harvest occasion at a rate of 4 tons DM ha^{-1}, *i.e.* a total input of 388, 76 and 664 kg ha^{-1} of N, P and K, respectively.

3.5 Animals and management (Papers IV and V)

In the study presented in Paper IV, 90 local female Moo Lath pigs of different age (30 pigs per age group) were used. The weaner pigs were 3 months old (BW 5.04 ± 0.34 kg), the grower pigs were 7 months (BW 20.2 ± 0.32 kg) and the finisher pigs 9 months (BW 39.9 ± 1.80 kg).

In Paper V, 48 female Moo Lath pigs were used. They were 7 months old, with an average initial body weight (BW) of 14.6 kg.

All female Moo Lath pigs were purchased from upland villages in the Vientiane province of Lao PDR. On arrival, the pigs were treated for internal parasites and vaccinated against foot and mouth disease (FMD) and classical swine fever (CSF). They were kept in quarantine pens for one week and any pigs with suspected health problems or noticeably lower growth rate were identified. Finally, healthy pigs were selected by visual assessment and were used in the experiments. The pigs were allowed to adapt to feed and pens for 14 days.

The pigs were housed in individual pens (1 m x 2 m) with a concrete floor. The pens were disinfected before the experiments and were cleaned daily with water, before feeding, during the experiment. The animals were weighed at the start of the experiment and thereafter weekly, always in the morning before feeding.

3.6 Diet and feeding (Papers IV and V)

In Paper IV, three experiments were conducted according to growth stage of local pigs, such as weaner (5-20 kg), grower (20-40 kg) and finisher (40-60 kg). The experimental diets were formulated to contain different levels of crude protein as follows:

In Paper IV, the experimental diet for weaners contained (DM basis) 14, 16, 18, 20 and 22% CP, and were formulated to contain (DM basis) 15.6 ± 0.06 MJ ME; the experimental diets for growers contained 11, 13, 15, 17 and 19% CP, and were formulated to contain 13.4 ± 0.07 MJ ME; and the experimental diets for finishers contained 9, 11, 13, 15 and 17% CP, and were formulated to contain 13.2 ± 0.10 MJ ME. All diets were formulated using ingredients from locally available feedstuffs (rice bran, maize, soybean meal).

In Paper V, control diet 1 was a traditional diet and control diet 2 contained soybean meal as the only protein supplement. The other six diets contained forage legume leaf meal (*Stylosanthes guianensis* Composite (Stylo) or *Aeschynomene histrix* BRA 9690 (porcupine joint vetch)) substituting for soybean meal CP at levels of 33, 66 and 100%. Thus diets 3, 4 and 5 contained Stylo leaf meal at levels of 13, 21 and 37% of the feed, respectively, while diets 6, 7 and 8 contained porcupine joint vetch leaf meal at levels of 11, 19 and 32% of feed, respectively.

The diets were offered in mash form with addition of water (2:1 w/w) at feeding. Feed was given *ad libitum* and twice daily, at 07:00 h and 16.00 h. Water was available all the time through drinking nipples.

3.7 Carcass analysis

In Paper V, all pigs were slaughtered at the end of the experiment for carcass analysis. The pigs were weighed 24 hours prior to slaughter and feed was withdrawn while water was available until 5 hours prior to slaughter. The pigs were slaughtered by stunning, followed by bleeding out. They were de-haired using hot water (80-100 °C), and head, hooves and inner organs were removed. The hot carcass was weighed and then split down the midline into two sides. One side was used for measuring carcass parameters, which included back fat at P1 (at the shoulder, over the third rib), P2 (over the 10^{th} rib) and P3 (over the ham) and the thickness of the eye muscle with the use of a ruler. The selected carcass half was dissected into the lean meat, bones and fat (back fat and abdominal fat). The small and large intestines were collected at slaughter, their contents were removed and their length and empty weight were recorded. The weight of other inner organs, including the stomach, liver, heart and kidney, was also recorded.

3.8 Sample collection and measurements

In Paper III, the first harvest of forage legumes was carried out 60 days after planting to ensure plant uniformity and then the treatments were applied. The treatments were continued for 1 year (from August 2009 to July 2010). The cutting height was 25 cm above the ground, or above at least 3-4 growing points to ensure survival of the plants. Whole plot biomass was immediately weighed in the field and sub-sampled for dry matter (DM) analysis.

In Papers IV and V, amounts of feed offered and refused were recorded individually daily during the experiments. Samples of the feed offered were taken weekly. Feed refusals were collected, weighed and recorded daily and pooled to weekly samples for DM determination.

3.9 Chemical analysis

Forage and feed samples were dried in a forced-air oven at 60 °C for 48 hours to determine DM content. Samples for chemical analyses were pooled treatment-wise. The samples were ground in a Wiley mill to pass a 2-mm screen and thereafter analysed for ash, crude fibre (CF) and nitrogen (N) content according to AOAC (1990). The CP content was calculated as 6.25 x N. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) content were determined according to the procedure of Van Soest *et al.* (1991).

Amino acid analysis was performed by ion exchange chromatography using a Biochrome 20 analyser (Phamacia Biotech Ltd, Cambridge, UK). Methionine and cysteine were analysed after oxidation with performic acid before hydrolysis. Tryptophan was determined after alkaline hydrolysis using 4 M $Ba(OH)_2$.

3.10 Statistical analysis

The data collected in Papers I and II were entered into a spreadsheet and analysed using PASW Statistics 18 (2009) for descriptive analysis of means, medians and ranges, frequency of distribution and variation. The growth rate and reproductive performance were analysed statistically by analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of Minitab Statistical Software (Minitab, 2007).

The data in Papers III, IV and V were analysed with analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of Minitab Statistical Software (Minitab, 2007). When the differences between means were significant at the probability level of $P<0.05$, the means were compared using Tukey's pairwise comparison test.

4 Summary of results

4.1 Pig rearing systems in smallholder production systems in Northern Lao PDR (Paper I)

Smallholder pig rearing systems

The farmers raised pigs in different production systems according to ethnic practices, distance from the town centre and agricultural production system. In general, there were three main production systems:

Free-scavenging system: In this system, pigs were allowed to scavenge freely for feed all year round. Farmers gave only small amounts of additional feed to scavenging pigs. Farmers practising the free-scavenging system kept pigs mostly for piglet production, and had 2-4 sows plus piglets. In most villages pigs were kept in simple shelters, but in some villages pigs simply stayed under dwellings, under rice storage sheds or under trees. Free-scavenging was typical for more remote, less accessible areas in which the agricultural system, especially crop production, was extensive. This system was practised by three main ethnic groups, Hmong-Mien, Tibeto-Burman and Mon-Khmer. The system was not common for the Lao-Tai ethnic group.

Semi-scavenging system: The semi-scavenging system was used for both piglet production and fattening. In this system, pigs were allowed to scavenge freely only after the main crops had been harvested. In the free scavenging time, farmers provided small amounts of feed each day and pigs had to find the rest of their feed by themselves. During the planting and crop growing seasons, pigs were confined either in pens or enclosures, built near to the villages or close to the crop production areas. At this time, pigs only received feed from their owners. This system was practised in all areas, but was more common in the most remote areas, and was practised more by the Mon-Khmer and

Hmong-Mien people, but not commonly by the Lao-Tai and Tibeto-Burman ethnic groups.

Year-round confinement system: This system was found mainly in the areas closer to the district centres. There were two different types of confinement: pens and enclosures, and pigs were normally kept in these throughout the year. The penning system was found to be the most frequently practised pig production system for the Lao-Tai and Tibeto-Burman ethnic groups, but was not common for the Mon-Khmer and Hmong-Mien groups. Pig production in this penning system was usually more intensive than in other systems, and farmers in this system had started to use exotic and crossbred breeds and feed concentrate to either piglets and/or to growers. Farmers vaccinated their pigs on a regular basis and sometimes also de-wormed them. The Mon-Khmer, Hmong-Mien and Tibeto-Burman ethnic groups used enclosure systems for raising pigs, with the aim of keeping pigs away from crops and improving village sanitation.

Constraints in smallholder pig production

The main problems in smallholder pig production systems were outbreaks of disease, slow growth rates, difficulty in finding feed and high mortality of piglets. In addition to these, several other problems such as insufficient funds to expand pig production, lack of labour to properly manage pigs and the high cost of commercial feed were mentioned. Outbreaks of disease was the most serious problem and often caused losses of 40-80% of the herd, but in some cases mortality was as high as 100%, particularly in free-scavenging and semi-scavenging production systems. Farmers had little knowledge of how to prevent disease epidemics and only a small number of farmers vaccinated their pigs against classical swine fever (CSF).

4.2 Pig feeding systems, productivity and reproductivity of pigs in smallholder production systems in Northern Lao PDR (Paper II)

Feeding systems in smallholder pig production systems

Feed resources used for pigs by smallholder pig farmers were mainly planted feeds (maize, cassava root, pumpkin fruit and leaves) and other locally available feedstuffs, such as crop by-products (rice bran and broken rice), distiller's waste (from local rice wine production) and green plant material from crops or collected from native plants.

Rice bran was used by almost all farmers surveyed. Maize, cassava, a taro-type plant called *bon* (*Colocasia esculenta*) and banana stems were also commonly used. Other feeds, such as broken rice, pumpkin fruits, distiller's waste and green plant material such as leaves of *yahuabin* (*Crassocephalum crepidioides*), paper mulberry (*Morus papyrifera*), *phak hom* (*Amaranthus viridis*), pumpkin tops and sweet potato leaves were also used, depending on availability. The availability of these feedstuffs varied throughout the year, and depended mainly on seasonality, agricultural practices in the area and the traditional practices of the different ethnic groups. The Lao-Tai group used more rice bran, broken rice, local alcohol distiller's waste and various green plant materials. Few farmers from the Lao-Tai group, who engaged in more intensive pig production systems, used commercial feed for their pigs. The other three ethnic groups used a mixture of available feedstuffs, including rice bran, maize, cassava and green plant material.

Most farmers fed their pigs twice a day, in the morning and in the afternoon. The provision of concentrate feed to the pigs was not common in the survey area. Some farmers (around 30%) provided salt to their pigs. Most farmers supplied water to their pigs only during feeding time as a mixture with feed. Only a small group of farmers supplied extra water during the day. Women and children were responsible for pig production in the family, particularly collection of feed, cooking of feed and feeding of pigs.

Productivity and reproductive performance

The growth rate of pigs differed among the four ethnic groups. The highest growth rate was found in the Lao-Tai group (140 g day^{-1}) and the lowest in the Mon-Khmer group (104 g day^{-1}). Pig growth rates also differed among households located in different clusters (*i.e.* at different distances from the district centre), and also depended on access to feed resources. Pigs reared by households closer to the district centre had higher growth rates (133 g day^{-1}) than pigs raised at a greater distance from the district centre (103 g day^{-1}).

Reproductive performance was similar across all ethnic groups. The only significant difference was in the number of live piglets per litter at weaning, which was highest in the Lao-Tai group (5.2) and lowest in the Hmong-Mien group (3.6). There were no differences in reproductive performance related to distance from the district centre. However, the number of piglets surviving from birth to weaning was highest in the areas closest to the district centre (5.3) and lowest in the areas further away (3.4).

4.3 Effect of harvesting interval on yield and chemical composition of five tropical forage legumes (Paper III)

Effects of variety, harvesting interval and season on DM yield of forage legumes

Variety, harvesting interval and season had significant effects on DM yield of the five forage legumes tested (*Aeschynomene histrix* BRA 9690, *Canavalia brasiliensis* CIAT 17009, *Stylosanthes guianensis*CIAT 184, *Stylosanthes guianensis* Composite and *Vigna unguiculata* CIAT 1088-4). Increasing the harvesting interval resulted in significantly increased DM yield in all species/varieties except Vigna. The highest DM yield was obtained when forage was harvested every 45 days compared with harvesting every 21 or 30 days (P<0.001), while differences between 21 and 30 days harvesting interval were not significant. Stylo Composite had the highest DM yield, while Vigna had the lowest (P<0.01). The DM yield of all species/varieties was equally affected by seasonal effects. All species produced the highest DM yields during the wet season, about three times higher than in the dry season (P<0.001). Stylo 184 had the most even yield distribution over the seasons, while Vigna did not survive the entire experimental period, as it dried off in the beginning of the dry season in all harvesting interval treatments. There were no interactions between species/varieties and harvesting interval treatment

Effects of variety, harvesting interval and season on chemical composition of forage legumes

Harvesting interval affected the chemical composition of the forage legumes. All species except Stylo 184 had the highest CP content with the shortest harvesting interval (P<0.001). There was a tendency for a lower CP content with extended harvesting interval, but this was only significant for Stylo Composite. Stylo 184 and Stylo Composite had the significantly lowest CP content, while Canavalia tended to have the highest CP content. Otherwise, differences between species/varieties were small.

The CF content in all species with the exception of Vigna was generally smallest with the shortest harvesting interval treatment (P<0.001). A similar pattern was observed for the ADF content with the exception of Stylo Composite, for which there was no significant effect of the harvesting interval treatment. With respect to NDF content, differences between harvesting interval treatments were generally not significantly different for Stylo 184, Stylo Composite and Vigna, while the content significantly increased with increasing harvesting interval for porcupine joint vetch and Canavalia. There were small differences in fibre content between the legume species with the exception of Vigna, which had the lowest content of fibre ($P<0.001$).

There was a seasonal effect on the chemical composition of the plants, in particular the DM and CP contents, with a similar pattern for all species. The DM content was higher in the dry season than in the wet season ($P<0.001$), whereas the CP content was higher in the wet season than in the dry season ($P<0.001$). There were no significant effects of season on the fibre content.

4.4 Effects of dietary protein levels on growth performance and feed intake in native Moo Lath pigs (Paper IV)

Effect of dietary protein level on performance of weaned Moo Lath pigs

The dietary protein level affected ($P<0.05$) daily feed intake (DFI), final BW and average daily gain (ADG) of weaned Moo Lath pigs, with greater final BW, ADG and DFI in total and as a percentage of BW in pigs fed diets with 18% CP or higher. Feed conversion ratio (FCR) was also affected by protein level in the diet ($P<0.05$), with the lowest values for pigs fed diets with 20% CP or higher.

Effect of dietary protein level on performance of growing Moo Lath pigs

The DFI, final BW and ADG were affected by the protein level in the diet ($P<0.05$), with the highest values of all three parameters in pigs fed the diet with 15% CP. The FCR was affected by protein level in the diet ($P<0.05$), with the lowest values in pigs fed the diet with 15% CP.

Effect of dietary protein level on performance of finishing Moo Lath pigs

The final BW and ADG were affected by protein level in the diet ($P<0.05$), with the highest values in pigs fed a diet with 11% CP or higher. The FCR was also affected by protein level in the diet ($P<0.05$), with the lowest values for pigs fed a diet with 11% CP or higher. The DFI was not affected ($P>0.05$) by protein level in the diet.

4.5 Effect of replacing of soybean protein with protein from porcupine joint vetch and stylo on growth performance of native Moo Lath pigs (Paper V)

Effect on feed intake

Growing Moo Lath pigs that received a diet with soybean meal (diet C) had higher (P<0.05) intake of DM (DMI), crude protein (CPI), metabolisable energy (MEI) and crude fibre (CFI) than the diet without soybean meal (diet T). Replacing soybean meal with legume leaf meal reduced (P<0.05) DMI, CPI, MEI and CFI, with a similar response for both Stylo leaf meal (SLM) and porcupine joint vetch leaf meal (PLM). Increasing replacement of soybean protein (33, 66 and 100%) with legume leaf meal protein resulted in a linear (P<0.05) decrease in DMI, CPI, CFI and MEI.

Effect on growth performance

The average daily gain (ADG) was higher (P<0.01) and the feed conversion ratio (FCR) was lower (P<0.05) in the diet with soybean meal (diet C) than in the diet without (diet T). Replacing soybean meal with legume leaf meal reduced ADG, with similar responses for both SLM and PLM, while FCR was unaffected. Increasing replacement of soybean protein (33, 66 and 100%) with legume leaf meal protein resulted in a linear (P<0.05) decrease in ADG, while FCR was unaffected.

Effect on carcass traits and organ weight

The experimental diets did not affect (P>0.05) dressing percentage of any treatment. However, slaughter weight, hot carcass weight, eye muscle thickness, back fat, fat in carcass and lean meat percentage were lower (P<0.05) with diet T than diet C. Replacing soybean meal with legume leaf meal reduced (P<0.05) slaughter weight, hot carcass weight, back fat at P2, fat in carcass and lean meat, with similar responses for both SLM and PLM. However, replacing soybean meal with legume leaf meal had no effect (P>0.05) on eye muscle thickness and back fat at P1. Increasing replacement of soybean protein (33, 66 and 100%) with legume leaf meal protein resulted in a linear (P<0.05) decrease in slaughter weight, hot carcass weight, back fat at P1, P2 and P3, fat in carcass and abdominal fat, while lean meat content was unaffected. There were highly significant differences (P<0.001) in weight of organs (stomach, liver, kidney, pancreas, heart and small intestines) and large intestine (P<0.01). The pigs that received diet C tended to have heavier organs (stomach, liver, kidney and heart) than those on diet T, SLM and PLM. However, there were no differences (P>0.05) in weight of pancreas, small and large intestines between diet T and diet C. There was similar weight of organs (stomach, liver, kidney, heart and large intestine) with both legume leaf meals. The level of soybean CP replacement by legume leaf meal had an effect on the weight of liver, kidney, pancreas and heart, but not on that of other organs (stomach, small and large intestine).

5 General discussion

5.1 Smallholder pig production systems in Northern Lao PDR

This thesis showed that the types of pig production systems employed by farmers in Northern Lao PDR are related to the production purposes, intensity of cropping and ethnic traditions (Paper I). Similar results have been reported by Keoboualaphet & Miklet (2003) and Phengsavanh & Stür (2006). The farmers surveyed in Northern Lao PDR kept pigs for three main purposes: (1) piglet production, (2) pig fattening for sale, and (3) a mixture of piglet production and pig fattening for sale. The type of production was often related to ethnicity. Traditionally, Hmong-Mien and Mon-Khmer farmers are the main producers of piglets to sell to other people in or within the surroundings of the village, to be used either for reproductive purposes or for fattening. Lao-Tai farmers, who mainly practise fattening of pigs, tend to buy piglets rather than producing piglets themselves. Tibeto-Burman farmers are engaged in both piglet production and pig fattening systems. However, since disease epidemics have caused serious animal losses in many villages, Lao-Tai farmers have started to produce piglets by themselves. At the same time, some Hmong-Mien and Mon-Khmer farmers have started to keep some pigs for fattening as well.

Smallholder farmers in Northern Lao PDR kept approximately 5 to 6 pigs per family (Paper I). However, the number of pigs per family was always related to the purpose of keeping pigs. Households producing piglets had on average 7 to 8 pigs, those that kept fattening pigs had 3 to 4 pigs and those producing both piglets and fattening pigs had 8 to 9 pigs. This was clearly higher than the average of 3 to 4 pigs per family reported previously for smallholder farmers in Northern Lao PRD (Vongthilath & Blacksell, 1999). However, the number of pigs per family in fattening systems in the North of Lao PDR (Paper I) was in general similar to that reported in other studies on smallholder pig systems in developing countries that raised only fattening pigs

(1-3 per household) (Le *et al*., 2002; Jones, 2002; Kagira *et al*., 2010; Karimuribo *et al*., 2011; Mutua *et al*., 2012). However, the number of pigs per family is always related to management and labour. In Paper I the farmers reported that in general, keeping a high number of pigs requires more time and labour inputs for collecting feed and there are higher risks when diseases break out, so most of them could not afford to have more pigs. This was in agreement with Ajala *et al*. (2009), who reported that feeding was the limiting factor in coping with a pig herd of increasing size. However, some farmers in Lao PDR keep many pigs for security as they can sell a few pigs immediately when cash is needed.

The native pig breeds Moo Lath and Moo Hmong are commonly kept in the study areas. These native breeds are important for farmers in free-range scavenging systems, as they are well adapted to harsh conditions, particularly to scavenging part of their nutritional needs in free-range conditions, and can survive on poor quality feed (Kennard *et al*., 1996; Deka *et al*., 2007; Nwakpu & Onu, 2007). In addition, these breeds have high fertility and good disease resistance (Lekule & Kyvsgaard, 2003). In the rural mountainous areas of Northern Lao PDR, it is important that the local breeds also produce fat, which is important for people to use in cooking. Pigs are often slaughtered during traditional ceremonies, when fat is always separated out, processed (fried) and stored for many months. For this reason, local farmers prefer to raise native pigs rather than imported (exotic) pig breeds (Phengsavanh & Stür, 2006). However, Paper I showed that the situation in some Lao-Tai villages located close to urban centres is different because of the high demand for lean meat. Lao-Tai farmers have started to keep crossbred and pure exotic breeds, as they have higher growth rates and produce more lean meat, which is requested in the city markets (Phengsavanh & Stür, 2006).

Smallholder pig rearing systems

In general, smallholder pig rearing systems can be classified as (1) free-range scavenging, (2) semi-scavenging and (3) confined (in an enclosure or a pen). All three systems occur in Lao PDR (Keoboualaphet & Miklet, 2002; Wilson, 2007), as well as in other tropical countries (Kimbi *et al*., 2001; Lekule & Kyvsgaard, 2003). A free-range scavenging system is practised mostly in remote areas, where agricultural production is still very extensive. Pigs are allowed to roam freely around houses and villages to scavenge for their feed. This is a low cost system with low output (Wilson, 2007). The scavenging system is not only practised by smallholder farmers in Lao PDR, but also commonly in rural areas of South East Asian and other tropical regions (Deka *et al*., 2007; Huynh *et al*., 2007; Kagira *et al*., 2010). A semi-confining system is practised in areas where cropping is slightly more intensive and where most farmers keep pigs for piglet production. In this system, sows and piglets are allowed to scavenge freely in the dry season, but are confined in the planting season in order to prevent damage to the crops. This system is also practised by smallholder pig farmers in Botswana and Nigeria (Permin *et al*., 1999; Ajala *et al*., 2007), where pigs are tethered or kept in enclosures during the rainy season since they are prone to damaging crops. The increasing availability of feed during the rainy season may also act as a motivation for tethering the pigs (Ajala *et al*., 2007). Paper I found that a confined system is more common in lowland and easy-to-access villages, where farmers mostly fatten pigs for sale. Similar observations have been made in other tropical countries (Kariga, 2001; Lamke *et al*., 2002; Deka *et al*., 2007).

One reason for confining pigs in enclosures or pens in study villages is that in addition to livestock production, farmers also engage in cash crop production, which provides other important income for the family. Thus allowing pigs to roam freely might cause damage to these crops. Secondly, the study villages are near to roads and easy to access, so they are potentially at a higher risk of being exposed to epidemic diseases brought in by animal traders. Therefore, the farmers tend to keep pigs under confinement in pens.

Smallholder pig feeding systems

Paper II found that farmers in the study area opted to use a range of locally available feedstuffs, such as agricultural by-products (rice bran and broken rice), maize, cassava and several green plant materials. This is generally similar to what has been reported in other traditional pig production systems (Keoboualaphet & Miklet, 2002; Nsoso *et al*., 2006; Lemke & Zarate, 2007; Kumaresan *et al*., 2007). This practice is likely to expose pigs to a limited supply of nutrients (Lekule & Kyvsgaard, 2003). Traditional feedstuffs mainly supply energy, while they are low in CP content. In general, the nutritional quality of these feedstuffs is low. For example, local rice bran contains a large amount of rice husks and therefore the CP content may be 7-8% or lower (Phonekhampheng *et al*., 2008). In contrast, the protein sources to which farmers have access come from green plant materials and are medium to high in CP, but the supply of this may become restricted during the dry season. However, the overall nutritional quality of these green plant materials may be low due to high fibre content, which may have negative impacts on digestibility and feed intake (D'Mello, 1992). All these factors influence the quality of traditional diets, which are nearly always insufficient in protein (Ocampo *et al*., 2005). For example, Kumaresan *et al*. (2009) reported that the CP content of pig feed in a mountainous area of North-east India was only around 7%, which is lower than the requirement of growing (14% CP) and finishing (10% CP) pigs of local breeds (Ly *et al*., 2003; Pham *et al*., 2010).

Although there are several feed resources in the area, the availability of these feeds differs over the year, which forces farmers to use the feed resources intermittently. Another limitation is that the amount of feed given to pigs is generally below their needs, which is also common in tropical smallholder pig production systems (Phengsavanh & Stür, 2006; Kariga *et al*., 2010). The underfeeding can be seen in many areas, and is due to the fact that the collection of green plant material is time-consuming. It often takes up to 3 hours per day and is usually done by women and children (Losada *et al*., 1995; Keoboualaphet & Miklet, 2002; Kumaresan *et al*., 2009; Kariga *et al*., 2010). In addition to this, there is loss of feed through poor design of the feed trough and there is competition for feed in the pens. This is a problem for small pigs in particular. As a result they scarcely get enough feed and tend to suffer from underfeeding (Phengsavanh *et al*., 2008). Thus, unbalanced diets and under-feeding are the main limitations in smallholder pig production systems, so pigs generally fail to realise their performance potential (Mutua *et al*., 2012).

Productivity performance of pigs in smallholder production systems

The growth performance of pigs in smallholder systems in Lao PDR is low, with an ADG of around 100 g (Paper II). This is comparable to that of other local pigs raised under tropical conditions, such as native Raad pigs in Thailand, Ban pigs in Vietnam and Nigerian pigs in Nigeria, which have ADG ranging from 120 to 130 g (Falvey, 1981; Lemke *et al*., 2006; Essien & Fetuda, 1989). However, Paper II showed that the growth rate of pigs was higher in the Lao-Tai ethnic communities and in areas closer to the urban centres, where the ADG was around 140 g. This may be explained by the fact that the Lao-Tai ethic group, which tends to live in lowland areas and often has a surplus of rice, uses more rice bran, broken rice and local alcohol distiller's wastes to mix with green plant material. Some have also started to use commercial feed. Duc *et al*. (1997) reported that under intensive conditions, the growth rate of Vietnamese Mong Cai pigs could reach an ADG of 280 g. Similarly, Phengsavanh & Phommaly (2010) reported that native Moo Lath Lao pigs grew up to 300 g per day when the traditional diet was supplemented with legume leaf meal. Therefore, in addition to the feeding, poor management and inbreeding have to be considered, as they are known to have a negative impact on the growth of pigs (Takahasi *et al*., 1991; Brandt & Moellers, 1999). Studies by Falvey (1981) and Stür *et al*. (2006) showed that the growth of native Thai and Lao pigs increased after deworming and supplementation of their diet with vitamins, minerals and legume leaf meal protein.

The reproductive performance of Moo Lath sows is relatively low, like that of other local breeds in the region (Le et al., 2005; Nakai, 2008), with on average 1.3 litter per year and around 6 to 7 piglets per litter. The performance found in Paper II is comparable to that reported by Ly (1999) for native Ban pigs in Vietnam and that of other unimproved breeds such as native pigs of a hill tribe pig in Thailand (Falvey, 1981), native pigs in Nepal (Gatenby & Chemjong, 1992) and Mukota pigs in Zimbabwe (Ncube et al., 2003). Besides the lower genetic potential of native pigs in Lao PDR, inbreeding and deficient feeding for lactating sows might be the main reasons for the low reproductive performance. Paper II found that a low quality diet was also likely to have a negative effect on the body condition of lactating sows. It usually took more than four months for sows to return to good body condition after weaning.

Another problem related to reproduction is boar selection and management. In many villages, top quality boars are often sold out for reproduction and fattening, so farmers often use the weaker boars left in the villages for breeding. Only a few of the farmers surveyed kept boars, which were rented out to other farmers for breeding. A similar situation can be seen in smallholder pig production in other developing countries and this can cause problems, since the low number of boars amongst farmers could lead to inbreeding (Wabacha, 2001; Lemke & Zerate, 2007). In the last few years, service providers have been established and bring boars to the villages for breeding, receiving piglets as payment (1-2 piglets per service) (Phengsavanh & Stür, 2006). However, farmers prefer to select from their herd, as after a few years they can fatten and sell the boar for meat. The management of boars is often problematic, as boars are often used for breeding at a young age and are underfed. Altogether, this indicates that increasing use of boars from the own herd and from the neighbours gives rise to inbreeding and consequently low productivity (Ajala et al., 2007).

In Paper II, it was found that the high mortality rate of piglets (up to 50%) usually occurred before weaning, and was of major concern to smallholders. The piglet mortality was higher than that reported for other smallholder pig production systems in other countries, such as 12% in Kenya (Wabacha et al., 2004), 19% in the Philippines (Lanada et al., 1999) and 4% in Vietnam (Thuy, 2001). Disease outbreaks and diarrhoea were the main causes of mortality. The outbreaks of disease may be related to lack of disease prevention measures, as well as poor management. The occurrence of diarrhoea in pigs involves interactions between sow, piglet, environment, management and nutritional status (Martineau et al., 1995; Chandra, 2002).

Production constraints in smallholder production systems

The main production constraints were mainly disease, high mortality of piglets and slow growth rate. Similar constraints have been identified in other traditional and smallholder pig production systems (More *et al*., 1999; Wabacha *et al*., 2004; Kariga *et al*., 2010). The most severe problems for farmers were those caused by epidemic diseases. Outbreaks were generally more severe in accessible villages than in remote villages which had limited contact with other villages and little or no influx of pigs from outside, and were therefore less prone to disease epidemics. As soon as villages in these remote areas become more accessible, however, the risk of accidental introduction of diseases increases drastically, through the visits of people such as meat and livestock traders. CSF, and most probably many other viral diseases, account for a large proportion of pig deaths in all pig rearing systems (Vongthilath & Blacksell, 1999).

The problem of diarrhoea in piglets is common in many smallholder pig production systems and causes considerable economic losses to pig farmers (Tuyen *et al*., 2005). Disease and diarrhoea occurrence in smallholder pig production in Northern Lao PDR may be related to the observed poor hygiene, and lack of disease prevention measures, as well as poor nutrition of the sow during gestation and lactation (Paper I). This latter observation was in agreement with Hong *et al*. (2006) who reported that the poor quality of feed and nutrient supply may be a contributory factor to a high incidence of diarrhoea in piglets.

Slow growth rate was primarily the result of poor quality and small quantity of local feeds provided to pigs, so the feeds and feeding system in smallholder pig production in Lao PDR clearly need to be improved. Options that have been explored in Lao PDR include the supplementation of traditional pig diets with forage legume leaf meal to improve the growth rate of native Lao Moo Lath pigs (Stür *et al*., 2007; Phengsavanh & Phommaly, 2010; Phengvilaysouk *et al*., 2011). One way to move forward would be to present these options to smallholder pig farmers through participatory methods in order to match them to household resources and production systems (Deka *et al*., 2007). The smallholder pig production systems need to be further intensified, as they have the potential to bring good revenue and can help to secure income security for smallholders and food security for the region.

5.2 Effect of harvesting interval on DM yield and quality of forage legumes

There were significant differences in DM yield among the five forage legumes studied (Paper III). The Stylo varieties (both Composite and CIAT 184) had higher average cumulative DM yield than the other varieties/species. Adjolohoun *et al.* (2008) also found that the yield of forage legumes was largely influenced by variety/species. The higher DM yield of Stylo varieties can be explained by the fact that they were able to maintain some growth during the dry season and had fast regrowth when the rains returned. These results were in agreement with studies in Lao PDR by Phengsavanh (2000), who reported that Stylo CIAT 184 was the only forage legume, from more than 100 varieties/species tested, that was suited to a wide range of agro-ecological environments in Lao PDR. Phaikeaew *et al*. (2004), Hare *et al.* (2007) and Adjolohoun *et al.* (2008) reported similar results from studies under comparable environmental conditions in Thailand and Benin. Apparently the effect of variety on DM yield is a result of plant ability to adapt to the local environmental conditions, particularly the soil and rainfall.

Porcupine joint vetch is another species which is considered to be well-adapted to various farming systems and environmental conditions (Peters *et al.,* 1994). It performed as well as Stylo 184 in Paper III and its yield level was in the same range as that reported from Nigeria by Merkel *et al.* (2000). Canavalia and Vigna showed poor adaptation to local conditions, as both varieties grew well only in the wet season, but suffered poor re-growth or dried out in the dry season. Therefore, the difference in ability of different varieties/species to stay green during the dry season has obvious practical implications for smallholder pig farmers in Lao PDR, who often face a feed supply shortage during the dry season.

As expected, the DM yields were affected by harvesting interval (Paper III). The longest harvesting interval (45 days) resulted in the highest DM yield of all species compared with shorter intervals (21 and 30 days). The results in Paper III are similar to those of studies on other tropical legumes by Mero & Udén (1997), Assefa (1998) and Hiep *et al.* (2008). The DM yield variation between harvesting intervals is due to the time allowed to plants for re-growth (Chaichi *et al*., 1996; Assefa, 1998). This could be related to the time needed to develop sufficient leaf area for maintenance of the plant (Trujillo *et al*., 1996).

It is well known from several studies (Kiyothong *et al*., 2002; Nworgu & Ajayi, 2005; Stür *et al*., 2006; Ajayi *et al*., 2007; Adjolohoun *et al*., 2008) that forage legumes have a high protein content (18-25%), which would provide opportunities for improving animal feed for resource-poor farmers. The data from Paper III confirmed this and showed an average CP content of the species studied that ranged from 19.0% (Stylo composite) to 22% (Canavalia). However, although forage legumes contain high levels of CP, they are also rich in fibre, and in many instances the fibre content may be equal to or exceed the CP content (D'Mello, 1992). This could have negative effects on the feed digestibility and is probably the main concern when selecting forage legumes for feeding pigs. However, the feed quality of forage legumes can be increased through suitable harvesting intervals (Adjei & Fianu, 1985; Kiyothong *et al*., 2002; Sukkasem *et al*., 2003). Thus, in Paper III the quality of forage legumes was improved by short harvesting intervals, with CP content increasing and CF content decreasing with a shortening of the harvesting interval. This may be the result of increased leafiness of the plants when the forage legumes are harvested at short intervals (Hare *et al*., 2004). Other studies of tropical legumes (*e.g*. Lazier, 1981; Adjei & Fianu, 1985; Hiep *et al*., 2008) have shown that their quality decreases with age, as reflected in decreased CP content and increased CF content with longer harvesting intervals. The results in Paper III suggest that a harvesting interval of 21 to 30 days would provide the best feeding quality and a reasonable yield for use as pig feed, especially of the Stylo varieties.

In addition to nutritional aspects, there is a need to consider other practical criteria used by farmers in selecting forage legumes. These include the ease of planting and harvesting, plant re-growth capacity after harvest and forage palatability to pigs (Stür *et al*., 2008). This will help farmers to identify and integrate suitable forage legumes into their production system as alternative protein sources for improving feed for pigs (Phengsavanh *et al*., 2004). If these feed resources are near to the village, it will make it easier for farmers to move from the traditional system to a more market-orientated system.

Moreover, if forage legumes are grown on their own land, farmers can gain other benefits such as soil fertility improvement, particularly in the upland region of Lao PDR, where low soil fertility is a major constraint to crop productivity and the cause of the chronic food insecurity of smallholder farmers (Douangsavanh *et al*., 2005). Thus, the integration of forage legumes into the cropping cycles could have the potential to enhance yields of subsequent crops through the increase in plant available nitrogen (N) in the soil (Odunze *et al*., 2004). This can be done through growing the legumes either in monoculture as a component in the crop rotation or in an inter-cropping system with crops such as maize or cassava, which are commonly planted by smallholders (Phengvichith, 2007). For example, maize cultivated in succession after a short fallow of Mucuna was reported to have significantly higher grain yield than the control plot without N fertiliser (Singh *et al*., 2004). A number of studies on inter-cropping (Odunze *et al*., 2004; Borin & Frankow-

Lindberg, 2005; Dung *et al*., 2005a; Phengvichith *et al*., 2006) have found that when forage legumes are inter-cropped with cassava and maize, this not only improves soil fertility but also increases crop productivity.

5.3 Effects of dietary protein levels on growth performance and feed intake in native Moo Lath pigs

The Moo Lath pig is one of the four native breeds kept by farmers in Lao PDR, the others being Moo Hmong, Moo Chith and Moo Deng (Keonouchanh *et al*., 2008). The Moo Lath pigs are characterised by a low BW, slow growth rate and high capacity to deposit fat (Paper I). Therefore, it is important to have a good knowledge of the genetic capacity of the pigs, because it is related primarily to the amount of dietary protein (amino acid) needed by the animals (Pham *et al*., 2010). It is well known that efficient animal production requires a careful balance between the animal's genetic potential and the quantity and quality of the nutrients consumed (Vansupen *et al*., 2008). Providing nutrients below the requirements will diminish growth performance. For instance, Paper II and Chittavong *et al*. (2012) reported that local pigs in smallholder production systems in Lao PDR suffer from poor nutrition, especially lack of protein, and concluded that this is one of the limiting factors for high performance of pigs in smallholder systems. However, Hansen & Lewis (1993) and Barea *et al*. (2006) pointed out that it is important also to avoid excess protein in the diet, since this will be counterproductive for growth and feeding efficiency. Therefore, it is of practical relevance to establish suitable levels of CP and amino acids in the diet of native Lao pigs.

Weaned Moo Lath pigs did not show any improvement in performance traits above a dietary CP level of 18% in DM (Paper IV). These results were in agreement with findings in Thailand on wild boar (Wattanakul *et al*., 2004) and native Kadon pigs (Vasupen *et al*., 2004) and in Lao PDR on native Moo Lath pigs (Keonouchanh *et al*., 2008).

Grower Moo Lath pigs showed the greatest feed intake and ADG, and the lowest FCR on a diet with 15% CP in DM. This result is supported by studies on protein requirements of growing native Mong Cai pigs in Vietnam (Ly *et al*., 2003; Pham *et al*., 2010), which showed that they required around 13 to 14% CP in DM for maximal growth. These results are also comparable to data on growing local breeds in other parts of the world, such as Italian pigs of the Cinta Senese breed that required around 13% of CP in DM (Sirtori *et al*., 2010) and indigenous pigs of Nigeria that required around 12% CP in DM (Anugwa & Okwori, 2008).

Finisher Moo Lath pigs showed the greatest final live weight and ADG, and the lowest FCR on a diet with 11% CP in DM or higher, while feed intake was unaffected by dietary CP level. The results are supported by results from studies on native Moo Lath pigs (Keonouchanh *et al*., 2008) and native Mong Cai pigs (Ly *et al*., 2003), suggesting that Moo Lath and Mong Cai pigs weighing more than 40 kg required a dietary CP level of 11 to 12 % in DM. This was also in line with the finding of Iberian pigs from Spain that require around 10% CP in DM (Barea *et al*., 2007).

Moo Lath pigs, at all stages of growth (weaning, growing and finishing; Paper IV) required less dietary CP than recommended by the NRC (1998). This could be due to the genetic make-up of native pig breeds, such as the Moo Lath, with lower muscle growth potential (Kumaresen *et al*., 2009; Jieng *et al*., 2012). In addition, the native pigs are early maturing and thus they tend to deposit body fat earlier than lean type pigs and therefore they require less protein per kg of feed than fast growing leaner breeds (Bikker *et al*., 1994; Chymonyo *et al*., 2005). Moreover, the ratio of fat to lean meat increases rapidly with increased live weight in native pigs and as a result their dietary CP requirement will be lower at higher weights than for lean types of pigs (Anugwa & Okwori, 2008; Pham *et al*., 2010).

The results from Paper IV indicate that reasonable target levels for CP in feed formulation for growing Moo Lath pigs should be 18% in DM for weaners, 15% CP in DM for growers and 11% CP in DM for finishers. This information is extremely valuable for smallholder farmers to define economically-favourable and environmentally acceptable levels of CP in pig diets to achieve optimal growth and maximum efficiency of nutrient utilisation for Lao pig breeds. However, further studies are needed to establish more precise protein and EAA requirements for growing Moo Lath pigs in order to achieve optimum protein nutrition and optimum performance of these pigs in smallholder production systems.

5.4 Effect of replacing of soybean protein with protein from porcupine joint vetch and stylo on growth performance of native Moo Lath pigs

In smallholder pig production in tropical countries, protein is perceived as the most limiting factor in the diet (Leterme *et al.*, 2005b; Ocampo *et al.*, 2005). Previous studies have shown that forage legumes have a high CP and EAA content and most of these legumes thrive in and tolerate adverse climate and soil conditions (D'Mello, 1995; Halimani *et al*., 2005; Phengsavanh & Stür, 2006). For these reasons, there has been a significant surge of interest in the use of forage legumes as sources of protein and other nutrients for pigs in smallholder production systems (D'Mello, 1995).

Effect on DMI

Low inclusion of leaf meal in the diet of pigs has been reported to increase DMI (D'Mello, 1995; Halimani *et al*., 2005). However, at higher inclusion levels DMI may be depressed, for instance with high inclusion of cassava leaf meal (Phuc *et al*., 2000), acacia and mopane leaf meal (Halimani *et al*., 2005), leucaena leaf meal (Phengsavanh *et al*., 2010b) and wild sunflower leaf meal (Fasuyi and Ibiyato, 2011). These results were confirmed in Paper V and in studies by Phengvilaysouk *et al*. (2011) and Kaensombath & Lindberg (2012), who found that replacing soybean CP with legume, cassava, wild sunflower and taro leaf CP resulted in lower DMI. The reduction in DMI was mainly caused by increasing fibre content in the diet with high inclusion rate. Increasing replacement of soybean CP resulted in a linear reduction in DMI with increasing dietary fibre (CF, NDF and ADF) content. Thus, in order to ensure a high DMI in growing pigs, the plant growth stage has to be considered, as that is a main factor influencing the composition and nutritive value of forage legumes. As plants grow, structural carbohydrates such as cellulose and hemicelluloses, together with the polyphenolic compound lignin, will increase. The plant fibre fractions may be poorly utilised by pigs (D'Mello, 1995), depending on their composition. The content of fibre will be a major issue if a substantial part of the soybean meal in the diet is to be replaced without affecting growth performance. In addition to the fibre content, several studies have also reported a reduction in DMI in pigs fed diets containing anti-nutritional compounds, such as mimosine in leucaena (Laswai *et al*., 1997; Cheverria *et al*., 2002). Moreover, the polyphenolic compounds found in most plant leaf meals may have negative effects on palatability, digestion and metabolism, with consequences for the DMI of pigs (Halimani *et al*., 2005; Regnier, 2011).

Effect on growth performance and carcass traits

In terms of growth performance, low inclusions of legume leaf meal gave the best comparisons to conventional diets (Paper V; Halimani *et al*., 2005). Moreover, low inclusion of forage legume leaf meal in traditional diets used in smallholder pig production supported an almost four-fold higher growth rate than obtained without supplementation (Paper I; Chittavong *et al*., 2012). Paper V clearly demonstrated the performance potential of native Moo Lath pigs when fed a nutritionally more adequate diet. The Moo Lath pigs were able to grow by up to 496 g per day when fed a diet with CP from soybean meal, which is similar to the growth rate of 520 g per day obtained by Keonouchanh *et al*. (2008) in their study on potential growth of native Moo Lath pigs fed nutrient-dense diets.

In Paper V, there was a decline in the growth rate of pigs that received diets where soybean meal CP had been replaced by CP from legume leaf meal. A marked reduction in growth rate (range 190-245 g day^{-1}) was apparent at 100% substitution level. A similar trend was observed in studies by Arage *et al*. (2005), Olayeni *et al*. (2006) and Phengvilaysouk *et al*. (2011). This can be explained by reduced feed intake resulting in lower ME and CP intake at high inclusion levels (Paper V). In addition, nitrogen retention may be impaired due to a reduction in CP digestibility and an increase in loss of endogenous protein (Jansman *et al*., 1995; Lindberg & Anderson, 1998; Phuc *et al*., 2000). Moreover, the EAA profile of forage legume leaf meal may not be as well balanced as that of soybean CP in relation to the EAA profile required by the growing pig (NRC, 1998; Leterme *et al*., 2005b). Therefore, in order to avoid impairing pig growth, it has been recommended that inclusion of leaf meal in the diet should not exceed 20-25% of total DMI in growing pigs (Phengsavanh *et al*., 2010b; Regnier, 2011).

Replacing soybean CP with legume leaf CP resulted in lower slaughter and hot carcass weight. However, eye muscle thickness and lean meat content were greater and back fat thickness and fat in carcass lower in pigs fed a diet where legume leaf meal CP had replaced soybean CP (Paper V). This finding was similar to results from other studies on feeding leaf meal to native pigs (Jimirez *et al*., 2005; Phengsavanh *et al*., 2010b; Phengvilaysouk *et al*., 2011). Paper V also showed that the back fat thickness and fat content in the carcass were greater when the soybean-supplemented diet was fed. This is probably due to the fact that increasing leaf meal content of the diet led to a decrease in the proportion of the digestible energy available for fat synthesis. Regarding carcass fat and lean content, the data in Paper V confirmed results from previous studies on native pigs such as Chinese Jinhua and Meishan pigs (Gispert et al., 2007; Mieo et al., 2009), Spanish Iberian pigs (Morales et al., 2003) and Creole pigs from Haiti (Renaudeau & Mourot, 2007). The higher back fat thickness and lower carcass lean content of these native pigs can be explained by their lower muscle growth potential and their greater ability to deposit lipids.

6 General conclusions

- Smallholder pig rearing systems in Northern Lao PDR are influenced by the farmer's reason for raising pigs, the intensity of cash crop production and ethnic traditions. The intensity of cash crop production, outbreaks of disease and resulting local regulations were the main drivers of changes in pig rearing systems in the areas surveyed in this thesis. The major constraints in the smallholder pig production systems surveyed were slow growth rate of pigs, outbreaks of disease, and high mortality of piglets. The latter two problems result in high economic losses for smallholders in Northern Lao PDR.

- Smallholder pig farmers relied on feedstuffs that are available on and around the farm. These feeds mainly provided energy and were low in protein, giving rise to a nutritionally imbalanced diet and resulting in poor growth performance and high piglet mortality. To improve pig productivity in smallholder systems, the problem of feed quality and quantity must be addressed. There is a need to prioritise and find the most practical options for farmers to overcome this major constraint to pig production.

- Stylo (*Stylosanthes guianensis* Composite and CIAT 184) and porcupine joint vetch (*Aeschynomene histrix* BRA 9690) can be recommended for use by pig farmers in Lao PDR. They produced high yields, showed an even growth pattern under rain-fed conditions, and their contents of CP were high when harvested at frequent intervals. Moreover, their contents of essential amino acids were adequate for growing pigs, and these legume species are easy to harvest.

- It is suggested that reasonable target levels for CP in feed formulation for growing Moo Lath pigs should be 18% of DM for weaners, 15% for growers and 11% for finishers. However, this is only the first indication of CP requirement for Moo Lath pigs, and further studies are needed to establish more precise protein and amino acid requirements for growing Moo Lath pigs.

- Forage legume leaf meal can potentially be used as a protein source to improve dietary protein supply and growth performance of Moo Lath pigs in smallholder pig production systems. However, legume leaf meal CP can only replace part of the soybean meal CP in the diet if high growth performance and attractive carcass traits are to be obtained.

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Acknowledgements

The studies presented in this thesis were carried out in five northern provinces (Phongsaly, Oudomxay, Luangphabang, Xayyabouly and Xiengkhuang) and at the Livestock Research Center (LRC), belonging to National Agriculture and Forestry Research Institute (NAFRI), Vientiane Lao PDR with financial support from The Swedish People and Government through the Swedish International Development Cooperation Agency, Department for Research Cooperation with Developing Countries (Sida/SAREC), and additional fund from Gines-Mera Memorial Fellowship Fund for Postgraduate Studies of International Center for Tropical Agriculture (CIAT). I am grateful for the support from all of these people and institutions.

I am greatly indebted to my main supervisor, Prof. Jan Erik Lindberg, for his mentoring and constructive advice during my studies. He made me much more confident as a scientist and researcher. His patience and encouragement during my illness and positive criticism made it possible to accomplish this work.

I am also greatly indebted to my co-supervisor Prof. Bodil Frankow-Lindberg, for her guidance through the forage legume agronomy study and constructive comments and valuable suggestions on the agronomy part of my paper and thesis.

My special thanks to Prof. Brian Ogle, a former coordinator of the MEKARN programme, for his valuable support and for reading my survey papers for English correction.

My sincere thanks to Assoc. Prof. Maria Neil for organising seminars and following up on my study progress. Thanks also to all professors and teachers at the Department of Animal Nutrition and Management, SLU, who taught and advised me in many fields of animal science; this knowledge will follow me throughout my professional career.

My thanks also go for all staff at the Department of Animal Nutrition and Management for sharing with me their knowledge, the favourable study environment accorded to me and their concern during my illness.

I am grateful to Dr. Bounhong Bouahom, director of NAFRI, for giving me permission, constructive comments and encouragement to study. Great thanks for his advice on surveying pig production systems.

My special thanks to:

Dr. Vanthong Phengvichith, the head of the Research Management Department at NAFRI, for his encouragement and practical advice on the agronomy and feeding trials.

Mr. Soukanh Keonouchanh, director, and all staff members at LRC, for providing research facilities and helping me to accomplish my experiments.

Mr. Ammaly Phengvilaysouk, Mr. Keo Xayphengphanh, Mr. Pheunsombath Nakkasem and Mr. Thanongsinh Dengkhounxay for excellent field assistance and taking care of all experiments carried out in LRC.

Mr. Somchanh Khamphavong and Phouthone Phonekhampheng for great help in conducting the survey in Northern Lao PDR, without their help the survey and experiments would not have been possible.

All staff members of the District Agriculture and Forestry Offices and Provincial Agriculture and Forestry Offices in the five Northern provinces of Lao PDR, for allowing me to use their office and transport facilities, and accompanying me to conduct the pig rearing and feeding system survey.

My great thanks to Dr. Werner Stür, former team leader of Forage Legume for Feeding Village Pigs Project, CIAT in the Asia regional office in Vientiane, Lao PDR, for his valuable advice on the pig rearing and feeding system survey and agronomic trial.

Dr. Rod Lefroy, regional coordinator of CIAT in the Asia office, Vientiane, Lao PDR, for his practical advice and additional financial support for my study.

All CIAT staff in the Asia office for sharing their valuable knowledge and expertise, and kindly allowing me to use their office space and internet facilities for my study.

Dr. Ngo Van Man, Mr. Nguyen Van Cong and the members of the SAREC/MEKARN project committee for their help, support and encouragement.

My friends at SLU from Lao PDR: Malavanh, Lampheuy, Daovy, and friends from various countries: Haoyu (from China), Bryan Mendieta (from Nicaragua), Visoun Millogo (from Burkina Faso), Vo Lam, Hue, Ngoc, Tham and Thi Da (from Vietnam) and Sath (from Cambodia) for their friendship, help, sharing cooking and encouragement during my time at SLU and at home in Lao PDR.

Last but not least, I would like to thank my family for all their love, encouragement and patience. Most of all thanks and appreciation to my wife Phetsamai Phengsavanh, who has been working hard and taken all responsibility for our family during my study time, was always encouraging and supportive during my illness, thanks for her love and understanding. Special thanks to my son, Vira, and daughter, Phonenapha, for their love and good behaviour. Great thanks to my brothers and sisters too for their help in looking after my family while I was studying.