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Strategies to improve the use of limited nutrient resources in pig production in the tropics

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Abbreviations

ADP	adenosine diphosphate
AMP	adenosine monophosphate
AnGR	animal genetic resources
ANF	antinutritional factor
ATP	adenosine triphosphate
cm	centimetre
Cp	creole pigs
DM	dry matter
FVMAP	faculty of veterinary medicine and animal production
g	gram
GLM	general linear model
GIp	genetically Improved pigs
ha	hectare
HPLC	high performance liquid chromatography
ILW	initial live weight
LSM	least square mean
m	metre
MB	mucuna bean
mm	millimetres
N	nitrogen
NDF	neutral detergent fibre
N_{min}	mineral nitrogen
NSP	non starch polysaccharides
PR	pig rotation
SAS	Statistical analysis system
S&B	slash and burn
SEM	standard error of the means
TIU	tripsin inhibitors units
VFA	volatile fatty acids
WoPRB	without pig rotation and without burn

Chapter 1 Introduction

One of the great challenges facing the world over the next decades is to preserve its natural resources while at the same time producing sufficient food to satisfy the demands of a growing human population (de Haan et al., 1997). The increased pressure for the control and abatement of environmental damage of industrial animal and crop production systems allows a renewed consideration of mixed farming systems. Attention is increasing to the importance to improve the efficient use of nutrients in a farming system as a way to design sustainable production systems (Preston, 1991).

In Mexico and other parts of the world, especially in the tropics, one of the most important mixed farming systems is the milpa, which is an organised unit, with integrated animal and crop production. In the milpa system in the south east of México, the Creole pig is well integrated in this system, but in recent years the import of other breed pigs has caused a reduction of their population. There is a need to characterise the potential of this breed to ensure its potential characteristics in the context of the production system under this breed is used.

The loss of equilibrium because of the pressure caused by the reduction on the fallow period in the milpa system requires the development of new strategies to provide adjustment particularly to sustain maize yield. Most of the strategies or alternatives proposed at the present date have been focused on improvements using crop rotations. The low adoption of this technology suggests the need to explore other possibilities including additional benefits on the animal component (Anderson et al., 1998). Because maize is the main crop planted in the milpa production system the use of pigs in rotation to maize cultivation was evaluated as a strategy to sustain maize yield. The design of the experiment was finalized in the discussion with peasants involved in the project “Optimising livestock integration into small-scale low external input crop systems” (Anderson et al., 1998).

The contribution of pig manure as a source of nutrients for plant growth in mixed farming systems in many parts of the world is recognized. However, the value of manure as a fertilizer can be influenced by diet management. It has been identified that high fibrous diets could improve the value of manure as a source of reliable nutrients for plant growth. In outdoor pig production the pig-plant interaction could influence the manure characteristics and consequently influence soil quality.

This thesis deals with the efficient use of nutrient farm resources available for animal and crop production by studying nutrient saving strategies, identifying new sources of nutrients, and improving the allocation of nutrients concentration within the farm. The present study was designed to support the understanding of nutrient flow within pigs and the interaction between the components of the production system (i.e. animal-plant-soil) to identify strategies to improve the use of nutrient resources.

Chapter 2 Literature review

2.1 Need for efficient use of limited natural resources

Conventional pig production has led to serious environmental problems, including both local and global pollution as well as the reduction of biodiversity. There is a need to improve the nutrient use efficiency not only at crop and animal levels but also at farm level.

It has been hypothesized by Preston (1991) that the design of appropriate strategies to use nutrients efficiently will lead to more sustainable farming systems. Some ethical norms and values in relation to the concept of sustainability are discussed by Becker (1996). According to Preston (1991) the design of sustainable livestock strategies has to be judged according to the likely impact on economic, ecological, ethical and sociological issues. Economic issues to be satisfied include international competitiveness in the price of the finished product, which requires maximizing comparative advantages of available natural resources. Ecological sustainability requires that the production system will result in 1) reduced emissions of the principal greenhouse gases carbon dioxide and methane, 2) reduced contamination of the soil and water resources, 3) an effective control of soil erosion and 4) integrated on-farm production of energy from renewable resources. The ethics of animal raising concern 1) the potential effect of production systems on animal welfare 2) as well as consumers' acceptability of foods (in terms of safety) produced in such systems. Sociological issues require an increase in employment opportunities, especially for woman, and that the production system encourages self-reliance with a minimum dependence on outside inputs. Van Bruchem et al. (1999) expands on the concept of sustainable production system by adding a variety of objectives that must if possible, be achieved simultaneously. This description of sustainable production systems considers different levels of hierarchical order and interactions among subsystems, such as the molecular or intracellular, the metabolism of organ/tissues, and on the animal breeding, nutrition or husbandry level. In addition, Van Bruchem et al. (1999) emphasizes that when production systems become unbalanced, nutrient use efficiency may decrease due to antagonistic feedback mechanisms between subsystems. On the other hand, in more balanced situations, synergistic effects may emerge and the performance of production systems as a whole may surpass the total of the subsystems.

In low external input production systems, small farmers in developing countries are interested and forced to improve their nutrient use efficiency due to their low capital for investment and operation.

As an alternative to conventional pig production, it has been formulated guidelines for organic pig production (IFOAM, 1996) and in the Europe Countries the EEC-Regulation 1804/1999, supplementing regulation no. 2092/91 include specifications for housing conditions, animal nutrition and animal breeding, as well as animal care, disease prevention and veterinary treatments (Sundrum, 2001). Hermansen and Kristensen (1998) state that organic production has to rely on efficient nutrient use at the farm level to maintain soil fertility and high production. Additionally, these authors state that the basic concept of organic farming is the use of a mixed farming system. As organic farming does not allow for use of synthetic amino acids for pig feeding and the use of mineral fertilizer for crop production, there is a tremendous need to improve the efficient use of nutrients at the farm level.

This framework of efficient use of nutrients provides the need to examine the implications of the nutrient flow on each hierarchical level and the implication on the structure and function of the production system.

2.1.1 Importance of mixed (animal-plant) farming systems

The possible benefits of animals on mixed farming systems are related to direct and supportive effects on the overall production system. Direct effects can be listed as: a) generation of resources to support cropping, e.g. provide capital for inputs to enhance cropping thereby total food production; b) addition of income to ensure economic welfare; c) provision of sustainable household income, e.g. sales of milk, eggs, meat; d) addition to community welfare through increasing purchasing and add high value foods; e) aid in maintaining soil fertility and adding useful microorganisms to soil; f) contribution to family nutrition, and g) service to cultural needs. While supportive effects can be listed as: a) support of fuller employment in rural areas; b) support of off-farm labour needs for required goals in cropping; c) possible incentives for use of on farm measures for soil and water conservation; d) aid in pest control for crops, e.g. grazing of crop residues; e) reduction of needs for labour in cropping; and g) ensure of overall farm stability (McDowell, 1993).

Many of the world's poor who live in low potential and unfavourable agricultural areas depend directly upon genetic, species and ecosystems biodiversity for their livelihoods (Anderson, 2003).

Local species and breeds within species often have advantages in terms of their ability to fulfil non-income and socio-cultural functions due to processes of natural and artificial selection for adaptive traits, and artificial selection for appearance traits (Table 2.1). Breeds that have been subjected to genetic selection for productivity traits- “improved” breeds- generally have greater genetic potential for output that responds to improving management levels (Anderson, 2003).

Table 2.1. Animal genetic resources (AnGR) by livestock function

Type of AnGR	Functions		
	Socio-cultural	Non-income	Income
Local	Often strong cultural significance attached to particular breed characters.	Adaptive traits important for survival and reproductive traits under unfavourable conditions.	Often perceived to be less productive and less able to respond to an improvement in management.
Crossbred (local x Improved)	Changes from local phenotype may have negative implications for these functions.	Often able to fulfil these functions as well as local breeds.	Combinations of adaptive and PT lead to preferences from livestock keepers.
Improved	Changes from local phenotype may have negative implications for these functions.	Lack of adaptive traits may inhibit their ability to fulfil these functions.	Best able to improve performance with increasing management level.

Source: Anderson (2003)

2.1.2 Pig manure as fertilizer

In farming system with limited use of inorganic fertilizers, there is a great importance of animal manure as a fertilizer. The advantages and disadvantage of using manure are closely interrelated; gaseous emissions at an early stage after application inevitably reduce the later positive effects on soils and crops (de Wit et al., 1997). The pig manure as fertilizer and the ways to improve its value is discussed in this study in relation to the characteristics of the production system of interest (milpa system) and the basic concept in relation to manure management. The first relevant issue is related to the pig nutrition and the genotype. This serves with the purpose to identify ways to improve the characteristics of pig manure as a fertilizer an aspect which is presented in section 2.3.2. The second important aspect is described in the section 2.5.1 as soil amendment with manure and plant uptake and the third aspect related to manure and soil microbial biomass in section 2.6.2.

2.2 Current socioeconomic situation in the study area

The first part of this study was carried out in the south-east of Mexico, in the Yucatan peninsula. The population of the peninsula consists of 3.2 million inhabitants in three states. In Yucatan there are 1.7 million inhabitants 60% of which are currently living in cities of more than one hundred thousand inhabitants (INEGI, 2000). The region has been inhabited by Mayan people for 3000 years. At the present time the mayan people comprise 50% of the local population.

The Yucatan state is divided in three agro-ecological zones. The central-north zone was primarily dedicated to sisal (*Agave fourcroydes*) cultivation and industrial processing for over 150 years. Since the collapse of this industry 10 years ago, however, the small farmers have been in the process of establishing a milpa system on the abandoned sisal plantations. This comprises roughly one third of the total territory of the Yucatan state. The southern zone is primarily dedicated to fruit production, mainly oranges, and due to the deep soils, the arable land is planted with crops such as maize. The eastern region is characterised by the practice of the milpa system followed by grassland establishment for cattle production. From the total pig production of the Yucatan state the highest number of farms are located in the central-north region.

2.3 Characteristics of pig production in Yucatan

Using the criteria of degree of integration with crop and its relation to land, the pig production in Yucatan can be described as either industrial[1] or integrated production systems. Industrial production can be divided into rural union (with government subsidized operations), and private farms. Both systems are large scale market oriented farms and use of high technology comparable to agricultural systems established in the USA or Europe. In these production systems, improved breeds of pigs selected specifically for pork production are used (e.g. Landrace, Yorkshire, Duroc, etc.), and diets are based mainly on conventional feedstuffs. This system also uses artificial insemination for pig breeding and the animals are reared in pens with concrete floors.

On the other hand, the typical semi-subsistence integrated crop-animal production system is the Milpa system. Peasant pig production uses mainly Creole breeds or its crosses with improved breeds without control of selection. Their diet is based on local feedstuffs; however, the diet is composed of three main components: maize, different forages and kitchen waste. The animals are housed mainly in pens built from local wood and stones. In

[1] Defined as production system in which less than 10 percent of the feed is produced within the production unit.

this production system pigs are not the only domestic animals reared, as farmers also raise chickens, turkeys and cattle (Anderson et al., 1998). INEGI (1993) estimated that there were 110,000 pigs in peasant farms whit an averages of 4 pigs per peasant farmer.

Large-scale private productions systems have the highest pig performance in comparison to the other production systems. There is low number of piglets weaned per farrowing and low feed efficiency in the peasants' milpa systems (Table 2.2).

Table 2.2. Pig production parameters according to production system in Yucatan, Mexico

Pig Production Parameter	Large scale private farm[1]	Rural Union Farm[2]	Small peasant holding[3]
Number of farrow/sow/year	2.05	1.6	1.8
Piglets weaned/farrowing	8.6	6.9	3.5
Percentage of fertility	86	79	90
Feed / gain ratio (15-100 kg)	3.25	3.5	6.0

[1]Rodriguez et al. (1990); [2]Richards and Rejon (1983); [3]Richards and Leyva (1985); cited by Santos (1999)

2.3.1 The Creole pigs

The first pigs were brought to Mexico by the Spaniards during the early of the XV century. The Spaniards imported these animals from the Iberian Peninsula and from Asia, due to the trade existing with Japan, China and Philippines (Lemus-Flores et al., 2001). Since then and due to the adaptation of the animals to the local environment, a local breed of pigs emerged.

It is possible to ascertain two main Creole pig types: the Mexican hairless pig, characterized by the lack of hair and the Cuino, which is of a remarkably small size. There is also a variety known as Mule foot that is similar to the Cuino but has a characteristic solid hoof resembling that of a mule, hence its name. The level of genetic diversity is high. The Mexican hairless pig belongs to a genetic lineage divergent from improved breeds (Lemus-Flores et al., 2001).

The Hairless and Cuino pigs are not commercially used for large-scale production. The sale price is very low due to an excess of fat, which lowers their market price by 30% to 40% compared to genetically improved breeds (Méndez, 1997). But these lard-type breed of pigs are important for the Mayans as they primarily cook with pork fat.

The Mexican Hairless Pig lacks hair on the skin's surface, and is of small size and grey black colour. It has an elongated head with a sub-concave side view, a long face and a narrow snout. The medium sized ears point down and to the front, slightly covering the eye zone and they have a comparatively short neck. The pigs show a slightly straight back, not very arched ribs and strong long feet. Their hind legs are longer than the front ones (Flores and Agráz, 1983). Examples of Creole pigs are presented in Fig 2.1.

Figure 2.1. Typical Creole sow and boar resting in a backyard in Yucatan

Between 1910 and 1970 the Mexican Hairless pig population in Mexico diminished from 95% to 30%, from a total estimated population of 2 million pigs and were substituted with imported breeds like Duroc, Poland Chine, Yorkshire, Hampshire etc., initiating a crossing process, that has continued up to the present (Anon., 1992). Currently the Creole pig can be found in Veracruz, Puebla, Tabasco, Campeche and Yucatan. On the Pacific coast they are raised in the states of Nayarit, Jalisco, Colima, Michoacan, Guerrero, Oaxaca and Chiapas (Lopez-Morales et al., 1999).

Anderson et al. (1999) found that the pure “Creole” population represented only 0.3% of the total backyard pig population in Yucatan. According to the annual statistics of Yucatan State, there were 29,331 backyard pigs in the year 1991 of which only 88 belonged to a pure population. According to these estimations and following the criteria used to consider a breed in danger of extinction as proposed of the FAO, the Creole pigs are in danger of disappearing in this part of Mexico.

The Mayans usually kept their pigs in their home gardens. In some areas it was usual to transport the pigs to field areas to consume the rest of the harvested crops. But following a law in 1973 (i.e. Ley ganadera del estado de Yucatan, in English: Livestock law of the

Yucatan State, Mexico) animals are required to be marked and fenced. This regulation confines Creole pigs to the home gardens.

Piglets are usually kept with the sow in the enclosure until they are two months old. If the pigs are fenced, the size of the enclosure varies from 4 to 16 m^2. Some solid food is given to the piglets as soon as they accept it. This kind of management was a result of technical recommendations from governmental programs aiming to improve the town's hygienic level. But Mayans prefer to let their pigs run free in the backyards of houses and on the streets. In some cases they tie up the pigs to reduce their radius of movement.

A typical piglet production unit at the family level consists of a small enclosure with two or three pens, one sow and, eventually, one boar (Moya-García, 1999). In the towns there is usually a boar to cover the sows. The cost for this service is commonly paid in the form of a piglet.

An investigation by Cabello (1969) in Lopez-Morales et al. (1999) dealt with the growing potential of the Mexican hairless pig compared with genetically improved breeds (i.e. Hampshire and Yorkshire x Duroc). The Hairless Pig was found to grow relatively slowly and to be significantly smaller than the genetically improved breeds. Moreover, when fed the same rations as the improved breeds, their weight gain was much lower (Table 2.3). However, the Creole breeds survived better on the locally available feed resources. Moya-García (1999) in a field research found out, than when farmers tried to substitute the concentrates in the diet of the improved breeds with forage and maize a lot of the genetically improved breed of pigs fell ill and died.

Table 2.3. Growing potential from Mexican hairless pig compared to genetically improved breeds (n=8)

	Creole pig	Hampshire	Yorkshire X Duroc
Initial weight	16.9	25.3	18.0
Weight at 86 day (kg)	48.8	72.0	66.4
Weight gain (g/d)	375[a]	546[b]	569[b]
Feed conversion	5.4	4.3	3.8

Values between columns with different literals are statistically different ($p < 0.05$).
Source: Cabello (1969) in López-Morales et al. (1999).

It is difficult to make comparisons between rapidly and slowly maturing pigs of the same age. At the same age these pigs will be at different stages of physiological growth. Comparisons of indigenous and improved pig breeds at the same metabolic age and under on-farm conditions may be needed to obtein fair comparisons between these breeds.

Although the Creole pig has not been submitted to genetic selection and differs from commercial strains in their characteristics, Vazquez et al. (1972) in Lopez-Morales et al. (1999) compared their performance under experimental farm conditions with the performance of commercial breeds (Tab. 2.4). There are no performance comparisons of the commercial breeds and Creole pigs in milpa production systems.

Table 2.4. Reproductive parameters in Creole and improved breed of pigs

	Improved Breed of Pigs			Creole
	Duroc	Hampshire	Yorkshire	
Born Piglets	9.27^a	9.18^a	9.52^a	$8{,}20^b$
Total birth weight (kg)	12.15^a	11.13^a	11.82^a	9.28^b
Mean weight at birth (kg)	1.39^a	1.24^{ab}	1.26^a	1.15^b
Mortality	3.74^a	2.33^b	1.83^b	2.32^b
Total piglets weaned	5.57^a	6.66^b	7.69^c	5.59^a
Mean weight at weaning (kg)	8.97^{ac}	8.89^{ab}	9.49^c	7.58^b
Weight at weaning (kg)	51.83^a	58.37^a	72.21^b	42.30^c
Total number of farrows	66	43	127	14

Values between columns with different literals are statistically different ($p < 0.05$).
Source: Vazquez et al. (1972) in Lopez-Morales et al. (1999)

Up to now only few *in situ* investigations have been carried out to evaluate the performance characteristics of the Creole pig and to select the animals under the usual conditions and resources of the peasant production system. Moreover there is a current debate on the important selection criteria for this pig breed.

With regard to the Creole pig's digestive capacity Chel-Guerrero et al. (1983) found that the inclusion of 20% alfalfa in the diet between 11 to 40 kg live weight did not reduce the digestibility of the dry matter (84.7 vs. 83% for a 0 and 20% inclusion alfalfa), but with proportions of 40 and 60% the reduction was statistically significant ($p < 0.05$) at 62.5 and 54.2% respectively. The Creole pig performance in this experiment with 0, 20, 40 and 60 % of alfalfa inclusion in the diet with similar protein level showed feed intake of 1.06, 1.15, 1.23, and 1.15 kg/day, weight gains of 0.299, 0.317, 0.263, and 0.192 kg/day and a feed conversion of 4.5, 4.0, 5.3 and 6.7 respectively. The authors state that the digestibility of the diets with 0 and 20% alfalfa inclusion are comparable to those of improved breeds of pigs, thus the low weight gain observed is possibly due to a low metabolic use of nutrients.

When comparing the Cuban Creole pigs, which are descendents from Spanish breeds, with Cuban improved pigs (i.e. CC21 pigs) Ly et al. (1998) found a lower digestibility in Cuban Creole pigs by feeding pigs of these breeds with a diet based on sugar cane molasses type B and soybean meal with 14.5% fibre (i.e. banana foliage meal, *Musa paradisiacal*).

2.3.2 Interaction between pig nutrition and genotype

To estimate the value of manure as a source of nutrients for plant growth and to maintain soil fertility, one often refers to average quantities of nutrients excreted per animal and per time for the different categories of animals kept under standard conditions (Jongbloed, 1984). Feedstuffs contain three mayor nutrients: carbohydrates, fat and proteins (plus smaller amounts of nucleic acids). When carbohydrates and fats are metabolized, they leave carbon dioxide and water as the only end products of oxidation. Proteins and nucleic acids also yield carbon dioxide and water, but in addition, the chemically bound nitrogen in these foodstuffs gives rise to the formation of nitrogen excretory products. Numerous factors related to animals or management have an effect on nitrogen excretion. Particularly feed or dietary protein supply is of special importance. The pigs excrete the nitrogen in faeces and urine. The digested nutrients, defined as the difference between the amount of nutrients consumed and excreted through the faeces, depends on factors related to the feed and to the animal. Faecal nitrogen excretion particularly depends on protein digestibility of the diet (Whitehead, 1995).

Once nitrogen is absorbed; the losses or excretions in the form of urea in the ur by the ine are typically governed quantitative and/or qualitative adequacy of protein supply to the requirements (Gatel and Grosjean, 1992; Whitehead, 1995). The qualitative adequacy has been described by Fuller et al. (1989) as the optimum dietary amino acids pattern for growing pigs.

The quality of a diet can influence feed intake, feed digestibility, and the partitioning of N between the urine and faeces (Torrallardona, 1999). This latter characteristic is important, as a large proportion of the N excreted in the form of urine can be lost from the system through volatilisation and leaching, whereas that in faeces can be collected, stored and used to benefit crop growth (Delve et al., 2001). The manure of animals which are fed highly digestible diets is more susceptible to N losses than that of animals fed with greater amounts of roughage (Powell and Williams, 1993), while feeding on roughage species of plants has been found to shift the balance of excreted N away from the urine more towards the faeces (e.g., Reed, 1986).

Genetically improved breeds of pigs have been well studied with respect to their nutritional requirements. They are generally reared by using high digestible diets. In genetically improved pigs different approaches have been established to reduce the nitrogen excretion. Gatel and Groesjean (1992) reduced the protein content in the diet from 17% to 15% and found similar faecal nitrogen excretion but lower urinary nitrogen in the low protein diet. These results show that when nitrogen provided in diet exceeds the requirements of the animal, it is not retained in the animal body tissue and consequently excreted.

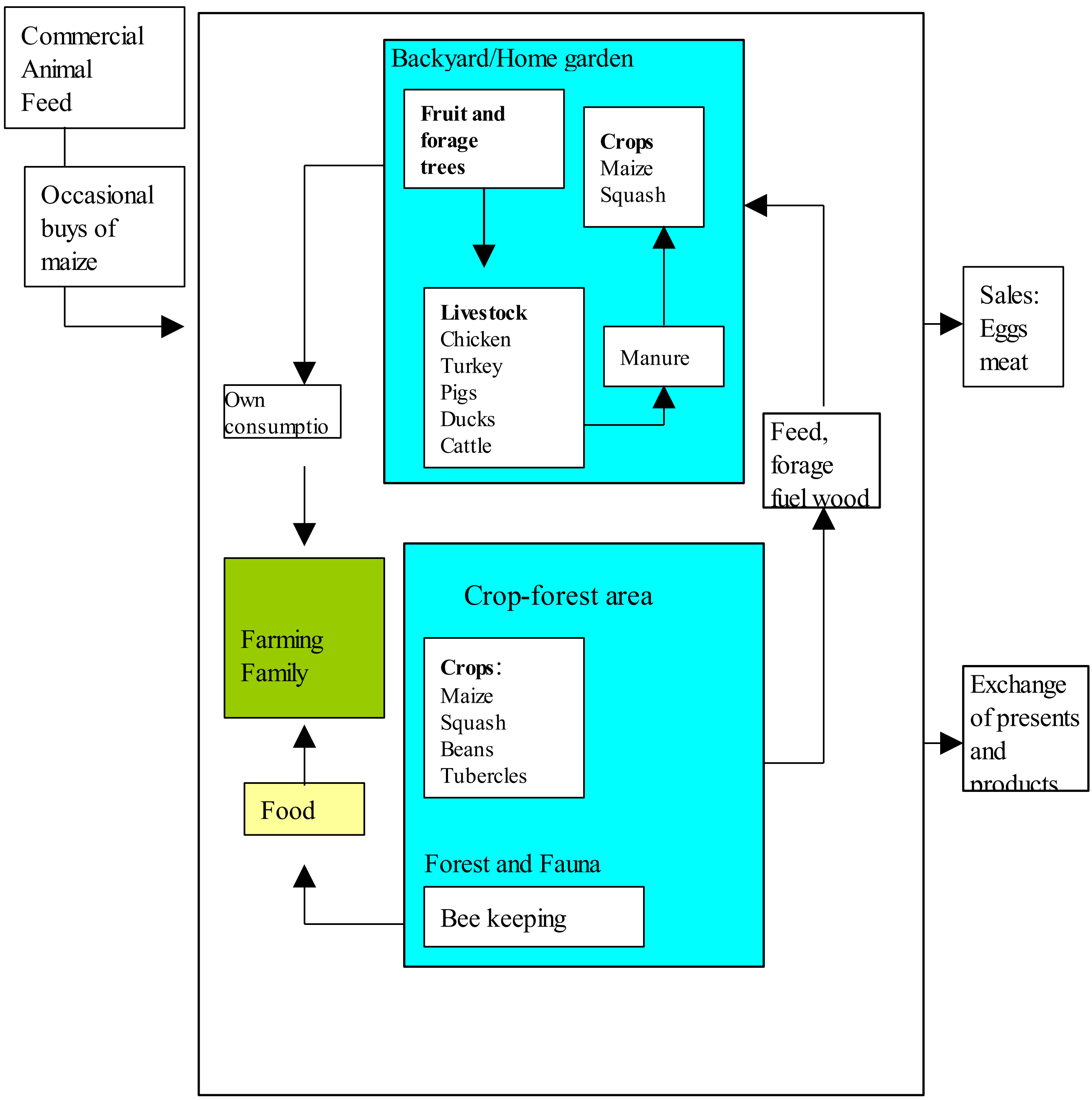
Another approach described and discussed by Henry and Séve (1993) and Torrallardona (1999) is based on the reduction of protein content in the pig diets, but ensuring that the requirements of all the essential amino acids and that of total nitrogen are met. Torrallardona (1999) found that a reduction of 19, 15, 14 and 12% of protein content in the diet reduced the nitrogen excreted and only in the diet with 12% the nitrogen retention was significantly depressed. Regarding to non genetically improved pigs for meat growth Ly et al. (2003) compared Vietnamese Mong Cai pigs and Large White pigs, with similar nitrogen intake the Mong Cai pigs showed 16% less protein retention and found that 40.8% of total nitrogen excretion was via faeces in Mong Cai pigs whereas the same index was only 33.8 in Large White animals. While urine was the main route of N elimination in both breeds eating a high fibrous diet.

2.4 Background of the “Milpa” production system in tropical Mexico

The milpa production system is used mainly by Mayan descendents. The milpa system is a slash and burn system, which relies upon the forest vegetation as the main input to restore soil fertility (Terán and Rasmussen, 1992). The milpa system can be classified as a mixed animal-cropping system, as it combines a number of different animal and crop species. Diagram 2.1 shows the food, feed and forage resource flows in the milpa system.

A typical milpa system is comprised of two periods, the cropping and the fallow period. The secondary bush vegetation is cleared and burned and the land used for maize, squash, and bean production, mainly for home consumption. In this system, no manual soil preparation is done. Other crops are sown into different parts of the plots depending on soil characteristics e.g. tuber crops and forage plants. The period of utilization for cropping is now 2 years followed by a fallow period. So the landscape is characterized by a patchwork of secondary vegetation at different stages of regrowth.

Diagram 2.1. Interactions between crops and livestock in campesino agriculture in south east Mexico



(modified from Anderson et al., 1998)

The farmers consider the productivity of the first year of cultivation to be better than the second year. As a result of the increase of weed biomass during the second year, farmers are forced to use herbicides to protect maize cropping, and the number of crop species planted is lower compared to the previous year. The farmers observe that when they use herbicides it is not possible to plant other crops due to the damage caused by these herbicides (Terán and Rasmussen, 1992).

In addition to the cropping area there are other components in the complex milpa farming system. Such areas include the home garden or backyard, the forest, and in many cases areas for cash crops (e.g. sisal, chillies and citrus). The seasonal activities in the milpa production system are listed in annex 2.

Besides being the basis for the milpa production, the forest provides the material required for the construction of the traditional Mayan houses. In addition, the flora is used for medicinal purposes, as fodder for livestock and for bee keeping. The fauna occasionally contributes to the nutrition of the local families.

In Mexico, an estimated 5 million ha are used for slash and burn system from these 500,000 ha are under cultivation and the rest in fallow period (Hernández-Xolocotzi et al., 1994).

About 90 % of the maize production in Mexico is cultivated during the period of spring-summer and only 6% is in irrigated areas (INEGI, 2002). That means that the maize production is highly dependent on climatic conditions. Description of maize production in Mexico and Yucatan are presented in Table 2.5.

Table 2.5. Maize yields in Mexico and Yucatan

Item	1995	2000	2001	Average
Total Production (Tons)				
Mexico	18,352,856	17,191,073	15,971,388	17,171,772
Yucatan	73,136	160,737	89,475	107,783
Hectares under cultivation				
Mexico	8,020,392	7,016,555	7,068,764	7,368,570
Yucatan	102,850	161,593	132,174	132,206
Maize yield (ton/hectare)				
Mexico	2.23	2.45	2.25	2.31
Yucatan	0.71	0.99	0.68	0.79

Source: INEGI (2002)

The reduction of the fallow period decreases the fertility of the soil and increases weed pressure (Hernández-Xolocotzi et al, 1994). One of the main problems of crop production in the North of the Yucatan Peninsula is the lack of enough labour to control weeds effectively. In addition, as this land was used exclusively for the cultivation of *Agave fourcroydes*, the forest is young (10 years old), resulting in an increase of weed pressure in the field (Caamal-Maldonado et al., 1996).

2.4.1 Feed available for pig feeding

The feeds available in the milpa system are derived from the crop area, the forest, the secondary vegetation and the home garden. The basic diet component for human and livestock in milpa system is maize (Acosta-Bustillos et al., 1998). Anderson et al. (1998) describe the partitioning of maize between family and livestock requirements with different maize availability in communities of the south of Mexico. In Table 2.6 the difference between the sum of daily family and livestock consumption and daily maize available is explained by sales of surplus to the local market or bought when necessary in local market.

Table 2.6. Partitioning of maize between family and livestock requirements

Maize available daily (kg)	Daily family consumption (kg)	Daily livestock consumption (kg)	Comments on food security
26.5	5.5	12	Sufficient maize produced for family and livestock
18.2	6	8	Many families face food insecurity in most years- declining food security. Family/livestock competition
11	6	7	
4	5	2	Insufficient maize produced to cover family requirements. Few livestock kept.

Source: Anderson et al. (1998)

Another important feedstuff is the squash; which is used for the home garden livestock, once seeds have been taken for sale or consumption. The peasants supplement maize with harvested local forage and seeds from trees (e.g. *Brosimum alicastrum, Leucaena spp.*), pasture (e.g. *Pennisetum purpureum*, *Cynodon nlemfuensis*), tuber crops (*Dioscorea alata L., Xanthosoma yucatanense* Engler.) and waste fruits (e.g. Citrus, Papaya, Watermelon). Moya-García (1999) describes two typical diets: peasant farmers with 4 pigs use between 1 to 1.5 kg of maize and 10 to 12 kg of squash with and without forage respectively. The amount of forage used was not exactly described.

The forages grow inside the homegardens or occur in the secondary vegetation areas around the communities; they are harvested at different times depending on availability and need. It is normally in the limits of their agricultural plots, or close to the narrow paths where the peasant farmers walk daily (Acosta-Bustillos et al., 1998; Moya-García, 1999; Kröbel, 2002). The forage used for domestic animals includes a great number of native species. Acosta-Bustillos et al. (1998) mention 215 forage species found on the Yucatan Peninsula. The forage type and the part of the plant consumed are related to their seasonal availability. During harvest time pigs eat the products with the lowest market value. This sometimes permits a better use of resources than the sale would provide. Examples of plants, which can be sold on the market or optionally be fed to the livestock, include beans, squash and yam. A list of these and some other relevant crops planted in the milpa system with their scientific names is given in annex 1.

Peasant families often let the pigs freely graze to supplement the maize grain feed whereas the pigs eat insects, larvae, earthworms, grasshoppers and mice. Household waste is also fed.

From January to April the use of forage plants seems to be reduced, coinciding with the dry period, and the maize reserve from the previous year has to be used. From May to September the use of forage is intensified due to the enhanced availability during the rainy season and the major period of activity in the milpas. Finally from October to December the amount of forage available has diminished and the use of products derived from the harvest increases (Acosta-Bustillos et al., 1998).

As a result of introduction of the management of cover crops to improve the milpa system, families have started to experiment with the use of mucuna (Mucuna spp.)grain as a feed source. The importance of mucuna bean as a protein source to improve pig diets in peasant systems merits further description.

General description of mucuna bean

The mucuna bean is a vigorous annual climbing legume, native from China, Malaysia or India (Duke et al., 1981). This legume is frequently referred to as *Stizolobium deeringianum* or *Mucuna deeringiana*. There is a cultivar from *Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wight), known in Mexico as “frijol terciopelo” or “mucuna” (Kay, 1978), and in other parts of the world as Velvet bean. This is a legume of the Fabaceae family, and there are approximately 12 mucuna species cultivated in the tropics, the most commonly cultivated are *M. deeringiana, M. utilis, M. pruriens, M.cochichinensis, M. nivea, M. carpiata, M. hassjoo* and *M. aterrima* (Duke et al., 1981). Being well adapted to the tropics, the mucuna bean dominates other plant species, and in a relatively short time can cover the total surface area of the soil (Escarzaga, 1987).

Yield production. A seed yield between 1680 to 2240 kg/ha has been reported in the USA (Kay, 1978). Table 2.7 reports the yield production in Yucatan, Mexico. In Honduras the farmers report that intercropped mucuna bean has increased maize yields between 30 to 50 % (Buckles et al., 1992).

Table 2.7. Seed yield of mucuna bean with or without stakes in different soil types in Yucatan, Mexico

Seed yield of Mucuna bean (kg/ha)	Type of soil*	Stake	Author
851		without	Carbajal et al. (1987)
1577		with	
1650	Kan cab (cambisol)	maize**	Lara and Sansores (1990)
1735	Kan cab (cambisol)	with	
622	t'zekel (lithosol)	with out	Lara and Escobedo (1991)

*Mayan soil classification scale (with the FAO soil classification equivalence).
**Maize used as a stake.

Chemical composition and nutritional value. The chemical composition and amino acid content of mucuna bean is reported in table 2.8. The average protein content in mucuna bean is 24.7 %. Although lower when compared to soybean (*Glicine max*); mucuna can still contribute as an important part of the protein supplement to animal feed.

Ravindram and Ravindram (1988) found an *in vitro* digestibility value of protein in raw and boiled beans of 71.5 and 80 % respectively. According to Duke et al. (1981), the mucuna bean is deficient in methionine and cystine, but contains a high concentration of lysine. These deficiencies of sulphur amino acids are a common characteristic of legumes (Pusztai, 1985). About 90 % of the total nitrogen extract in mucuna beans is starch (Souza et al., 1991). The content of fat in mucuna beans (5.5%) is higher than in other legumes (e.g. *Canavalia ensiformis* 2.9% and *Cajanus cajan* 1.2 %) (Arora, 1995). The dry matter digestibility found in mucuna is 56.6 % (Souza et al., 1991). The nutrient content of the mucuna bean shows a potential to be included as a feedstuff. It must be taken into consideration that as with all legumes, mucuna contains anti-nutritional substances, and measures must be taken to overcome this.

Anti-nutritional substances. The use of legumes in animal feed is limited as they contain anti-nutritional factors (ANF) that interfere with the process of digestion, absorption and utilization of nutrients in animals (Pusztai, 1985). Mucuna bean is reported to contain tannins, protease inhibitors, cianogenics glucids, lectins and L-dopa described below. Other compounds reported are fisostigmina (Duke et al., 1981) which is an alkaloid to stimulate the intestinal and vesicle muscles (Frimmer, 1973) and N-dimetiltriptamina (CSIR, 1962), which has hallucinogenic properties.

Souza et al. (1991) found in *Mucuna deeringiana* 5.3 % of tannins. Liener (1989) report that mucuna bean contain trypsin inhibitors. Souza et al. (1991) determined in mucuna bean 43.6 trypsin inhibitory units (TIU)/mg of protein. De la Vega et al. (1981) removed the trypsin inhibitory activity of the mucuna bean (from 15.5 to zero TIU/mg) after boiling. Laurena et al. (1994) found cianogenic glucids concentration in the seed of a *M. pruriens* of 24-44 mg/g. Souza et al. (1991) determined that the mucuna seed contains haemagglutinating activity of 0.15 titel/mg protein.

Table 2.8. Chemical composition and amino acid content of mucuna bean (*Stizolobium deeringianum*) and soybean (*Glicine max*)

Nutrients %	14 accesions[1]	*Stizolobium deeringianum*[2,3]		Soybean[2]
Moisture	10.00		11.96	
EM (MJ/kg)	10.50			
CP	23.40	24.00	26.70	38.00
Fat	5.70	5.00	5.68	18.00
Fibre	6.40	5.00		5.00
Ash		3.50	4.97	4.60
NFE	59.50	51.40		43.21

A.A %	14 accesions[1]	*Stizolobium deeringianum*[2,3]		Soybean[3]
Lysine	1.45	1.49	1.24	2.40
Methionine	0.28	0.29	0.21	0.54
Cystine	0.21	--	0.16	0.64
Threonine	0.94	--	0.98	1.50
Triptofan	--	--	0.45	0.55
Isoleucine	1.12	--	1.82	2.00
Leucine	1.78	--	1.67	2.80
Phenylalanine	1.12	--	1.22	1.80
Tyrosine	1.19	--	1.18	1.20
Valine	1.29	--	0.93	1.80
Arginine	1.85	--	1.46	2.80
Histidine	0.49	--	0.64	0.89
Glycine	1.08	--	1.19	2.00
Proline	1.38	--	1.66	--
Serine	1.14	--	1.21	--

NFE= Nitrogen free extract

Source: [1]Duke et al. (1981); [2]Parr (1988), [3]Souza et al. (1991), [4]Balloun (1980).

L-Dopa (3-(3,4-dihydroxyphenyl)-L-alanina) is a phenolic amino acid which is part of the protein fraction of the mucuna seed. It has a chemical structure similar to L-Tyrosine and Mimosin and is derived from 3-4 dihidroxipiridina (3-4 DHP), which can be associated as tyrosine analogue and considered as a bociogenic agent (Kumar and D'Mello, 1995). In the animal, the L-Dopa produces catecholamine (adrenalin and noradrenalin) which are neurotransmission agents, before later producing dopamine (Frimmer, 1973). Ravindram and Ravindram (1988) suggested that the L-Dopa has a toxic effect when consumed in high amounts. Daxenbichles et al. (1971) reported that in 11 varieties of mucuna bean the content of L-Dopa was between 3.1 to 6.7 % DM, with the highest in *M. holtonii*. Arulmozhi and Janardhanan (1992) found in *M. monosperma* 4.5 % of L-Dopa. L-Dopa can be oxidized in presence of moisture by atmospheric oxygen and becomes dark

(Budavari, 1989). Interestingly Rajaram and Janardhanan (1991) using termed treatments, were able to remove the adverse effects of all anti-nutritional factors except of L-Dopa.

Performance of animals fed with Mucuna. Using a proportion of 28% in balanced diets Trejo et al. (1999a) and Trejo and Belmar (2000) found a better acceptance of mucuna bean compared to other legumes seeds (*Canavalia ensiformis* and *Albizia lebeck*). Different authors report that the inclusion of raw mucuna bean reduces the live weight gain of chickens (Olaboro, 1991; Del Carmen et al., 1999 and Trejo et al., 1999b). To improve the productive performance, Duque (1993) reported similar live weight gains of broilers using 20% inclusion of soaked, heated and husked mucuna seed. Salas and Segura (1990) determined that part of the anti-nutritional substances in mucuna were removed after autoclaving. Trejo et al. (1999b) reported an improvement of the live weight gain of broilers through the inclusion of up to 42% in the feed of mucuna seed soaked for 24 hours. Del Carmen et al. (1999) improved broiler performance using toasted mucuna bean at 20% inclusion, but noted a decline in performance at 30% inclusion. In the context of low external input crop systems Trejo et al. (2004), using supplemented diets, reported an improvement of the live weight gain of chicken when mucuna bean was boiled for 30 minutes.

Duke et al. (1981) report that pigs fed with high amounts of mucuna bean suffered from vomiting and diarrhoea, related to the content of L-Dopa in the mucuna bean. However, they failed to report the exact amounts of mucuna bean used in their study. Parr (1988) suggest that the boiled velvet bean can be used as 20 to 30 % of total diet. The author also recommend only 2.5% inclusion of raw beans in the diet due to the content of protease inhibitors that reduce growth performance. Ruiz and Belmar (1999) found a reduction of pig performance using 25% of raw mucuna bean but with mucuna beans soaked for 24 hours, pig performance was similar to the control diet without mucuna.

2.4.2 Soil characteristics

Yucatan is characterised by a mosaic of different soils, which can be found within small distances (Duch-Gary, 1991). According to FAO, the soils in Yucatan can be classified into three groups from the north (gulf coast) to the south (central Yucatan). These are, a) soils located at the cost and deltas (Regosols, Solonchaks, Histosols), b) humus rich carbonate soils with a high content of stones of different sizes (Lithosols, Rendzinas, Cambisols) located at the flat plain of Yucatan, and c) soils deposited by run-off water (Cambisols, Vertisols, Gleysols). These are found around the hilly areas.

From the Mayan classification the most obvious distinct types are the black coloured Box luum or Ek luum found on the small elevations of land and also in the plains, the red Kan kab (limited to the plains), and the Tzek el that is a stony soil found at the surface (Gundel, 1998).

In relation to their agricultural use, the main difference between the soils is, that maize can be found in both soil types, whereas yucca and sweet potatoes is limited to the kan kab soil.

2.5 Strategies to improve the "milpa" slash and burn system

The main reasons for burning crop residues in the milpa system are to reduce weeds and to eradicate insect pests. For small farmers, with little economic resources and limited by the stony nature of the soils, burning of crop residues is an adapted technology to easily clear a crop area (Teran and Rasmussen, 1992).

The available low-external-input agriculture strategies to address problems of reduced productivity by restoration of soil fertility and weed control include: intercropping, alley cropping, cover cropping and green manure, biomass transfer, compost, animal manure, and improved and enriched fallows.

Cover crops and green manures. A cover crop is a crop grown to provide soil cover to prevent erosion by wind and water, regardless of whether it is later incorporated. Green manuring involves the incorporation of a crop while it is still mainly green into the soil for the purpose of soil improvement. In addition to providing ground cover and, in the case of a legume, fixing N, they may also help to suppress weeds and to reduce insect pest and diseases. Since 1992 a legume based cover crop system has been introduced into rural Yucatan communities as an alternative to the traditional milpa to provide green manure and weed control. The system is known as "labranza minima", which means "minimum tillage system" (Anderson et al., 1994). The most commonly used legumes are *Mucuna* *pruriens* and *Canavalia ensiformis* (Gündel, 1998). It is a sedentary system of food production that does not require the burning of secondary vegetation. Legumes are intercropped with maize to improve soil properties. Additionally, the seeds produced have been identified as an important source of nutrients to improve the diets of animals (Anderson et al., 1998).

Improved fallows. Shifting cultivation alternates periods of crop production with periods of fallow to restore soil fertility and suppress weeds. An “improved fallow” is the use of specific fast growing leguminous trees, shrubs and other plants to improve soil fertility compared to than would occur otherwise, while an “enriched fallow” comprise the use of trees or shrubs of economic value planted into the fallow so that farmers can derive some income from them while the land is regenerating.

Intercropping. This can be defined as the growing of two or more crops on the same land area within the same year. Various forms of intercropping have been a central feature of many tropical agricultural systems for centuries. In the milpa system, intercropping is part of the production system as described before and illustrated in Diagram 1.

Alley cropping. Is an agroforestry practice, in which hedgerows of trees and shrubs are established and annual crops are cultivated in the alleys between the hedgerows. The hedgerows are pruned before planting the crop and periodically while it is growing. To prevent shading, the trees are pruned and these pruning are applied to the soil as green manure and/or mulch. Between cropping cycles, hedgerows are usually allowed to grow without pruning. In recent years, various alternatives designed to improve the milpa system have been promoted (Caamal-Maldonado et al., 2001).

Biomass transfer techniques. In an effort to relocate nutrients from forest to agricultural land, tropical farmers have traditionally used a variety of biomass transfer techniques. These have involved the use of naturally occurring biomass (i.e., tree or grass material). Other methods of transferring biomass include “biomass banks” of species such as *Leucaena leucocephala*, which provide nutrients for crop growth, and organic material used, to physically improve the soil. The use of wild tamarind (*Lysiloma latisiliquum* (L.) Benth.) leaves as mulches is promising (Caamal-Maldonado et al., 2001). Other ways of biomass transfer are the use of so-called cut-and-carry grasses, where biomass is harvested and transported, in this case specifically to provide fodder for animals. In the milpa system this strategy is practiced by the farmer to provide forage from the forest or the secondary vegetation to feed the pigs kept in the homegarden.

Compost. Compost is the aerobic, thermophilic decomposition of organic wastes to relatively stable humus. Although decomposition processes occur naturally, the aim of compost-making is to control the conditions to a level that allows faster decomposition. The biophysical conditions that are required for effective composting are generally those that are required by the micro-organisms at various stages of the composting process that is, good moisture levels, moderate temperatures, mixed quality organic matter, and a fairly neutral pH range.

Animal manure. The use of animal manure as a source of crop nutrients is often a nutrient-harvesting technique in which nutrients are gathered through grazing of a relatively large area and concentrated on a smaller area where crops are grown.

Plant leaves and animal manure are organic compounds that help to improve the soil by increasing water retention capacity, thus impeding nutrients loss by leaching, by decreasing erosion and surface drainage and by helping to control weeds and other pests.

2.5.1 Soil amendment with manure and plant uptake

Leaching of nutrients in manure results from applications of nutrient levels that exceed crop production needs, applications at times when crops do not need the nutrients or when variable soils and water conditions exist. The reduction in yields with low-quality organic manure is generally attributed to the immobilization of N by microbial growth (immobilization process described before).

As described above the dynamic of nutrients from manure promote process that release nutrients more slowly compared to inorganic fertilizers. Crop residues and manures are often used in temperate regions to control soil erosion and to maintain soil organic matter. The beneficial effects of animal manure on crop yield, when applied in sufficient quantities, can not only enhance crop yield in the year of application, they can also provide residual benefits for subsecuent years (Graves et al., 2004). Aggarwal et al. (1997) found a significant increase of pearl millet grain yield (68% higher in amended soil compared to the control) in an arid tropic region using farmyard goat manure applied 20 kg N/ha /year.

2.6 Improved pigs in temperate climates and outdoor systems

The continuous increased demand of meat has promoted genetically improvement of pigs for meat production. Pig meat production has been provided by these intensive production systems. However, different motivations promote the establishment of outdoor farms such as: a) economic, reduction of cost in term of infrastructure b) new farmers, c) new areas in the farm for pig production, d) to improve animal welfare, e) the need of new spaces in the farm, f) fattening their own piglets produced, and g) to reduce the stocking rate.

Outdoor farming systems for pig production are practised at an increasing number of German farms. In Germany the use of pig outdoor management began since 1980. The number of sows under outdoor production has increased from 370 in 1992 to 9140 in 1997. This represents 0.36 % of the total sows. These sows are distributed on 44 farms with an average of 200 sows per farm. These farms are located in Schleswig-Holstein, Mecklenburg-Vorpommern, Niedersachsen and Brandenburg (Pfeiler, 1999). More recently Sontheim (In preparation) studied 80 farms with 18,000 sows which represent 0.75 % of the total sows of Germany.

European Organic Livestock Standards (EC Regulation 1804/1999, incorporated into EU regulation 2092/91 on organic production) for pig keeping in an organic system restrict the maximum number of pigs to an equivalent of 170 kg N/ha/year. That represent a stocking rate of 14 pigs/ha and 714 m^2/pig/year. It is important to remark that not all the organic farms consist of outdoor systems and vice versa.

2.6.1 Alternative feedstuffs for outdoor pigs in Germany

There is considerable interest in reducing feed cost by using cheaper feeds and by improving the efficiency of feed used. But little published information is available on assign alternative feedstuffs to pigs kept outdoor. Mature pigs have the potential to digest cellulose, and factors which influence the ability of animals to utilise fibrous feeds are: particle size of feeds, presence of anti-nutritive factors, the balance and concentration of nutrients, the degree of lignification of the fibre, and probably, genetic characteristics of the animals.

Several factors must be taken into account when considering the use of alternative feeds, the most important being their nutrient content and the nutrient requirements of the animal, which must be met within a finite appetite (Machin, 1990). This aspect is particularly important in outdoor conditions where pigs are provided with concentrate diet and a number of forage feeds (grass, cabbages, swedes, turnips, fodder beet and potatoes). Feeds which may particularly suit the outdoor sow include potatoes, fodder beet, swede, turnip, cabbage, grass silage and maize silage, which all have an acceptable nutritional value. However, due to the comparatively lower feed intake of growing pigs from this potential feedstuffs those with lower bulk density should be selected.

Other benefits of alternative feeds include: a) Behaviour and animal welfare. Stereotyped behaviour has been reduced, lying time increased.

b) Decreased lower critical temperature. Because of the heat of fermentation, the sow appears to have a lower critical temperature when consuming fibrous feeds. This is particular important in cooler climates.

c) Improved health. There have been suggestions of improved health, particularly in the digestive tract, trough the use of diets containing bulky feed materials. Thereby the, ulceration of the stomach may be reduced (Machin, 1990). Recently a corelation between microbial activity and the immune system has been described by Jenkins et al. (1999). These authors explain that fermentable carbohydrates that have a prebiotic activity selectively promote the growth and activity of beneficial bacteria (such as bifidobacteria and lactobacilli). Bifidobacteria can inhibit the growth of potential pathogens and stimulate components of the immune system.

Two of the alternative feedstuffs with potential to be used in outdoor pig production are Jerusalem artichoke (*Helianthus tuberosus*) and Turnip like-rape (*Brassica rapa var. rapa*).

The Jerusalem artichoke is a flowering vegetable native to North America; in German it is known as "Topinambur". The nutritional composition of the tuber part of Jerusalem artichoke consists of 16 to 24% dry matter, between 9.2 to 9.7% crude protein, 4.1 to 4.8% crude fibre and 80% nitrogen free extract (Table 2.8) The tuber of Jerusalem artichoke is characterised by its content of the fructan inulin. The mature tubers of Jerusalem artichoke contain 5 to 10% of fructans (Becker and Nehring, 1969). The digestibility of the organic matter is between 86 and 89% (Friesecke, 1984).

Farnworth et al. (1993) stated that the addition of fructans in the diet of monogastrics had beneficial effects on nutrition and metabolism. These changes have been attributed to the fact that feeding fructans to monogastrics animals alters the intestinal bifidobacteria population (Yazawa et al., 1978). Farnworth et al. (1995) evaluated in weaned pigs of 8 kg the inclusion in the diet of 0, 1, 3 and 6% of Jerusalem artichoke tuber on the performance and the volatile fatty acids (VFA). They found a quadratic effect on feed intake and feed efficiency but no negative effect on weight gain. The VFA had also a quadratic effect ($p < 0.05$) and the main VFA found was acetic acid. The acetic acid have been shown to be a characteristic fermentation product of Bifidobacteria (Bezcorobainy, 1989). Except for valeric acid, the concentration of VFA (acetic, propionic, butyric, isobutyric, isovaleric) was greatest for the group eating 3% Jerusalem artichoke.

Piloto et al. (1998) using pigs of 14.6 kg initial live weight feeding a diet containing 0, 33, 66, and 100% Jerusalem artichocke found no significant differences in feed intake, daily gain and feed efficiency of pigs fed 33% Jerusalem artichoque. However, with higher inclusion level the performance parameters were significantly reduced ($p < 0.001$).

An other alternative feedstuff is the Turnip like-rape, named "Stoppelrübe" in German. It is a moderate good source of fibre, calcium and vitamins A and C. The turnip is one of the oldest cultivated vegetable and thought to have originated in northern Europe about 2000 years B.C. Before the spread of potatoes, the highly nutritive turnips varieties, were among the most important staple food for man and animals. Today, turnips are not as widely used but recent interest to find local feedstuffs has brought attention to this plant which grows best in cooler climates. The nutritional composition of this plant is described in table 2.9.

Table 2.9. Chemical composition of Jerusalem artichoke and Turnip like-rape

	Jerusalem artichoke		Turnip-like rape		
	DLG (1991)	Jost (1991)	DLG (1991)		Becker and Nehring (1969)
Content as %			Tuber with leaves	Only tuber	Only leaves
Dry matter	22	16-20	10.0	9.0	9.0
Organic matter	94.1	--	82	86.7	--
Crud protein	9.2	9.7	19.9	14.2	1.8
Fat	0.8	0.7	2.2	1.4	0.3
Crud fibre	4.1	4.8	14.0	12.0	1.0
Ash	--	7.9	18.0	13.3	2.2
Starch	72.4	--	--	--	--
Nitrogen free extract	80.0		45.9	59.1	3.7

2.6.2 Manure and soil microbial activity

The decomposition of plant and animal residues is brought about mainly by microbial enzymes by soil fauna, particularly earthworms are often important in the early stages. Manure returned to the land has proved beneficial not only for fertility and increased organic matter but also causes a higher number of soil microorganisms breaking down residual plant materials (McDowell, 1993). Soil organic matter includes stable humus material, plant and animal residues in various stage of decomposition and the microbial biomass. The microbial component of the soil includes bacteria, actinomycetes, fungi, algae, protozoa and microfauna. In many soils, the soil microbial biomass accounts for 1-

3% of the total organic matter. However, the biomass makes a greater contribution to the soil than theses proportions suggest (Whitehead, 1995).

The average concentration of N in microbial cells is usually 5-10% on a dry matter basis and thus higher than the concentration in the bulk of the soil organic matter. The biomass therefore contains a larger proportion of the soil organic N than it does of the total organic matter, often accounting for between 2 and 6% of the total soil N. If the supply of available C is not limiting, soil microorganisms compete with plants for the inorganic N present in the soil and convert it into microbial tissue. This immobilized N is unavailable to plants until there is a net decline in the microbial biomass when some microbial N is mineralized. Microbial N exists in two main forms, first as cytoplasmic protein which decomposes readily, and second as cell-wall components which are more resistant to decomposition. The beneficial effects of N released from manure as ammonium (NH_4) and nitrate (NO_3) appear directly after application. However, nutrient losses, especially volatile nitrogen, can occur rapidly after excretion in dry conditions; the losses can be between 15 and 35%. The urea in the urine component of slurry is hydrolysed rapidly to ammonium, the hydrolysis being complete within a few days at temperatures of > 10ºC. The application of pig slurry has shown higher rates of volatilization compared to that of faeces only (Whitehead, 1995). The manure characteristics should be considered in order to maximize the nutrient value of its nitrogen content and to minimize environmental pollution. In fact only a fraction of the nitrogen content is incorporated by the crop. The remainder is lost through volatilization, denitrification or nitrate leaching, remains in the soil as NH_4 fixed to clay minerals or is incorporated in humic substances (Ceccherini et al., 1998).

Mineralization of N occurs when the organic forms in soil organic matter and in plant and animal residues are converted into inorganic molecule. Mineralization results almost entirely from microbial activity. It is essentially "ammonification" (i.e. the conversion of organic N to ammonium N) but nitrification, the subsequent oxidation of ammonium to nitrate, may be considered as being part of the mineralization process.

Immobilization is the reverse of mineralization, i.e. the transformation of inorganic N into organic forms. One major route is through the assimilation of inorganic N by soil microorganisms. Both mineralization and immobilization occur continuously in the soil, and both processes are retarded by cold and dry conditions. The balance between the two processes can vary widely from soil to soil, and from time to time in any soil, depending on the nature of the organic materials. In Figure 2.2 atypical N cycle in a pig outdoor system is described.

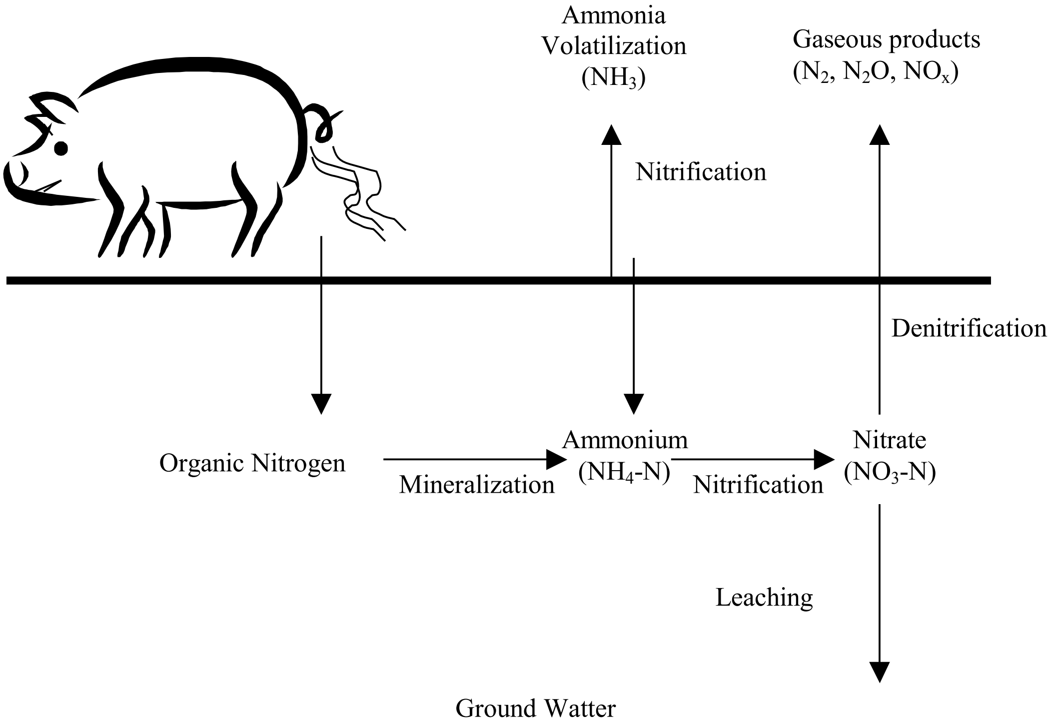


Figure 2.2. N cycle in outdoor (adapted from: BLF 1991)

The decomposition of plant and animal residues in a soil always results in some of the C and N being mineralized. During decomposition, some of the C is assimilated as small molecular compounds and immobilized by the microbial biomass, but some is inevitably mineralized to CO_2 due to microbial respiration. The net mineralization of C normally begins immediately after the addition of the organic material to the soil, and the CO_2 escapes to the atmosphere. However, the net mineralization of N often occurs more slowly, and it may take months or even years before it is appreciable.

The plant material and animal excreta that form the immediate source of organic N in the soil vary widely in composition, and consequently in the extent to which their N accumulates in the soil. It is well established that organic materials with a high C:N ratio (> 30:1) are slow to release inorganic N and may cause some immobilization, at least temporarily, whereas materials with low C:N ratio (< 20:1) usually release inorganic N rapidly through mineralization (Whitehead, 1995).

Agricultural practices that influence the amount of organic matter in soils also affect the amount of microbial biomass. Increases in microbial biomass can occur as a result of the repeated application of slurry (Whitehead, 1995). Organic farming systems are characterized by an enhanced abundance and diversity of earthworms and beneficial soil arthropods; they also have been shown to be more protective than conventional farming systems, providing long-term soil fertility and system stability (Mäder et al., 1996). The same authors showed that soil microbial biomass, the microbial biomass to soil organic carbon ratio and soil respiration increased in the following order: unfertilized, mineral [conventional (mixed mineral/organic)], organic and bio-dynamic, indicating a higher amount of nutrients in the microbial biomass and a higher potential to mineralize organic substances in both organic treatments.

Properties of the soil, such as water infiltration rate, water holding capacity (organic matter content), texture and ration exchange capacity, affect how much manure can be efficiently utilized by crops. Due to increased soil aeration, organic matter in manure is decomposed more rapidly in coarse-textured soils than in fine-textured soils and more rapidly under warm, moist conditions than under cold, dry conditions. However, fine textured soils will retain the nutrients longer in the upper profile (where plants roots can get to them) (Whitehead, 1995).

2.9 Conclusions

There is a lack of information regarding the digestive and metabolic capacity of Creole pigs fed with diets typically used in milpa system. There is consequently a need to determine this potential in order to relate it to the feed resources available in order to improve pig diets. That information can possibly contribute to find out adaptive traits to optimize the management of this breed.

The reduction of the fallow period in the milpa system causes a reduction of the fertility and increase of weeds which consequently reduce the maize yield. This problem suggests the need to identified strategies to sustain the crop cultivation in the same area for more than 2 years. The need to save nutrients or return nutrients to the crop by direct application of pig faeces was identified as a strategy that can possibly sustain maize yield.

In outdoor conditions where the pigs are provided with concentrate diet and have the possibility to consume alternative (roughage) feedstuffs (i.e. grass, tuber plants), the question arises to which extend these conditions influence the nutrient excretion in the faeces and their effects on the soil.

Pig nutrition can be a key factor to optimize the partitioning of excreted nitrogen and the quality of the manure as a source of nutrients for crop growth in this way reducing nutrient losses.

Research questions

The questions to be addressed in this study therefore were the following:

(1) What are the differences between Creole and genetically improved pigs with regard to their digestive and metabolic characteristics?
(2) What are the benefits of integrating pig and crop production in the same geographic space?
(3) What is the influence of forage in the hind gut of pigs and the implications for soil biology?

The first two research questions were investigated under tropical conditions in Mexico and the third research question was studied in the temperate climate in Germany. In this thesis emphasis is placed on the relationship between the components of the systems under study. The first part of the thesis was part of the project "Optimising livestock integration into small-scale low external input crop systems" and its main aim was to provide the institutional research necessary to encourage farmer' on-farm experiments and support participatory rural appraisal. The research problem was identified through a combination of field research and literature review, the field research is reported in Anderson et al. (1998).
Although the third research question was carry out in a temperate climate the main objective was not to contrast the condition of the production systems but to complement and cover one important aspect of the overall objective of this study.
The present study was designed to understand the nutrient flow within pigs and the interaction between the components of the production system (i.e. animal-plant-soil) to identify possibilities to improve the efficient use of resources. Diagram 2.2 presents the description of the study.

The research questions were answered by the following **research objectives:**

The first research objective was:
To determine the digestibility and nitrogen balance of low and high quality diets by using improved and Creole breeds.

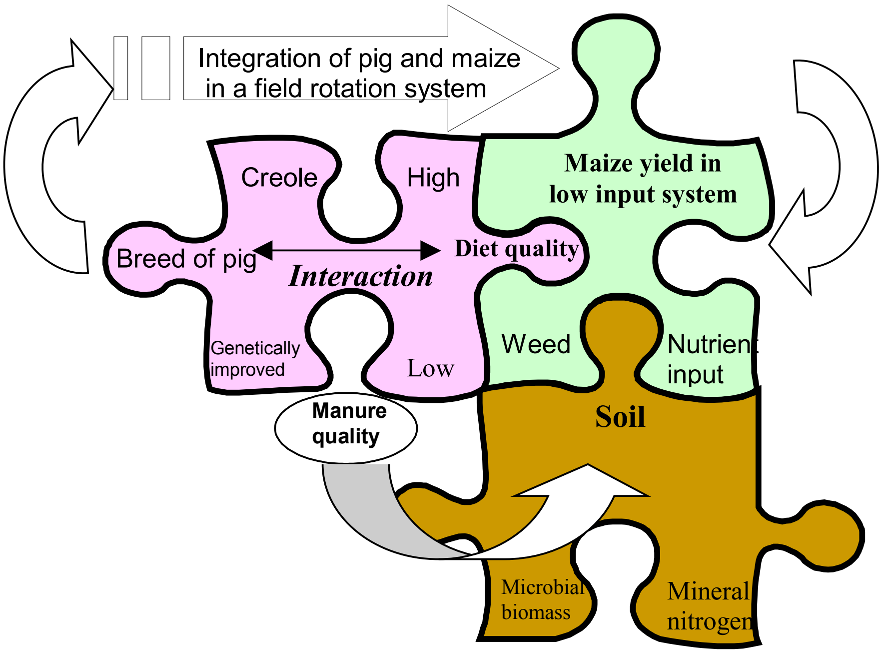
The second research objective was:

To determine whether the use of pigs in a field rotation system has a beneficial effect on the following cultivation of maize.

The third research objective was:

To determine the effect of forage on microbial activity in pig faeces kept outdoor and the influence of pig faeces on soil micro-biology.

Diagram 2.2. Overall view of study strategies to improve the use of limited nutrient resources in a low input pig production system (Milpa system)



Chapter 3 Digestibility and nitrogen balance in Creole pigs and improved breed of pigs fed with low and high quality diets

3.1 Introduction

Peasant pig production in the South of Mexico is primarily characterised by the use of Creole pigs (Cp) kept in the backyard. However, Cp are increasingly being replaced by genetically improved pigs (GIp). Often, peasant farmers believe that GIp are more profitable than Cp because of their higher weight gain and leaner carcasses. However, the GIp have high nutrient requirements to reach a high performance when these are not covered a low performance is found. On the other hand, the hypothesis of the present experiment was that the Cp may match better with the feed available in peasant production system [e.g. mucuna beans (*Stizolobium deeringianum*) and fibrous feedstuffs].

Based on the importance of maize as important food and feed in the milpa system, its substitution as a feedstuff in the diet of pigs can make more food available for peasant farmer family consumption. Mucuna bean (MB) is used as a green manure in the milpa system to improve soil fertility and to increase maize yields. However, the beans from mucuna occasionally have no practical use in the production system (Anderson et al., 2001). Recently, some experiments have been conducted on the use of MB in chicken feeding (Trejo et al., 1999b; Del Carmen et at., 1999; and Trejo and Belmar, 2000). However, comparatively little research has been done on MB and pigs. The objective of this study therefore was to determine the digestibility and nitrogen balance of low and high quality diets in Cp and GIp.

3.2 Materials and methods

The experiment was carried out at the Faculty of Veterinary Medicine and Animal Production of the Autonomous University of Yucatan in Yucatan, Mexico. This site has a tropical climate with an annual average temperature of 27.7 ºC and an annual precipitation of 800 mm (Gobierno del Estado de Yucatán, 1983).

3.2.1 Animals

Sixteen male Cp and sixteen male GIp weighing 40 kg were used in this experiment. All pigs used in this experiment came from the Faculty of Veterinary Medicine and Animal Production from the Autonomous University of Yucatan. The GIp used were PIC x

Seaghers. Figure 3.1 shows one of the Mexican Creole pigs used in this experiment and Figure 3.2 shows two GIp used.

3.2.2 Experimental diets

Four experimental diets were used: diet (A) maize only (crude protein 8.5%), diet (B) 25% of mucuna beans previously boiled and dried + 75% of maize (crude protein 12.5%), diet (C) 25% of grass (*Panicum maximum*) previously dried + 75% of maize (crude protein 12.5%) and diet (D) balanced diet with 16% crude protein according to the nutrients requirements for growing pigs (NRC, 1998; see Table 3.1).

The diet with only maize was used as the control, reflecting the feeding conditions for pigs in rural backyards in the southeast of Mexico, where maize usually represents the main or only component of the diet during certain seasons of the year (Rejon et al., 1996; Anderson, 1998). The diets B and C were taken as improved diets given their 4% higher protein content, compared to the diet with only maize. Diet B was designed to improve the nitrogen level by using locally available protein rich feed. Diet C with forage was designed to evaluate a diet with high crude fibre content, since the forage available has both a high protein and high crude fibre content. These diets (B and C) contained the same level of protein but had different levels of crude fibre. The other control (diet D) was a balanced diet based on maize and soybean meal, representing the conventional diet used to rear genetically improved pigs under commercial conditions.

Diets A, B and C were considered as of low quality as they did not cover the nutrient requirements for improving genetically growing pigs and diet D was considered as a high quality diet.

Diet D shows an almost ideal amino acid composition compared to the recommended values of NRC (1998), while diet A showed extreme excess of limiting essential amino acids with respect to Lysine. Diets B and C showed a moderate excess of methyonine and cystine, but lower treonine and tryptophan in diet with B and moderate excess of treonine and tryptophan in diet C Table 3.2).

Figure 3.1. Male Mexican Creole pig used in this experiment

Figure 3.2. Male genetically improved pigs used in this experiment

Table 3.1. The contents and nutritional composition of the diets used

Main feedstuffs	Diets			
	Maize	Maize-Mucuna	Maize-grass	Balanced
Protein level	Low	Medium	Medium	High
Contents g/kg				
Maize	972	726	670	754
Soy meal 44			110	211
Mucuna grain		250		
Grass			200	
Lysine			0.31	0.61
Methyonine				
Calcium	8.6	4.4	6.0	9.0
Orthophosphate	14.3	14.0	9.0	20.0
Salt	4.0	4.0	4.0	4.0
Minerals	0.5	0.5	0.5	0.5
Vitamins Roche	0.3	0.3	0.3	0.3
Bayonox	0.2	0.2	0.2	0.2
% Estimated nutrient composition				
Crude protein *	8.5	12.5	12.5	16.0
M.E. (Mcal/kg)	3.33	2.49	2.54	3.05
Crude fibre *	2.23	2.92	8.32	3.23
Lysine	0.24	0.57	0.51	0.85
Methyonine + cystine	0.39	0.42	0.40	0.55
Treonine	0.35	0.26	0.43	0.63
Tryptophan	0.09	0.07	0.13	0.20
Calcium *	0.65	0.65	0.66	0.84
Total phosphorus	0.50	0.50	0.50	0.69

*Determined in the laboratory

Table 3.2. Amino acids patterns of the diets used in comparison to the ideal protein pattern (NRC, 1998)

	NRC (1998)	Diets			
		Maize	Maize-Mucuna	Maize-grass	Balanced
amino acids in %					
Lysine	100	100	100	100	100
Methyonine + cystine	57	166	73	78	65
Treonine	60	146	46	84	74
Tryptophan	18	36	11	26	24

Treatment of Mucuna beans: The MB was boiled for thirty minutes at 100 °C in a water-MB ratio of 2:1 (kg/kg). Afterwards, MB was dried in an oven at 60 °C. In a next step the MB was milled to 3 mm.

3.2.3 Experimental procedure

Pigs were adapted to the diets for a period of seven days (diets offered *ad libitum*). Afterwards, faeces and urine collection was carried out for seven days. There were two breeds and four diets in four blocks. The pigs were kept in individual steel metabolism crates, which were 1.0 to 1.4 m long and 40 to 70 cm wide with full visibility and adjustable to the size of the experimental animals with a feed box added to the front and a steel box overhang and a plastic box on the floor, properly adapted to collect separately faeces and urine. The feed intake was calculated as the difference between feed offered and feed refused by each animal, from which a value for the mean food intake per pig per day was derived. The live weight gain was calculated on an individual pig basis using the initial and final weight. Using daily feed intake and live weight gain per pig, the feed conversion was calculated. The duration of the each block was fourteen days. Data of performance (feed intake, live weight gain and feed conversion) were collected for fourteen days and feed intake of the digestibility and nitrogen retention were for seven days. The pigs were allocated to one of the four dietary treatments in a randomised block design with factorial arrangement 2 breeds (Creole or genetically improved pigs) x 4 diets (A, B, C and D) with four blocks and one replication per treatment in each block. There were four repetitions per treatment. The experimental unit was the animal.

3.2.4 Experimental design and statistical analysis

Data from the performance, digestibility and nitrogen utilization trial were analysed using the GLM procedure of SAS (1996) as a randomised block design with factorial arrangement 2 x 4 according to the model: $Y_{ijk}=A_i + B_j + (AB)_{ij} + b_k + (tb)_{ijk} + e_{ijk}$, where Y_{ijk}= observed value for factor i and factor j in block k; A_i and B_j = represent the main factors; $(AB)_{ij}$ = interaction of factors; b_k = mean yield for block k; $(tb)_{ijk}$ = interaction of the effects of factors and block, and e_{ijk} represents the random unit variation within a block. Factors taken into account were breed of pigs (Creole or genetically improved pigs), and diet (diet A, B, C, and D). Least square means (LSM) was used to compare of treatment means.

3.3 Results

3.3.1 Performance

Independently of the diet, the Cp showed a higher feed intake. As is shown in Table 3.2 the feed intake was 29% higher in Creole pigs (2.1 kg/day) in comparison to that of improved pigs (1.5 kg/day) ($p < 0.01$). There was a reduction of 29% feed intake in the diet with grass (diet C) in comparison to the other three diets ($p < 0.01$).

The live weight gain was higher in Cp compared to GIp (612 vs. 419 g/day for Cp and GIp respectively) ($p < 0.01$). A significant interaction was found between diet x breed ($p < 0.01$). Table 3.2 shows that with the low quality diets (diets A, B and C) the live weight gain was higher in Cp compared to the GIp. Inversely, with the balanced diet the live weight gain was higher in GIp.

Feed-gain ratio was lower in Cp compared to the GIp (3.71 vs. 4.79 kg of feed /kg of live weight gain in Cp and Gip, respectively). However, there were no statistically significant differences between breeds of pigs ($p > 0.05$). Feed conversion was lower in Cp with the low quality diets (diets A, B and C) compared to improved pigs. But the feed conversion was lower in the GIp with the high quality diet (diet D) in comparison to Cp (Table 3.3).

These results indicate that the Cp genotype better exploits low quality diets compared to Gip. GIp in contrast show a better performance with high quality diet compared to Cp.

3.3.2 Apparent digestibility

Feed intake recorded during the seven days of the digestibility trial showed similar trends compared with the data of 15 days. It is important to note that the significance of the interaction of the diet and breeds was higher ($p < 0.001$) compared to the 15 days measured ($p < 0.053$).

The apparent digestibility of dry matter, NDF and crude protein in Cp and GIp fed with low and high quality diets is shown in Table 3.3.

Diet C (with high crude fibre level) reduced the dry matter and NDF digestibility compared with the other three diets. This effect ocurred in both breeds ($p < 0.01$). The reduction of dry matter and NDF digestibility were 15 and 40% in Cp and GIp respectively. There was no statistically significant difference in dry matter and NDF digestibility between breeds ($p > 0.05$). These results suggest that the inclusion of crude fibre in the diet had a negative effect on digestibility independent of genotype.

Regarding protein digestibility, the lowest digestibility was found in diets B (with mucuna) and C (with grass) followed by diet A ($p < 0.01$). The highest digestibility was found in diet D. The protein digestibility of balanced diet was 13% higher compared with that of the three other diets. Similar protein digestibility was observed in diets with mucuna and grass (diets B and C, respectively) ($p > 0.05$). There was a 5% lower protein digestibility in GIp compared to Cp ($p < 0.05$) (see Table 3.4).

3.3.3 Nitrogen utilization

The nitrogen utilization in Cp and GIp fed with low and high quality diets is described in Table 3.5.

Due to the higher diet intake, nitrogen intake was 31% higher in Cp compared with the GIp (41.2 vs. 31.4 g/day in Cp and GIp respectively). In Creole pigs nitrogen intake was lower in diets with only maize and with grass (diets A and C). However, improved breed of pigs had lower nitrogen intake with diets A and B. The nitrogen intake was 86% higher in the balanced diet compared with that of the other three diets.

The nitrogen in the faeces of pigs fed with diets B, C and D was 37% higher compared with that in diet A. There were no statistically significant differences in faeces nitrogen between breeds ($p > 0.05$).

In Cp the nitrogen absorption was lower in diets A and C (25.0 and 24.9 g/day), followed by diet B (34.5 g/day). The highest nitrogen absorption was found in diet D (48.9 g/day) ($p < 0.01$). In GIp nitrogen absorption was lower in diets A, B and C (15.9, 16.6 and 19.6 g/day) compared to nitrogen absorption in diet D (46.5 g/day) ($p < 0.01$).

The nitrogen concentration in urine was 110% higher in the high protein diet (diet D) compared to the other three diets ($p < 0.01$). The urine nitrogen in Cp was 64% higher compared with GIp ($p < 0.01$). With the high protein diet (diet D) there was 126% more nitrogen in urine compared with the low and medium protein content diets (diets A, B, and C).

The nitrogen retention (g/day) was 109% higher in the balanced diet (diet D) compared to that of the other diets ($p < 0.01$). GIp retained 44% more nitrogen compared to the Cp ($p < 0.01$). The highest nitrogen retention was observed in the GIp genotype in the high protein balanced diet. While medium nitrogen retention was observed in both the Creole and the improved breed of pigs in medium protein diets (B and C), low protein retention was observed only when maize diet (diet A) was fed.

The nitrogen retained as percentage of nitrogen consumed was 40% higher in GIp compared with Cp (28 vs. 46% in Cp and GIp, respectively).

When feeding low quality diets, there was a higher nitrogen intake and nitrogen absorption rate of Cp than of GIp. However, there was more nitrogen excreted through urine.

When feeding the high quality diet (diet D) there was a similar nitrogen intake and nitrogen absorbed between the Cp and GIp. However, there were three times lower nitrogen retention as a total and as a percentage of the nitrogen intake in Creole pigs than in the improved pigs.

3.3.4 Partition of excreted nitrogen

There was a significant interaction effect between factors breed and diets ($p < 0.01$), so the total nitrogen excreted depended on the breed and diet in question. GIp had 62% more excreted nitrogen in diets A, B, and C compared with diet D. 55% more nitrogen was excreted in Cp with diet D compared with diets A, B, and C (Table 3.6).

However, there was no effect of interaction of factors (breed x diet) on the proportion of nitrogen excreted through the faeces and urine ($p > 0.05$). The percentage of nitrogen excreted in faeces was higher in GIp compared with Cp (44 vs. 28% in GIp and Cp respectively). The lowest nitrogen in faeces was observed in diets D and A (28 and 31%, respectively) followed by the diets B and C (41 and 45%, respectively). In contrast, the percentage of nitrogen excreted in urine was lower in GIp compared with Cp (56 vs. 72% in GIp and Cp, respectively). The lower nitrogen excretion in urine was observed in diets C and B (56 and 59%, respectively) followed by the diets A and D (69 and 72%, respectively): (Figure 3.3 show these results).

Table 3.3. Performance of Creole and genetically improved pigs fed with low and high quality diets

Item	Diet	Breed		Average	Anova		
		Creole	Genetically improved		Factor	SEM	p > F
Feed intake (kg/day)	Only maize	2.33	1.57	1.95	Diet	0.09	0.001
	Maize-mucuna	2.29	1.37	1.83	Breed	0.06	0.001
	Maize-grass	1.52	1.20	1.36	D x B	0.13	0.053
	Balanced	2.12	1.83	1.97			
	Average	2.1	1.5				
Weight gain (kg/day)	Only maize	0.682	0.313	0.498	Diet	0.05	0.001
	Maize-mucuna	0.680	0.263	0.471	Breed	0.04	0.001
	Maize-grass	0.385	0.285	0.335	D x B	0.07	0.001
	Balanced	0.660	0.818	0.739			
	Average	0.602	0.419				
Feed conversion *	Only maize	3.53	6.23	4.88	Diet	0.60	0.07
	Maize-mucuna	3.39	6.14	4.77	Breed	0.43	0.08
	Maize-grass	4.64	4.51	4.58	D x B	0.85	0.08
	Balanced	3.28	2.26	2.77			
	Average	3.71	4.79				

SEM = Standard error of the means; D x B= interaction diet x breed
*kg of feed /kg of live weight gain.

Table 3.4. Digestibility of different diets fed to Creole and genetically improved pigs

Item	Diet	Breed		Average	Anova		
		Creole	Genetically improved		Factor	SEM	p > F
Feed intake (kg/day)	Only maize	2.42	1.64	2.03	Diet	0.08	0.001
	Maize-mucuna	2.44	1.24	1.84	Breed	0.05	0.001
	Maize-grass	1.81	1.45	1.63	D x B	0.14	0.001
	Balanced	2.21	2.12	2.17			
	Average	2.22	1.61				
Digestibility							
Dry matter (%)	Only maize	89.3	89.4	89.4	Diet	0.84	0.01
	Maize-mucuna	88.9	86.9	87.9	Breed	0.60	0.26
	Maize-grass	75.8	75.1	75.5	D x B	1.13	0.82
	Balanced	87.9	86.6	87.3			
	Average	85.5	84.5				
NDF	Only maize	79.3	78.9	79.1	Diet	1.62	0.01
	Maize-mucuna	86.1	83.0	84.5	Breed	1.14	0.63
	Maize-grass	49.5	48.0	48.7	D x B	3.57	0.75
	Balanced	76.8	78.6	77.7			
	Average	72.9	72.1				
Crude protein	Only maize	82.2	77.2	79.7	Diet	1.68	0.01
	Maize-mucuna	76.2	70.9	73.8	Breed	1.18	0.04
	Maize-grass	74.9	74.2	74.6	D x B	2.37	0.74
	Balanced	87.7	84.1	86.1			
	Average	80.4	76.7				

SEM = Standard error of the means; D x B = interaction diet x breed

Table 3.5. Nitrogen utilization of different diets fed to Creole and genetically improved pigs

Item (g/day)	Diet	Breed		Average	Anova		
		Creole	Genetically improved		Factor	SEM	p > F
N intake	Only maize	30.4	20.6	25.5	Diet	1.18	0.01
	Maize-mucuna	45.3	23.4	34.4	Breed	0.86	0.01
	Maize-grass	33.1	26.4	29.8	D x B	0.40	0.01
	Balanced	55.9	55.3	55.6			
	Average	41.2	31.4				
N in faeces	Only maize	5.4	4.7	5.0	Diet	0.14	0.01
	Maize-mucuna	10.8	6.8	8.9	Breed	0.09	0.11
	Maize-grass	8.3	6.8	7.5	D x B	0.11	0.03
	Balanced	6.9	8.8	7.8			
	Average	7.8	6.8				
N absorbed	Only maize	25.0	15.9	20.5	Diet	0.77	0.01
	Maize-mucuna	34.5	16.6	25.6	Breed	1.12	0.01
	Maize-grass	24.9	19.6	22.3	D x B	0.30	0.01
	Balanced	48.9	46.5	47.7			
	Average	33.4	24.7				
N in urine	Only maize	16.3	8.4	12.3	Diet	0.61	0.01
	Maize-mucuna	21.0	7.4	14.2	Breed	1.19	0.01
	Maize-grass	13.6	6.6	10.1	D x B	0.37	0.01
	Balanced	38.3	13.1	25.7			
	Average	22.3	8.9				
N retained	Only maize	8.9	7.5	8.2	Diet	0.53	0.01
	Maize-mucuna	13.5	9.2	11.4	Breed	0.41	0.01
	Maize-grass	11.3	13.0	12.1	D x B	0.54	0.01
	Balanced	10.7	33.4	22.1			
	Average	11.1	16.0				
Nitrogen retained (%)	Only maize	29.0	36.4	32.7	Diet	0.35	0.29
	Maize-mucuna	29.7	39.4	34.6	Breed	1.62	0.01
	Maize-grass	33.4	48.2	40.9	D x B	0.70	0.01
	Balanced	18.8	60.5	39.7			
	Average	27.8	46.2				

N = Nitrogen; D x B = interaction diet x breed; SEM = Standard error of the means.

Table 3.6. Partition of total nitrogen excreted in Creole and genetically improved pigs fed with low and high quality diets

Item	Diet	Breed		Average	Anova		
		Creole	Genetically improved		Factor	SEM	p > F
TNE (urine and faeces g/day)	Only maize	21.63	13.10	17.37	Diet	1.56	0.001
	Maize-mucuna	31.76	14.18	22.97	Breed	1.10	0.001
	Maize-grass	21.91	13.29	17.65	D x B	2.20	0.01
	Balanced	45.18	21.87	32.53			
	Average	30.12	15.63				
Nitrogen in faeces (%)	Only maize	24.51	37.44	30.98	Diet	2.64	0.001
	Maize-mucuna	33.95	47.72	40.84	Breed	1.86	0.001
	Maize-grass	38.62	50.34	44.48	D x B	3.73	0.25
	Balanced	14.88	40.28	27.57			
	Average	27.99	43.94				
Nitrogen in urine (%)	Only maize	75.48	62.56	69.02	Diet	2.63	0.001
	Maize-mucuna	66.05	52.27	59.16	Breed	1.86	0.001
	Maize-grass	61.38	49.66	55.52	D x B	3.73	0.25
	Balanced	85.12	59.72	72.42			
	Average	72.01	56.06				

TNE = Total nitrogen excreted; D x B = interaction diet x breed;

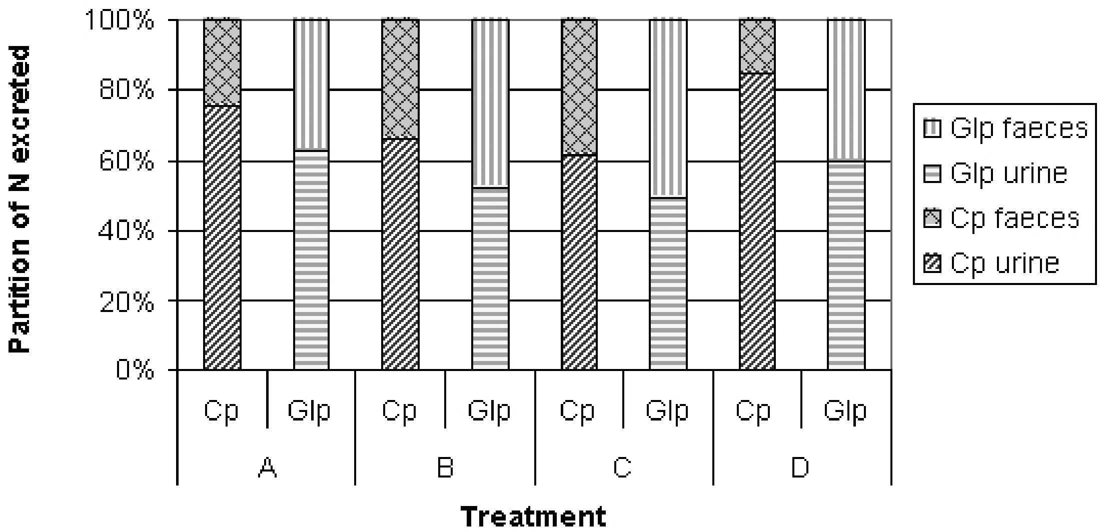


Figure 3.3. Partition of total nitrogen excreted in Cp and GIp fed with low and high quality diets (A, B and C as low quality and D as high quality)

3.4 Discussion

3.4.1 Performance

Feed intake was significantly higher in Creole pigs in comparison to improved pigs. The lower feed intake of GIp was observed in the low quality diets (A, B and C). This is in agreement with Henry et al. (1988); Henry et al. (1992) and Henry and Séve (1993) who showed that lean genotypes are more sensitive to amino acids imbalance than conventional types resulting in negative effects on appetite.

There was a reduction of feed intake in diet C with grass. This result is in agreement with Kennelly and Aherne (1980), they increased 2.5 times the crude fibre content of the diet for growing GIp (Yorkshire x Lacombe). With the low quality diets A, B and C the live weight gain was significantly higher in Creole pigs compared to the improved pigs. It can be expected that the high metabolizable energy in the diets has promoted high fat growth in Cp, this characteristic in Cp is well described in the literature (Lopez-Morales et al., 1999). However, similar live weight gains were found with the high quality diet. Inversely, the feed:gain ratio was higher in Creole pigs with the low quality diets compared to GIp, but there was a lower feed:gain ratio in GIp with the high quality diets in comparison to Cp (Table 3.2).

3.4.2 Apparent digestibility

There was a similar apparent digestibility of the dry matter and NDF in all diets except for the low digestibility in the diet with grass (diet C). The average crude fibre in diets A, B and D was 2.8%, compared with 8.3% in diet C. The increase of fibre content reduced significantly the digestibility of the diet. This is in agreement with different authors who showed that an increase of fibre in the diets reduce the digestibility of the dry matter and protein (Bakker et al., 1995; Lenis et al., 1996).

There was no effect of genotype on digestibility of the dry matter and NDF. These results are in contradiction with Ly et al. (1998), who found a lower digestibility by Cuban Creole pigs compared with Cuban improved pigs (see description of this work in section 2.5.1). Possibly the difference in the crude fibre level and the source of fibre between experiments can explain this disagreement.

The lower digestibility of protein in diets B and C was probably due to the high content of phenols in mucuna bean in diet B (Daxenbichles et al., 1971; Trejo, 1998). In contrast to diet B, however, reduction of nitrogen digestibility in diet C was probably due to the percentage increased of crude fibre (Lenis et al., 1996). In this diet there was no difference in the nitrogen digestion between breeds. This result sustains partially the idea that Creole pigs have special development of gastrointestinal tract for more efficient digestion of fibrous diets. However, a greater feed intake in Cp even with high fibrous diets compared to GIp and the similar digestibility could be associated with higher capacity of gastrointestinal tract for digestion in Cp. This hypothesis needs to be supported by experimental evidence.

3.4.3 Nitrogen utilization

With low quality diets (A, B and C) the higher nitrogen retention per percentage of nitrogen consumed in GIp compared to Cp was possibly due to the combination of the low nitrogen intake and their high nitrogen needs for growth. On the other hand, there was a higher nitrogen intake and amount of nitrogen absorbed in Cp than in GIp with low quality diets.

In low quality diets there was higher nitrogen retention as percentage of nitrogen consumed in improved pigs than in Creole pigs but there was similar nitrogen retention as a total (g/day) between breeds. The higher nitrogen intake of Creole pigs was in the diet with mucuna (diet B). In this diet there was higher nitrogen absorption but also a higher amount of total nitrogen in faeces and urine.

The nitrogen retention (g/day) in diets with 8% (diet A) and 12% crude protein (diets B and C) is similar to nitrogen retentions in Iberian pigs using diets with 6 and 12% crude protein reported by Odriozola et al. (1969) with nitrogen retention of 11.2 and 13.1 g/day, respectively.

There was a similar nitrogen intake and nitrogen absorbed between the Creole and improved pigs with the high quality diets (diet D). However, there was a three times lower nitrogen retention (g per day) in Cp than in GIp. It reduced the nitrogen retention as a percentage of the nitrogen intake in Cp compared to GIp. This suggests lower nitrogen requirements of Creole pigs in comparison to improved pigs.

The increase of N intake led to a higher N absorption. However, this was not the same in both breeds. For GIp a significant increase was seen only between the low quality diets (A, B and C) and the high quality diet. While in Cp with diets A and B nitrogen absortion increased with nitrogen intake. Although differences in nitrogen level, nitrogen intake and absorption between diet A and C, were similar, probably the crude fibre content and bulk density limited the feed intake.

There are no previous studies regarding nitrogen balance comparing Cp with GIp. However, Ly et al. (2003) compared a Vietnamese Mong Cai pigs (unselected genotype for meat growth) with the Large White pig. They used a diet based on maize and wheat bran with 18% crude protein and 7.0% crude fibre. They found lower nitrogen retention in Mong Cai pigs compared to the Large White pigs. The total nitrogen excretion was higher in Mong Cai pigs. However, the partition of nitrogen excreted was 40.8 and 59.2% in faeces and urine, respectively, with Mong Cai pigs and 33.8 and 67.0% faeces and urine, respectively, with Large With pigs.

3.4.4 Partition of nitrogen excreted

Digestion of protein in pigs gut can be attack by enzymatic activity in the small intestine. Feedstuffs with high fibre can not be attack by enzymes produced in the small intestine but by undigested protein and which pass to the large intestine are attack by microbial activity and play and important role as a source of nutrients for microbial growth in the large intestine. Another limiting factor for protein digestion in the small gut of pigs is the phenolic amino acids which form part of the protein fraction. This complex molecule limits the enzymatic digestion of the protein. The phenolic amino acids can be also attacked by microbial activity in the large intestine. Although nitrogen from fibre and phenolic amino acids are digested in the large intestine they do not contribute to nitrogen absorption. Its contribution is to microbial growth and these produce short fatty acids that can be absorbed and slightly contribute to metabolic energy.

The increase of protein through roughage (low digestible) feedstuffs (diet B and C) in the diet of Cp shifted the relation of excreted N away from the urine towards the faeces. This result is in agreement with those of Reed (1986). The shift of N excreted from urine towards the faeces could have been due to the binding of protein by phenols in mucuna bean of diet B which causes a lower protein digestion in the digestive tract as confirmed in the protein digestibility results. Low digestibility of the nitrogen was also observed in diet C. On the other hand, the high quality diet (diet D) was more susceptible to N losses in the urine. A similar tendency was observed in GIp concerning the shift in the balance of excreted N away from the urine towards the faeces by increasing the protein in the diet by using roughage feedstuffs. However, the high digestible diet (D) was less susceptible to N losses in urine compared to the low protein diet (A). An interesting observation was that protein losses in urine with diet D was higher compared to those of pigs fed with diets B and C. Differences in the nitrogen retention potential between Creole and improved breeds may explain these results.

3.5 Conclusions

Performance

The results of this experiment show that the quality of the diets affected on the feed intake of Cp and GIp. A high fibre diet reduced feed intake in both Cp and GIp. Low quality diets reduced feed intake in GIp but not in Cp. This is possibly related to the different demands of nutrients for pig growth. The same trend was observed for live weight gain. Weight gain was higher in GIp using balanced diets, while an inverse result was observed with the other diets.

Digestibility

A reduction in digestibility of DM and FDN was observed in high fibre diet (diet B) in both breeds. Although a of the similar digestibility with high fibrer diet was observed in Cp and GIp it maybe hypothesized that Cp have a higher capacity to digest fibre since feed intake was higher in this breed than in GIp. Leading to a higher total amount of feed digested.

Nitrogen utilization

The N retention was similar in Cp independent of the fed regimen. In a balanced diet the N retention was higher in GIp than in Cp. To avoid extreme protein losses a diet with 12%

protein is enough for Creole pigs. To express the high potential of nitrogen retention in improved pigs, it is necessary that they receive high quality diets.

Partition of nitrogen

Roughage diets (diets B and C) with medium protein level shifted the balance of excreted nitrogen from urine towards the faeces. This is relevant when the faeces of pigs are used as a nutrient source for plant growth.

The use of low quality diets match better with the potential of Creole pigs' for nitrogen retention. To use genetically improved breeds of pigs is not recommended when only low quality feedstuffs are available. The results above suggest that Cp perform satisfactory with the feed resources available in peasant systems.

Chapter 4 Integrating pigs and maize production in a low input production system in tropical Mexico

4.1 Introduction

In the tropical Mexico, the milpa system is one of the most important mixed farming systems which integrate animal and crop production. However, the spatial separation of crops and animals results in a one way flow of nutrients from the crop fields to the home gardens. Additionally, the main problems facing the milpa system are: shortened fallow periods, decreasing soil fertility and an increasing weed pressure. Farmers counteract these problems with the application of mineral fertilizers and herbicides (Gündel, 1998; Graefe, 2003). In particular the use of herbicides has caused a reduction of companion crop diversity associated with maize such as squash and beans (Caamal et al., 1996). Current pressures on the milpa system require the development of new technologies to sustain production.

Innovations with cover crops have shown effective method for weed control and maize yield improvement (Caamal-Maldonado et al., 2001). However, the low adoption of this technology suggests the need to explore other possibilities including additional benefits for the animal component (Anderson et al., 1998).

The milpa system is organized in an area for crop plantation, a backyard farming and a forest area. The crop plantation area consists mainly of maize (*Zea mays L.*) complemented by different squash and bean species. Animals such as pigs, chicken, goats, even cattle are located in the backyard sub-system (Anderson et al., 1998). Crop and animal production in the milpa system has been the focus of many research groups. However, little attention has been placed on the optimal integration of crop and animal production. There are reasons to assume that a pig's direct fertilization with faeces can sustain the maize yield. On the other hand, weeds after cultivation could play a role as forage feed source for pigs.

The implementation of a pig rotation instead of a slash and burn system to prepare the land for cultivation is a method that implies a qualitative change in the milpa shifting cultivation.

The working hypothesis of this study was that the integration of pigs and maize production in the same area of land provides an alternative to the milpa system by enhancing the recycling of nutrients to stabilize crop yields.

The main objective of the experiment therefore was to determine whether the use of pigs in a field rotation system has a beneficial effect on the following cultivation of maize.

4.2 Materials and methods

The experiment was carried out at the Faculty of Veterinary Medicine and Animal Production (FVMAP) in Yucatan, Mexico between 2000 and 2003. The soil was a heterogeneous, shallow, rocky (limestone), clay-loam, with a pH of about 7.7, and 1.6% organic matter.

4.2.1 Experimental treatments

There were three treatments and three years of evaluation comprising each one cultivation period. The experimental field (100 by 100 m) was subdivided into eight plots of 20 by 60 m. The treatments were designed as follows: traditional slash and burn (S&B), keeping pigs before the cultivation of maize (PR), and a control treatment without pig rotation and without burn (WoPRB). The experimental field was selected in a forest area of the FVMAP with approximately 10 years of fallow; maize was cultivated the year before the start of the experiment. The management in plots for S&B of the previous year consisted in the use of slash and burn; and for plot in the treatments with and without pigs no burning was used. The treatments are described in Table 4.1. During the dry season different methods of land management were carried out. The S&B treatment was established every year according to the local farming practices described in annex 1. In the PR treatment the pigs were kept on the plots before maize cultivation and in the treatment WoPRB there was a manual slash without burn. S&B treatment was repeated twice, while for the PR and WoPRB treatments, there were three repetitions (Figure 4.1).

Table 4.1. Experimental treatments and management the year before the start of the experiment

Treatments	Cultivation management before to start the experiment (2000)		Years 1 -3 (2001, 2002 and 2003)	
	Season		Season	
	Dry	Rain	Dry	Rain
S&B	Slash and burn	Maize cultivation	Slash and Burn	Maize cultivation
PR	Slash without burn		Pig keeping	
WoPRB	Slash without burn		Slash without burn	

4.2.2 Management

Animals: For the PR treatment a group of 4 or 6 male Creole pigs (Cp) per repetition were used with 10 kg initial live weight (ILW) for the first period and 27 and 37 kg ILW for the second and third period. Except for the first season, pigs were kept on the plots before the cultivation period. The pigs remained in the plots during the dry season for around 100 days (between February and June). The pigs were fed on a mixed diet of boiled mucuna beans (*Stizolobium deeringianum*) and maize in a proportion of 25 to 75. Mucuna beans were boiled for 30 minutes using 2 litres of water per 1 kg of mucuna. The beans were then sun-dried and ground in a hammer mill using a 3 mm sieve. In the plots of pig rotation there were natural shade (trees) of 15 m^2 and huts of 6 m^2 size. Based on the initial weigh and number of pigs the stocking rate of pigs were 60, 108 and 148 kg of pig LW/plot for the first, second and third year of evaluation (Fig. 4.2).

Maize cultivation: Maize was planted each 80 cm apart (25 000 plants/ha) at the beginning of the raining season (in June). Distance between furrows was 1 m. After germination, seedlings were thinned to 2 plants per position. 35 days after sowing the maize manual weed control was carried out in all treatments. These procedures were repeated each year. The maize variety Nal-xoy which is a cross-breed of Nal-tel and Tuxpeño, was used in all four years.

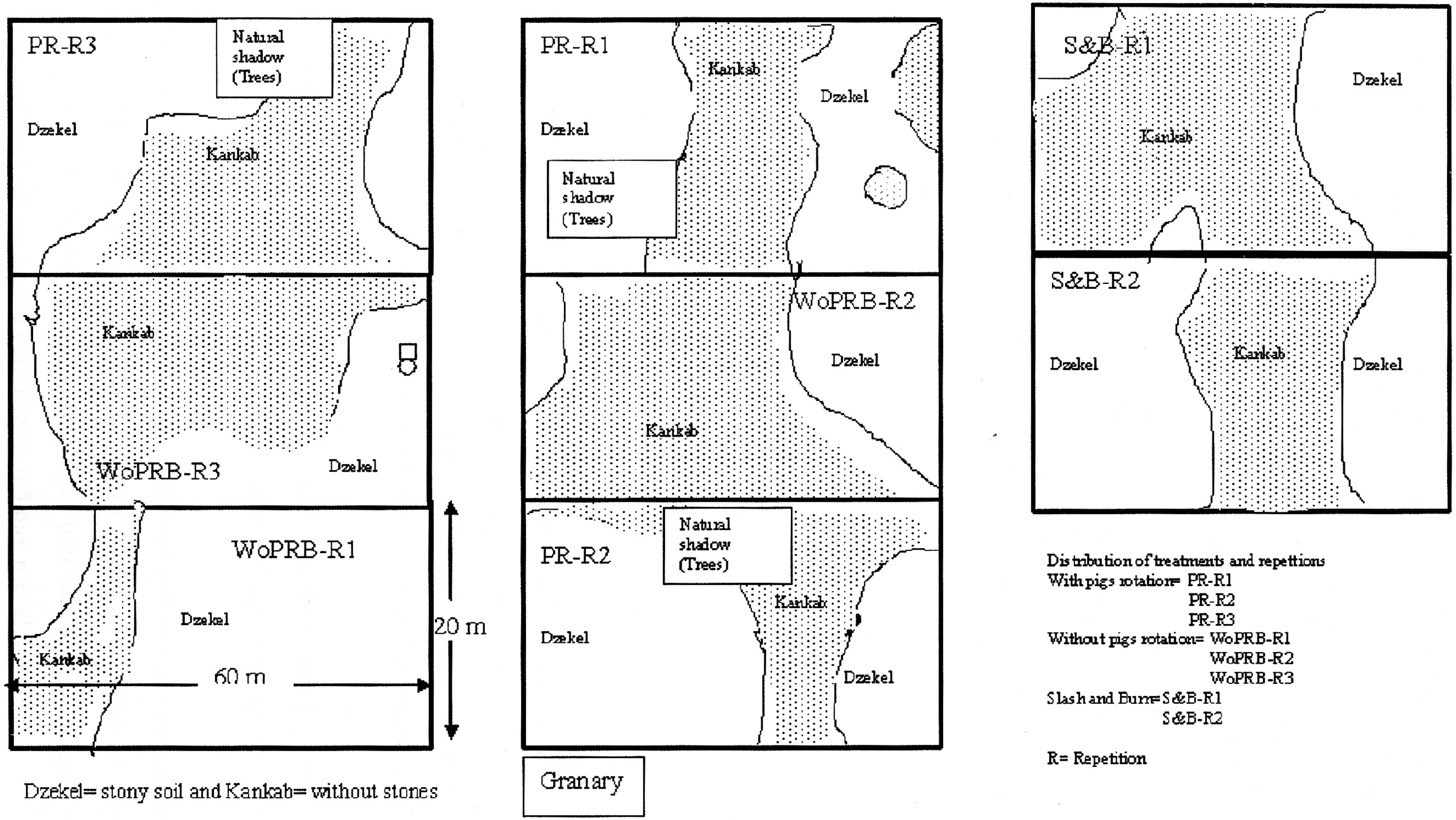


Figure 4.1. Description of the soil type in the experimental area of the experiment „integration of pigs and maize production“ and treatment distribution

Figure 4.2. Group of Creole pigs foraging in a PR treatment experimental plot

4.2.3 Measurements

Pig performance: Feed intake was calculated as the difference between feed offered and feed refusal by each group of pigs, from which a value for the mean food intake per pig per day was derived. The live weight gain was calculated on an individual pig basis using the initial and final weight. Using daily feed intake and live weight gain per pig, the feed:gain ratio was calculated.

Weeds biomass: The biomass of weeds was measured every crop cycle, 30 days after sowing (before weeding). In each plot fifteen random sampling were taken using a 0.25 m^2 square. The biomass of weeds was cut 5 cm above the soil in fresh and a sub-sample was taken to determine its dry matter in an oven at 60 ^{0}C. To avoid border effects, the 2 m outer limits of each plot were not considered for sampling.

Labour time: The labour time for weed control was determined 35 days after sowing of maize during the experimental year 1, 2, and 3. It was recorded by observing the time spent for weeding.

Soil mineral nitrogen was determined at the first and last year of cultivation at the beginning of the cultivation period (June). The first year of cultivation it was also determined at the end of the cultivation period (October). Ten samples per plot were taken at 0-5 cm depth and extracted with 0.5 M K_2SO_4 0.5 mol after shading for 30 minutes.

Maize yield: Maize grain yield per treatment was assessed by sampling every third plant of every second furrow of each plot repetition. The total number of plant sampled accounted for 10% of the total plants. Based on this sample was estimated the kg/ha maize yield grain. A sub-sample of maize grain of each treatment was analysed for its nitrogen content by the Kjeldahl method. Maize plantation in the second year was destroyed by Hurricane Isidore on September 22, 2002 but pig performance in the treatment PR during this year was not affected.

Nitrogen input/output: The digestibility of the diets used in this experiment was determined in the experiment one. Based on these results and the total feed intake recorded during the pig stay (number of pigs and days spent on the experimental area) the input of nitrogen through the faeces was estimated. The equation used was as follows: N_{input}=TNI - (TNI/Digestibility of the N). Where= TNI= Total nitrogen intake during the pig stay.

The output of nitrogen was estimated according to the nitrogen content in the maize grain and the yield recorded. The calculations of kg N/ha were made with the following formula: N_{output}= CP% in total maize grain yield/6.25.

The percentage recovery of fertilizer N in harvested crop is usually expressed in terms of the "apparent" recovery, calculated from the total amounts of N in the crop and fertilizer. The apparent recovery is defined as the amount of N in the crop of a fertilized area, minus the amount in the crop of a comparable unfertilized area, expressed as a percentage of the N applied. Due to the different conditions caused by the treatment S&B, the N recovery was estimated based only in the treatments without burning (PR and WoPRB).

4.2.4 Experimental design and statistical analysis

Data from the maize yield, weeds biomass and soil mineral nitrogen were calculated using the GLM procedure of SAS (1996) for a randomised block design with a 3 x 2 factorial arrangement according to the model: $Y_{ijk}=A_i + B_j + (AB)_{ij} + b_k + (tb)_{ijk} + e_{ijk}$, where Y_{ijk}= observed value for factor i and factor j in block k; A_i and B_j = represent the main factors; $(AB)_{ij}$ = interaction of factors; b_k = mean yield for block k; $(tb)_{ijk}$ = interaction of the effects of factors and block, and e_{ijk} represents the random unit variation within a block. Factors taken into account were treatments (S&B, PR, and WoPRB) and year of evaluation. Least square means (LSM) was used to compare treatment means.

4.3 Results

4.3.1 Pig performance

Results of pig performance are presented in Table 4.2. As a result of increased ILW the feed intake was higher in the second and third year compared to the first year (0.73, 1.27, and 1.39 kg/pig/day for first, second and third year). Live weight gain showed the same trend with 0.16, 0.32 and 0.29 kg/pig/day for first, second and third year. Feed conversion showed a slightly reduction in the second year compared to the other years (4.82, 3.93, and 4.81 for first, second, and third year respectively). Pig performance was similar in the three groups within each year ($p > 0.05$).

Table 4.2. Feed intake, live weight gain and feed conversion in Creole pigs fed with maize and mucuna beans (*Stizolobium deeringianum*) during three periods

	Year			Average
	1 (2001)	2 (2002)	3 (2003)	
Days on the plots	110	95	105	
Number of pigs/repetition	6	4	4	
Initial live weight kg	10.1 ± 3.1	27.3 ± 5.6	37.3 ± 10.4	
Stocking rate	60.6	109.2	149.0	
Feed Intake kg/day	0.73	1.27	1.39	1.13
Live weight gain kg/day	0.16	0.32	0.29	0.26
Feed conversion	4.82	3.93	4.81	4.52

4.3.2 Maize yield

The maize yield in the year before the start of the experiment showed significant differences ($p < 0.01$) between S&B and the plots without use of burn [1684 ($n = 2$) and 893.0 ($n = 6$) kg DM/ha for plots with S&B and without S&B]. The maize yield is described in Table 4.3 and Figure 4.3. The average value of plots without S&B ($n=6$) of the previous year (893.0 kg DM/ha) is presented as average of plots ($n = 3$) assigned to the corresponding experimental treatments (822.5 and 963.4 kg DM/ha for PR and WoPRB treatments respectively). In the first and third year of the experiment a reduction of maize yield was found in S&B; similar result was found in the treatment WoPRB ($p < 0.01$); whereas no reduction was found in pig rotation (PR) compared to the year before starting the experiment ($p > 0.05$). The reduction of maize yield in the S&B treatment was of 34% and 71% for the first and third year compared with the year previous the experiment, while in WoPRB the reduction was 42 and 44% for the first and third year respectively. For PR

the first year increased about 32% and the third year reduced in the same degree with a slightly total reduction of 10% compared to the year before starting the experiment.
The first year of evaluation maize yield in PR was 94% higher compared to WoPRB ($p < 0.01$) and similar to S&B ($p > 0.05$) (1084.1, 558.1, and 1107.9 kg/ha for PR, WoPRB and S&B respectively). In the third year of evaluation a higher maize yield was found in the PR compared to the WoPRB and S&B treatments ($p < 0.01$) (741.9, 312.0, and 316.5 kg/ha for PR, WoPRB and S&B respectively). However, on average maize yield (i.e. year 1 and 3 of evaluation) was similar in the S&B and PR treatments ($p > 0.05$) but the maize yield in these treatments was higher compared to the WoPRB (913.0, 435.1, and 712.2 for PR, S&B, and WoPRB respectively) ($p < 0.01$).

4.3.3 Weed biomass

The year before the experiment showed significant differences ($p < 0.01$) between S&B and the plots without use of burn [345 (n=2) and 1279.5 (n=6) kg DM/ha for plots with S&B and without S&B]. The average value of plots without S&B (n=6) of the previous year (1279.5 kg DM/ha) is presented as average of plots (n=3) assigned to the corresponding experimental treatments (1303 and 1256 kg DM/ha for PR and WoPRB respectively) (Table 4.3).
In the first and second year of the experiment an increase of weeds was found in S&B and a reduction in the third year comparable to the first year of the experiment (345.0, 873.0, 1899.5 and 987.5 kg DM/ha for the previous, first, second and third year of cultivation respectively). In the treatment without pig rotation and without burn an increase of 65% was observed in the first year of experiment and these value was sustained during the following years (1256, 2065, 1920, and 1732 kg DM/ha for the previous, first, second and third year of cultivation respectively). The treatment with pig rotation showed a reduction in the first year followed by an increase in the following years (1303, 809, 1263, and 1732 kg DM/ha for the previous, first, second and third year of cultivation respectively).
The weeds biomass in the first year was 145% higher in the WoPRB treatment compared with the S&B and PR. The weeds biomass in the second year was 50% higher in the WoPRB and S&B treatments compared with the PR. The weeds biomass in the third year was 75% higher in the WoPRB and PR treatments compared with the S&B.
The average of the three years of evaluation of the WoPRB showed 52% weeds biomass compared to S&B and PR.

4.3.4 Labour time

Labour time for weed control was reduced 31% in PR compared to WOPRB only in the first year of evaluation; the following years there were no differences. The first year of evaluation the labour time was similar in treatments PR and S&B. After the first year the labour time showed no uniform response related to the weeds measured.

4.3.5 Mineral nitrogen and N recuperation in maize grain

The mineral nitrogen in the soil is shown in Table 4.5. Although no significant differences were detected there was a tendency toward higher mineral nitrogen in the soil in the treatment with pig rotation.

The N recuperation in maize grain in the PR treatment was 24.6 and 11.8% the first and third year of cultivation compared to WoPRB.

Table 4.3. Results of maize yield, weeds, and nitrogen input-output in treatments with and without pig rotation and milpa system

Item	Management previous Year	Previous year	Treatment	Year			Average	Anova		
				1	2	3		Factor	SED	P>F
		2000		2001	2002	2003				
Maize yield (kg/ha)	S&B(n=2)	1684.4	S&B	1107.9	-	316.5	712.2	T	129.7	0.03
	WoPrB(n=3)	822.5	PR	1084.1	-	741.9	913.0	Y	92.50	0.01
	WoPrB(n=3)	963.4	WoPRB	558.1	-	312.0	435.1			
			Average	916.7		456.8				
Weeds		345.0	S&B	873.0	1899.5	987.5	1253.5	T	225.2	0.001
		1303.0	PR	809.0	1262.6	1759.0	1267.8	Y	127.7	0.01
		1256.0	WoPrB	2065.0	1919.9	1732.0	1919.8			
			Average	1249.3	1699.3	1492.8				
Nitrogen output (kg/ha)		22.4	S&B	14.2	-	4.1	18.2			
		11.0	PR	13.9	-	9.5	23.4			
		12.8	WoPRB	7.1	-	4.0	11.1			
			Average							
Nitrogen input (kg/ha)		-	S&B	-	-					
		-	PR	27.6	43.0	46.7	39.1			
			WoPRB							

SEM= Standard error of the means. Factors = T, treatment and Y, year.

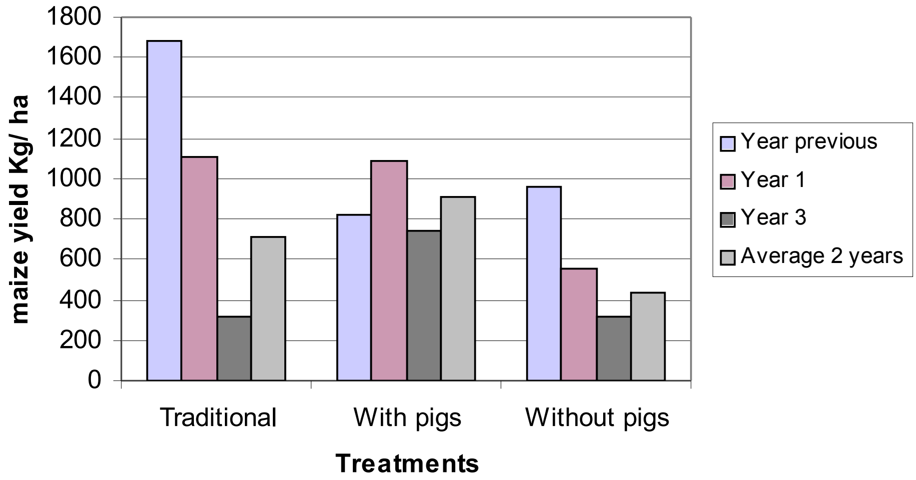


Figure 4.3. Maize yield of treatments with or without pig rotation and the traditional milpa system of slash and burn

Table 4.4. Labour time for weed control 35 days after sowing maize

Treatment	Experimental year (labour time*)		
	1	2	3
S&B	10.2	12.5	15.0
PR	10.3	15.4	15.0
WoPRB	15.0	16.5	16.5

*Average hours pro plot (each plot of 1200 m^2)

Table 4.5. Mineral nitrogen in the soil at the first and last cultivation period

Experimental year	Sampling date	Mineral nitrogen (mg/kg soil)			SEM
		S&B	PR	WoPRB	
2001	Beginning cultivation period (June)	40.6	52.0	36.0	9.9
	End cultivation period (October)	14.4	30.0	13.6	5.4
2003	Beginning cultivation period (June)	17.1	41.13	30.3	6.6

4.4 Discussion

4.4.1 Pig performance

In the literature there are no data available of Creole pigs kept in outdoor with similar conditions of this study. In pens Chel-Guerrero et al. (1982) using a diet of 16% crude protein based on sorghum and soy meal found a feed intake of 1.3 kg/day, 300 g/ live weight gain per day and 4.5 feed conversion (kg feed:kg live weight gain).

Compared with the first experiment carried out in cages (see chapter 3, section 3.3.1) the feed intake and weight gain was 42% lower by keeping pigs in outdoor than in cages (1.33 kg/pig/day feed intake (average of the last two years of evaluation, years 2 and 3) and 2.29 kg/pig/day in the experiment in metabolic cages). Clearly the different conditions of the experiment influenced these results. But it shows that possibly the concentrate diet intake was modified when forage was available in outdoor conditions.

The similar pig performance in terms of feed intake, live weight gain and feed conversion of the three repetitions of each year can be interpreted as a similar input of nutrients (through the faeces of the pigs) in each repetition of the PR treatment. The lower pig performance in the first pig rotation can be explained by the lower initial pig weight in comparison to the two following years. The increase of the initial live weight was made in order to increase the stocking rate per pigs per area to finally increase the input of nutrients trough the faeces.

4.4.2 Maize yield

Different authors report a reduction of maize yield after the first year of cultivation when the slash and burn is used (Levy-Tacher and Hernandes-Xolocotzi, 1992; Illcley-Granich, 1994). Teran and Rassmussen (1992) found a reduction of 46% of maize yield between the first and second year of cultivation. In the present study the reduction of maize yield was 34% and 71% for the first and third year respectively. Similar reduction was seen in the treatment WoPRB whereas in the treatment PR there was a stable maize yield. The stable maize yield in PR can be possibly explained by the combination of lower weeds and the input of nutrients.

The increase of maize yield in the treatment PR in comparison with the treatment WoPRB found in this experiment is comparable with Aggarwal et al. (1997). These authors reported an increase of 60% of pearl millet grain yield by using 20 kg ha^{-1} $year^{-1}$ N from goat manure compared with a treatment without fertilization during two consecutive cropping cycles in an arid tropical region. Mucheru et al. (2004) using cattle manure at equivalent of 60 kg ha^{-1} $year^{-1}$ N found 90% increase of maize yield in two consecutive cropping cycles. However, the main difference between the literature cited and this study is that the pig manure in this study was directly applied to the soil during 100 days in contrast to other studies in which the manure was applied just before the bigining of the cropping cycles. Other possible differences can be in relation to the quality of the manure used.

During the first year of cultivation, although an input of nutrients (i.e. through the pig faeces) in PR treatment, the maize yield in PR was similar compared with the S&B. Previous studies have shown that the burn release nutrients available to plant growth (Sánchez, 1981). After two years of cultivation the higher maize yield in the PR treatment compared to the other treatments can possibly be explained not only by lower weeds but also by a reduction of nutrients available for plant growth. The later comparison shows evidence of the importance of weeds biomass and nutrient availability for plant growth under the conditions of this experiment.

Sánchez (1981) reported that peasant farmers abandon the crop area when they don't expect that the following crop cycle will yield more than 50 % of the first cultivation. The information found in this experiment let to explain and confirm why peasant farmers usually cultivate only for two years the same crop area. The crop yield found in PR treatment was not reduced the first year of cultivation and the third year was similar to the previous cultiastion, that could be of interest for peasant farmers.

4.4.3 Weeds biomass

There are only few experiences using pigs as a method to control weeds. In India Chinnamuthu (1996) reported the use of pigs to control the noxious weed nut sedge (*Cyperus nilotica*). Every year before planting rice, pigs are used to eat the plants and tubercles of this weed.

Examining the first year of cultivation by using the pig rotation the weeds were 61% less compared with WoPRB treatment but similar with S&B treatment. This suggest that weeds can be reduced by using pigs in rotation and is able to substitute the use of burn as a method of land preparation as has been used traditionally. However, after the first year of pig rotation there was observed a continuous increase of weeds biomass although an increase of the pig stocking rate. In the third year of cultivation although, similar amount of weeds biomass was observed, a significant higher maize yield was found in treatment PR compared with treatment WoPRB.

4.4.3 N recuperation by maize grain

The amendment of soils with manure has shown low apparent N recovery. The low recoveries in soil amended with manure have been explained due to N immobilisation when the plant N demand was high. That shows the lack of synchrony between crop nutrients demand and mineralization.

As the use of pig manure is not a common practice in the region of Yucatan, Mexico there are no data available about the N recuperation by maize grain. In arid tropical region Aggarwal et al. (1997) reported a level of 14 and 12% apparent N recuperation in grain yield of pearl millet amended with 20 Kg/N/ha of goat manure. Compared to the present study a higher apparent N recuperation was found. This could be due to differences in the type of manure and the time and way of manure application. Additionally, the pig rooting activity, a certain tillage simulation, can probably improve the rate of N mineralization not only of the N applied in faeces of pigs but also the organic N of the soil, which in total could increased the N available for a better maize yield. This hypothesis needs to be proved by further research.

Long term experiments have shown that continuous use of manure can cumulatively increase N mineralization and further improve the N recuperation and crop yields. Possibly the high pluvial precipitation during the second year of cultivation (year of the Hurricane Isidore) influenced a high losses of nutrients by leaching. There were 200 mm of rain in 24 hours (Sep. 26th. 2002), during the month of September 2002 there were 8 times more rain, this increased the annual rain in 75% compared to the other years during the period of this experiment. In annex 3 a graphic of monthly pluvial precipitation during the four years of the present experiment is presented.

4.5 Conclusions

The use of pigs in a field rotation system sustained the production of maize. This strategy can provide advantages in stabilizing maize yield without the use of fire by influencing the weeds biomass and the input of nutrients through the faeces. The slight increase of soil mineral nitrogen suggest an increase of the rate of nutrient mobilization the question arise on which degree the N recuperation was from the N applied though the faeces of pigs or from the N mineralized from the soil organic matter. The Creole pigs show an acceptable performance level under outdoor conditions. The high feed intake combined with the low nutrient requirements of Creole pigs, determined in the first experiment; support the acceptable performance of Creole pigs under the outdoor conditions. Further research is needed to optimise the use of pigs for a sustainable production of maize.

Chapter 5 Microbial activity in the hind gut of pigs kept in outdoor with or without forage and potential benefits to soil biology

5.1 Introduction

Feeding pigs with roughage diets has been proposed as a way to reduce the N losses from urinary N excretion by using feedstuffs which enhance bacterial nitrogen assimilation in the hindgut by a high content of easily-fermentable non-starch polysaccharides (Kreuzer et al., 1998), which can possible, benefits the binding of N in the microbial biomass of faeces. The high availability of forages in the milpa production system for pig feeding gave reasons to study this as a possible third strategy to improve the nutrient use of limited nutrient resources in the milpa pig production in the tropical Mexico.

The use of high digestible concentrate diets with low fibre content encloses risks in relation to nutrient losses in urine. In conventional pig production systems it is common to feed the pigs with concentrate diets. But in outdoor production systems there is an interaction between the pigs and the forage available on the plot which could enclose a high content of fibre as well as the concentrate diet. Thus, the problem identified was the low fibre in the pig diets increases the risk of nitrogen losses in urine.

The low digestibility of forages compared to concentrate diet is a factor that can influence the microbial biomass and the nitrogen in the faeces of pigs. In fact forage fibre is a source of nutrients for microbial growth in large intestine (Kirchgessner et al., 1994). Microflora in the large intestine of pigs contains all of the predominant ruminal cellulose degrading bacteria, particularly adult animals in comparison to younger animals (Kirchgessner et al., 1994; Varel and Yen, 1997). There are reasons for the assumption that the lower the digestibility of feedstuffs the higher the nitrogen in faeces. The microbial biomass in faeces can be an indicator of fibre degradation in pigs' large intestine.

The question arises whether the organic binding of nitrogen in the faeces can be enhanced by providing forage in the diet of pigs as their have the ability to effectively utilise dietary fibre. and faeces of pigs with high microbial biomass will contain more nutrients for microbial growth in the soil.

The experiment was based on the hypothesis that forage available on the field can improve the microbial biomass not only in pig faeces but also in the soil.

The objectives of the experiment were to determine the microbial biomass in pig faeces with or without the offer of forage under outdoor conditions and the effect of different types of pig faeces on the microbial biomass in the soil.

5.2 Materials and methods

5.2.1 Site and soil

A field and a laboratory incubation experiments were conducted on the experimental farm 'Staatsdomäne Frankenhausen' and the laboratory of Soil Biology and Plant Nutrition, Faculty of Organic Agricultural Science, University of Kassel; Germany between September to December 2003. This site has a template climate with an annual average temperature of 8.5 ºC and an annual precipitation of 700 mm.

5.2.2 Field experiment

The field trial consisted in keeping pigs in outdoor by using different plots with and without forage to study the performance and microbial activity in pig faeces. Pigs were kept in plots with two different forages and without forage. Moveable electric fences were used to create small paddocks. Every week a new area was opened to foraging.

The experimental treatments were as follow:

1. Control with 110% concentrate diet according to the pig nutrients requirements without forage in the plot,
2. Experimental treatment with 100% concentrate diet and Turnip-like rape (*Brassica rapa var rapa*) in the plots,
3. Experimental treatment with 80% concentrate diet and with Jerusalem artichoke (*Heliantus tuberosus L.*) in the plots.

Faeces of pigs from each treatment were named as faeces WoF, Tlr and Ja and respectively. For more detailed description of treatments see Farke and Sundrum (2005) since the present experiment was carried out as part of that study.

5.2.2.1 Animals

The performance of pigs was determined in 92 pigs with an average live weight of 75 ± 10 kg. The pigs were dewormed one week before starting the experiment. There were used cross breeds of pigs, Hampshire x Pietrain/ Duroc x German Landrace and Pietrain/ Duroc x German Landrace. The number of pigs in each treatment was 18 for the control treatment and 37 in each treatment with forage, the breed of pigs and sex was balanced in each treatment. The pigs were weighed at the beginning of the experiment and after 40 days. The concentrate feed offered was recorded for the 40 days of the experiment. Estimation of feed intake per pig was calculated by dividing the total amount offered between the numbers of pigs per group. Feed efficiency was calculated by dividing the feed offered in relation to the weight gained.

Adenylates as microbial biomass indicator was determined in the faeces of pigs before starting the experiment (day 0) and after 30 and 40 days. Six pigs per each treatment were sampled. The samples were taken directly from the rectum. It was assessed by duplicate the dry matter of pig faeces.

5.2.2.2 Diet and water

The pigs were feed with a pellet fattening diet consisted with 12.9 MJ metabolisable energy and 14.2 % crude protein. The amount of concentrate diet offered to the pigs in the control treatment correspond to 100% nutrients requirements for 750 g daily live weigh gain, according to the GfE. (1987). For treatment without forage the offer of 110 % of concentrate diet was designed to fulfil extra requirements for winter season. The treatment with Turnip-like rape was of 100% due to the low availability of this plant on the plot. And the treatment with Jerusalem artichoke was of 80% due to the high amount of this plant available on the plots. The pigs had free access to water.

5.2.3 Laboratory experiment

The faeces of pigs of field experiment were used to investigate the effect of pig faeces on the soil. The soil was collected close to the experimental area but without pig outdoor management. After sampling, the soil was transported to laboratory and sieved to 2 mm. The experiment was conducted with a pseudoglay soil described by Brandt (2001): 1.16% C, 0.14% N total, 8.13 relations C/N, 10.86 mg/100 g P (P_2O_5), 22.34% clay, 3.86% sand and 73.80% silt.

The incubation experiment in the laboratory was done in climate chamber adjusted to 15ºC. The treatments consisted of 50 g DM of soil plus 4 g of fresh pig faeces and 2 g of maize straw as described below. The soil, fresh pig faeces and maize straw, where necessary, were mixed the first day of the experiment and incubated for 21 days in 500 ml bottles and then closed. The soil was wetted at field capacity for 3 days before the experiment. Five repetitions per treatment were used, and repetitions were taken from five different pigs per treatment. The treatments used were as follow (n = 5):

a) Control treatment only soil,
b) Soil amended with faeces of pigs WoF (S+ faeces WoF),
c) Soil amended faeces of pigs Tlr (S+ faeces Tlr)
d) Soil amended with faeces of pigs Ja (S+ faeces Ja),
e) Soil amended with faeces of pigs WoF and maize straw (S+ faeces WoF + MaS),
f) Soil amended with faeces of pigs Tlr and maize straw (S+ faeces Tlr + MaS), and
g) Soil amended with faeces of pigs Ja and maize straw (S+ faeces Ja + MaS),

5.2.4 Soil and faeces chemical analysis

There was measured the chemical composition of pig faeces after 30 days kept in outdoor. Faeces and soil incubated (after 21 days) mineral nitrogen was measured. Carbon and total nitrogen were determined using gas chromatography after combustion at 1200 ºC using a Carlo Erba ANA 1400 Analyser.

5.2.5 Microbial biomass

Measurements of adenine nucleotides and calculations of the adenylate energy charge (AEC) were made according to the procedure of Bai et al. (1988) as described by Dyckmans and Raubuch (1997). This technique is based on the measurement of the adenylates in cells [adenine-tri-phosphate (ATP), adenine-di-phosphate (ADP) and adenine-mono-phosphate (AMP)].

There were weighted moist samples of the faeces treatments equivalent to 0.30 g of dry faeces and a moist sample of the 21 days incubated treatments equivalent to 3 g dry soil to 100 ml tubes. The extraction samples were stirred with 4 ml DMSO (Dimethylsulfoxid) for two minutes. Then 16 ml of a 0.01 M Na_3PO_4/0.02 M EDTA (Ethylendiamintetraessigacid) buffer (pH 12) was added and stirred for further 2 minutes. Afterwards the tubes were sonified for 2 minutes. An aliquot of soil suspension (0.5 ml) was mixed with an equal volume of Benzalconium chloride solution, and then it was sonified again. The solution was passed through a membrane filter (0.45 μm) using under pressure. The extracts were reacted with chloroacetaldehyde to form the fluorescent 1.N^6-etheno-derivatives for fluorometric determination. The extracts were filled up to 5 ml with 0.1 m KH_2PO_4 buffer. A derivatisation was made after stirring the test tube and incubating over 30 minutes at 85 °C. Aliquots of the cooled samples were filled in brown vials and covered. 0.200 ml was injected by the autosampler in a HPLC.

Preparation of standard solutions. A set of standards was determined, each containing 2, 4, 6, 8 ng of AMP, ADP, ATP, respectively.

Standard solution I (three solutions containing a single component):

14.35 mg AMP-Na_2 x $6H_2O$

11.59 mg ADP-K_2·x $2H_2O$

11.90 mg ATP-Na_2 x $3H_2O$

were filled up with 0.01 M Na_3PO_4 to 100 ml each. This was related to a concentration of 100 µg/g. 0.5 ml of each solution was taken and filled up to 50 ml using 0.01 M Na_3PO_4 (Standard solution II).

Standards were prepared by mixing 100 to 400 µl standard solution II with 0.2 ml chloroacetaldehyde (CAA) and adding 0.1 M KH_2PO_4 to give a final volume of 10 ml. 200 µl of each solution was injected and 100 ml, 200 ml, 300 ml and 400 ml of each chemical were related to 2 ng, 4 ng, 6 ng, 8 ng, respectively. There was a linear relationship on adenylate content and signal response between 0 ng and 8 ng of AMP, ADP and ATP.

HPLC-Detection. The HPLC-Unit contains a high pressure liquid pump, autosampler, Pre- and separation column, column heater, fluorescence detector and detection unit containing Computer und Software. The columns were heated to 26-27 °C. The column was equilibrated for 3 hours before first measurements were possible. After each run (containing 20 – 25 samples) the column was flushed for 0.5 h with H_2O: Methanol (50%/50%, v/v). The samples were injected after intervals of 30 minutes.

The calculations of AMP, ADP and ATP content in one sample were made using the following equation:

$$\frac{[ATP]}{g\ DM} = \frac{H \times \frac{WG+20}{0,5} \times 25}{g\ DF}$$; analogous for [ADP] und [AMP]

H = ng AMP (ADP, ATP)/200 µl injection volume

WC = water content of the faeces sample

$\frac{WG + 20}{0,5}$ = Conversion factor for dilution steps (0,5 ml taken from 20 ml + water content faeces sample)

25 = conversion factor injection volume (200 µl from 5 ml)

g DF = Gram dry faeces

To calculate the total adenylate content was used the following equation:

[AMP] + [ADP] + [ATP] = total adenylate content (A_t) (ng g^{-1} Faeces)

for conversion into nmol:

1 mol AMP = 347.2 g

1 mol ADP = 427.2 g

1 mol ATP = 507.2 g

The calculation of Adenylate-Energy-Charge (AEC) was made with the following equation.

$$\mathrm{AEC} = \frac{\frac{1}{2}[ADP]+[ATP]}{[AMP]+[ADP]+[ATP]}$$

5.2.6 Microbial activity: Respiration

During the incubation time there was measured the microbial activity by soil respiration rate (estimation of CO_2). The detection of respiration rates was performed over short periods starting at daily and later at 0, 4, 11, 14, 17 and 21 days.

Soil respiration is one of the oldest and still the most frequently used parameter for quantifying microbial activities in soils. It is defined as the absorption of oxygen and discharge of carbon dioxide by microbial activity. It includes the total gas exchange of predominantly aerobic and anaerobic metabolism. This results from the breakdown of organic substances which are biologically available and their mineralisation. The biological reaction of the soil is made up of a wide range of individual activities, which result from the condition of the soil and its constituents. This method is based in the estimation of CO_2 involved during the incubation of soil in a closed system. CO_2 is trapped in a NaOH solution, which is then titrated with HCl (Isermeyer, 1952).

Material. Flasks of 250 ml with rubber rings and caps, adjustable incubator, automatic titrator and CO_2 absorption glass tubes. Chemicals and solutions; Sodium Hydroxide (NaOH – 0.05 M), Hydrochloric Acid (HCl – 0.05 M), Barium Chloride solution ($BaCl_2$ saturated).

Procedure. Flasks were labelled and 60 g of soil were weighted and placed in the bottom of the 250 ml flasks for the determination of CO_2. The soil water hold capacity was determined and the missing water was added with a pipette so it was possible to proceed with the experiment. All the flasks were covered with plastic because of the gases and put them in the thermostatic camera at 15^0C.

Titration. After the incubation period the samples were taken out of the thermostatic camera and titration with hydrochloric acid was the following operation. The NaOH in the glass tubes inside the flasks must be taken out and be transferred to a glass tubes with NaOH. There was attention that none of the soil will accidentally also be transferred to the glass. This NaOH was supposed to capture the CO_2 from the soil, so titrating with HCl is possible to know how much CO_2 is absorbed. Then, saturated barium chloride solution is added (5 ml) to the NaOH because this substance will transform the CO_2. After the addition the solution gets clouded. As much CO_2 contained in the NaOH more clouded it will get. Finally, three drops of phenolphthalein were added and the solution got pink coloured. The turning point will happen when the solution turned white.

Calculations were made by using the following formula:

$$\mu g\, CO_2 - C\, d^{-1}\, g^{-1}\, soil = \frac{(V_0 - V) \cdot M \cdot E}{T \cdot B \cdot TS} \cdot 1000$$

V_0 = ml HCl–volume of blank

V = ml HCl–volume of incubated soils

M = Concentration of HCl (mol/l)

E = 6 (Molecular weight of C / valency of Ba = 12 / 2)

T = Incubation time in days

B = g fresh soil

TS = Dry weight / Fresh weight

Microbial Biomass estimation by Chloroform Fumigation and Extraction (CFE) Method: Chloroform fumigation of soil kills and lyses microbial cells with the release of cytoplasm into the soil environment; thus the cell material can be extracted from soil (Jenkinson 1966, Brookes et al., 1985).

15 g of soil were weighed and after that was made the extraction with K_2SO_4 and analysed carbon and nitrogen on the DIMATOC machine. It was also weighted another 15 g for the unfumigated control which was just extracted with K_2SO_4. So, as the chloroform killed all the living forms it is possible to make a comparison with the non-fumigated soil and estimate the biomass in soil.

Material: Vacuum desiccators, vacuum line (electric pump), horizontal shaker, freezer, paper filter, flasks, funnels, DIMATOC machine. Chemicals and Solutions: Chloroform ($CHCl_3$), Potassium Sulphate (K_2SO_4).

Procedure: The experiment started by making the fumigation. It was weighted 15 g of soil from the incubation experiment to brown flasks and put in the desiccator. It was measured 30 ml of chloroform (liquid) to a glass and put inside the desiccator with a few boiling chips to make the ebullition point of $CHCl_3$ lower. With the vacuum line, the pressure became lower from 1040 mbar to 220 mbar and, because of that, the chloroform reached the ebullition point and was transformed into the gas form and was able to get in the soil and kill all the microorganisms. The desiccator was then incubated in the dark for 24 hours. After fumigation, $CHCl_3$ was removed by repeated evacuations to make sure that no chloroform was left and the flasks were taken out for the extraction with 60 ml of K_2SO_4. The samples were put in the shaker for ½ hour and then were filtered and transferred to plastic cups and put in the freezer for prior analyses.

The unfumigated control was placed in 100 ml plastic flasks (15 g of incubated soil experiment) and 60 ml were added of the extractant K_2SO_4 0,5 M (ratio: 4:1) and the procedure was the same before: shaker for ½ hour, filtration and then put them in the freezer for further analyses.

On the day after, the cups with the extractant were taken out of the freezer and transferred to small glass cups to analyse in the DIMATOC machine. The analyses made were to carbon and nitrogen.

Formulas

$$\mathrm{C}\,[\mu\mathrm{g\ g^{-1}\ soil}] = \frac{(S-L)\cdot(E+W)}{SDW}$$

S	=	C [µg ml-1] of soil
L	=	C [µg ml-1] of control
E	=	Volume of extraction solution [ml]
W	=	soil water content [ml]
SDW	=	Dry weight of soil [g]

Calculation of C in microbial biomass (C_{mik})

$$E_{\mathrm{C}} = \mathrm{C_{fum}} - \mathrm{C_{ufum}}$$

$$\mathrm{C_{mik}}\,[\mu\mathrm{g\ C\ g^{-1}\ Soil}] = \frac{E_{\mathrm{C}}}{k_{\mathrm{EC}}}$$

C_{ufum} = organic Carbon, extracted from none fumigated soils
C_{fum} = organic Carbon, extracted from fumigated soils
k_{EC} = 0,45 (Wu et al., 1990; Jörgensen, 1995; Joergensen and Mueller, 1996) extractable part of the carbon which is fixed by the microbial biomass

Calculation of N in microbial biomass N_{mik}

$$E_N = N_{fum} - N_{ufum}$$

$$N_{mik}\ [\mu g\ N\ g^{-1}\ soil] = \frac{E_N}{k_{EN}}$$

N_{ufum} = Total-N, extracted from none fumigated soils
N_{fum} = Total-N, extracted from fumigated soils
k_{EN} = 0,54 (Brookes et al., 1985; Joergensen and Mueller, 1996) extractable part of the nitrogen which is fixed by the microbial b

5.2.7 Statistical analysis

Data from the adenylates (total adenylates, ATP and AEC) in pig faeces were analysed using the GLM procedure of SAS (1996) as a randomised block design with factorial arrangement 3 x 3 according to the model: $Y_{ijk}=A_i + B_j + (AB)_{ij} + b_k + (tb)_{ijk} + e_{ijk}$, where Y_{ijk}= observed value for factor *i* and factor *j* in block *k*; A_i and B_j = represent the main factors; $(AB)_{ij}$ = interaction of factors; b_k = mean yield for block *k*; $(tb)_{ijk}$ = interaction of the effects of factors and block, and e_{ijk} represents the random unit variation within a block. Factors taken into account were the forage available on the plot (with and without forage on the plot), and time of sampling (0, 30, and 40 days). Least square means (LSM) was used to compare the means of treatment.

The chemical composition and pig performance was analysed with a one way randomised design.

Data of microbial biomass (i.e. adenylates and chloroform fumigation and extraction method), microbial activity and mineral nitrogen were analysed in a factorial arrangement 3 x 2 +1. Factors taken into account were the addition of faeces (faeces WoF, Tlr and Ja) and the addition or not of maize straw plus a control treatment without faeces and without maize straw. In total there were seven treatments. LSM was used to compare the means of each treatment.

5.3 Results

5.3.1 Field experiment

5.3.1.1 Quality of pig faeces

Nitrogen and carbon in pig faeces: Results of mineral nitrogen (ammonium and nitrate) in pig faeces after 30 days under outdoor management are in Table 5.1. Similar mineral nitrogen content was found in all faeces types ($p > 0.05$). Total nitrogen, carbon, and the relation of nitrogen/carbon in pig faeces are described in Table 5.1. The content of total nitrogen was significantly higher in faeces Ja compared to faeces WoF and Tlr (24.1, 22.4, and 28.0 mg N/g DM for pig faeces WoF, Tlr and Ja respectively). The content of total carbon was also significantly higher in faeces Ja compared to faeces WoF and Tlr (292, 261, and 331 mg C/g DM for pig faeces WoF, Tlr and Ja respectively). The dry matter in faeces Ja was lower compared to faeces WoF and Tlr ($p < 0.10$). Figure 5.1, shows a group of pigs kept in a plot with Turnip-like rape.

5.3.1.2 Adenylates in pig faeces

Results of ATP and total adenylates in faeces of pigs feed with concentrate diet only and with the offer of Turnip-like rape and Jerusalem artichoke on the plot are shown in Table 5.2 and Figures 5.2 and 5.3. At 30 and 40 days a significantly higher ATP and total adenylates content was found in faeces of pigs feed with Jerusalem artichoke compared to the control group (faeces WoF) and faeces Tlr ($p < 0.01$). The lower ATP and total adenylates found in Tlr at the starting day (day 0) of the experiment was considered due to the previous management. No differences on AEC were found in all the treatments in all the sampling times.

Table 5.1. Effect of feed management on chemical composition in pig faeces

Treatments	Parameters						
	Dry matter in faeces %	Mineral nitrogen mg/g DM			Total nitrogen and carbon mg/g DM		
		NH_4	NO_3	N_{min} total	N	C	C/N
Faeces WoF	29.8	0.91	0.045	0.95	24.1[a]	292.4[a]	11.9
Faeces Tlr	32.7	0.87	0.040	0.91	22.4[a]	261.1[a]	11.7
Faeces Ja	26.3	1.00	0.050	1.08	28.0[b]	331.2[b]	12.1
SED	1.74	0.12	0.003	0.12	1.21	15.62	0.47

Figure 5.1. Group of pigs kept in a plot with Turnip-like rape. The right side of the picture shows a previous plot and the left side the first day in a new plot

Table 5.2. Adenylates in pig faeces samples kept in outdoor management with and without forage

Item Nmol/g DM^{-1}	Treatment	Sampling time Days 0	30	40	Average	Anova Factor	SED	p > F
ATP	Faeces WoF	34.5	13.0	16.4	21.3	T	3.9	0.002
	Faeces Tlr	22.0	19.4	28.9	23.4	ST	2.2	0.05
	Faeces Ja	36.7	30.7	33.5	33.7	T x ST	2.0	0.05
	Average	31.1	21.0	26.2				
Total adenylates	Faeces WoF	80.4	37.7	48.0	55.4	T	22.3	0.001
	Faeces Tlr	53.5	70.4	76.9	67.0	ST	6.7	0.10
	Faeces Ja	98.0	149.7	136.3	128.0	T x ST	7.3	0.04
	Average	77.3	85.96	87.05				
AEC	Faeces WoF	0.55	0.50	0.48	0.51	T	0.02	0.01
	Faeces Tlr	0.51	0.40	0.44	0.51	ST	0.02	0.001
	Faeces Ja	0.55	0.48	0.51	0.45	T x ST	6.32	0.71
	Average	0.54	0.46	0.48				

SED= Standard error of the means.
Faeces WoF = Faeces of pigs feed with concentrate diet only
Faeces Tlr = Faeces of pigs feed with concentrate diet and Turnip-like rape on the plot
Faeces Ja = Faeces of pigs feed with concentrate diet only and Jerusalem artichoke on the plot

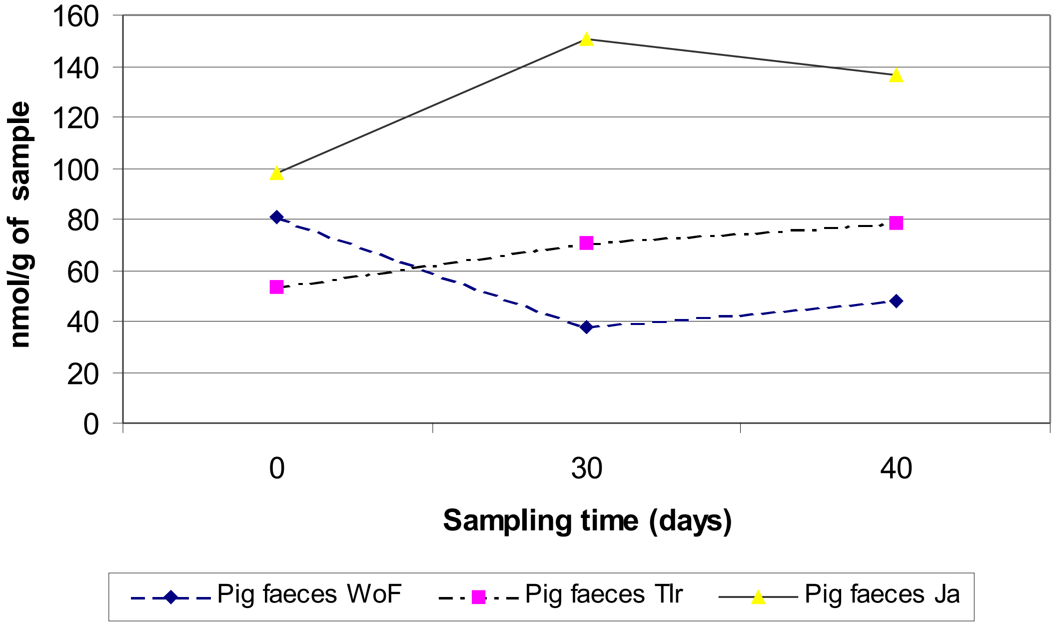


Figure 5.2. ATP in pig faeces samples kept in outdoor management with and without forage

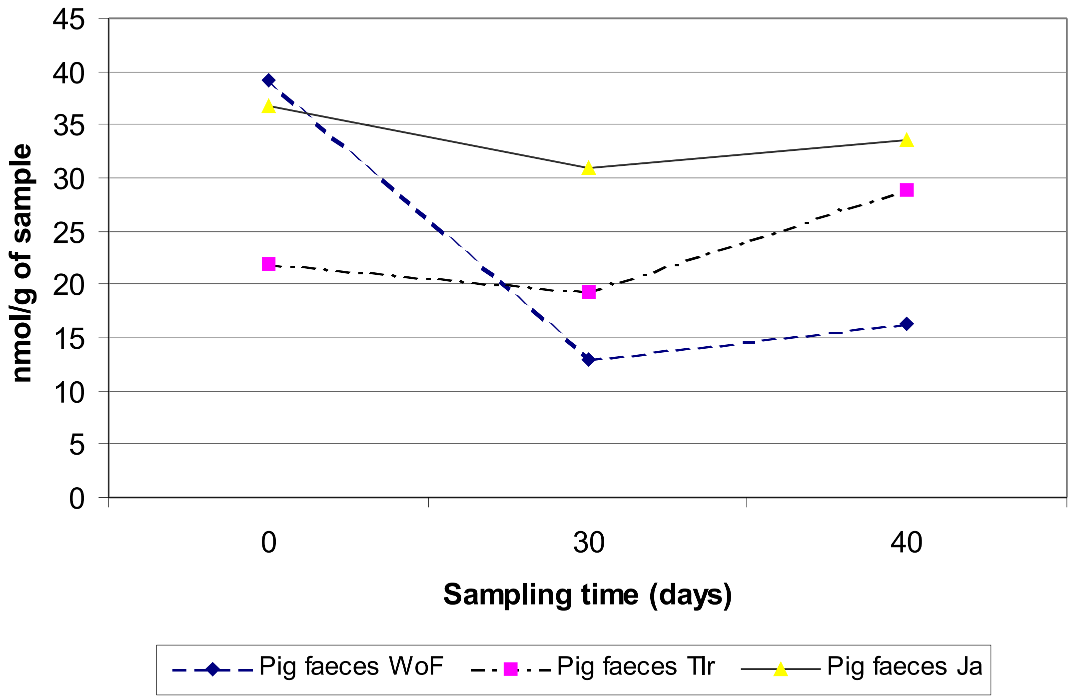


Figure 5.3. Total adenylates in pig faeces samples kept in outdoor management with and without forage

5.3.1.3 Pig performance

Performance of pig kept outdoors is described in Table 5.3. Live weight gain was higher in the treatments with Turnip-like rape and Jerusalem artichoke compared with the control treatment without forage ($p < 0.01$). The higher weight gain found in Jerusalem artichoke is particularly important considering the lower concentrate diet offered. There were no measurements of feed intake of Turnip like rape and intake of Jerusalem artichoke but the higher weight gain found in this treatment suggests an important contribution of nutrients of the plants (forage and tubers) available. This effect was more relevant in Jerusalem artichoke treatment compared to the treatment without forage on the plot.

Table 5.3. Performance of pigs kept outdoors with and without forage on the plots

Item	Treatment			SEM
	Without forage	Turnip-like rape	Jerusalem artichoke	
Initial weight (kg)	74.6	75.1	76.4	1.8
Feed intake (kg/day)	2.55	2.50	2.21	-
Live weigh gain (kg/day)	0.671[a]	0.746[b]	0.759[b]	0.02
Feed conversion	3.56	3.29	2.74	-

Values within the same row with different literals differ significantly ($p < 0.05$).

5.3.2 Laboratory incubation of pig faeces in soil

The total nitrogen and carbon added to the incubation through the pig faeces and maize straw in the treatments is described in Table 5.4. The input of total nitrogen to the soil was slightly higher in the treatments with faeces from Turnip-like rape and Jerusalem artichoke compared to the treatment with faeces without forage.

5.3.2.1 Microbial biomass

Adenylates in the soil incubated with pig faeces.

The incubation of pig faeces improved the ATP in the soil (3.0, 7.5, 9.2 and 10.1 nmol/g S DM for soil without faeces, soil with faeces WoF, Tlr and Ja respectively) ($p < 0.01$). Similar trend were observed in relation to total adenylates in the soil compared to the control (4.8, 12.5, 15.0, and 16.3 nmol/g DM for soil without faeces, soil with faeces WoF, Tlr and Ja respectively) ($p < 0.01$). There was a tendency towards an improvement of ATP and total adenylates by using faeces from pigs fed with Turnip-like rape and Jerusalem artichoke (Table 5.5). Except for treatment amended with faeces Tlr, maize straw addition improved the ATP and total adenylates compared with the treatments with faeces without maize straw (12.8, 10.9 and 14.0 nmol/g DM of ATP and 21.5, 16.7 and 23 nmol/g S DM of total adenylates for treatments with faeces WoF, Tlr and Ja respectively). There were no differences in the adenylate energy charge (AEC) between treatments. These values were higher compared with AEC in pig faeces.

Table 5.4. Addition of nitrogen and carbon to the soil incubation

Treatment	**Addition to the incubation** mg/g DM					
	Nitrogen		Carbon		Total addition	
	Faeces	Maize Straw	Faeces	Maize Straw	Nitrogen	Carbon
Control	0	0	0	0	0	0
S+ faeces WoF	28.3		341		28.3	341
S+ faeces Tlr	29.1		339		29.1	339
S+ faeces Ja	29.5		349		29.5	349
S+ faeces WoF + **maize straw**	28.3	25.1	341	817.6	53.4	1159
S+ faeces Tlr + **maize straw**	29.1	25.1	339	817.6	54.2	1156
S+ faeces Ja + **maize straw**	29.5	25.1	349	817.6	54.6	1166

C and N microbial biomass.

There was an increase in microbial nitrogen (N_{mic}) and carbon (C_{mic}) with the addition of faeces and with the addition of straw ($p < 0.01$). There was a tendency toward an improvement of the microbial nitrogen and carbon by using faeces Tlr and Ja (faeces from pigs on the plots with forages). The increase of C_{mic} was 5.1, 5.2, and 6.2 times for treatments with faeces WoF, Tlr and Ja respectively compared with the control without faeces and 9.3, 10.2 and 11.7 for treatments with faeces WoF, Tlr and Ja with maize straw. The increase of N_{mic} was 5.6, 6.1, and 6.7 times for treatments with faeces WoF, Tlr and Ja respectively compared with the control without faeces and 9.4, 9.7, and 11.2 for treatments with faeces WoF, Tlr and Ja with maize straw. In Table 5.5 results are presented of nitrogen and carbon microbial biomass.

5.3.2.2 Respiration

A higher respiration rate was found in treatments with faeces of pigs compared with the control (161.9, 3090.3, 2983.2, and 3802.9 µg CO_2/g DM for treatments without faeces and with faeces WoF, Tlr and Ja respectively) ($p < 0.01$). A higher respiration rate was found in treatments with maize straw compared with treatments without maize straw (6188.3, 5251.7, and 6461.7 for treatments with faeces WoF, Tlr and Ja with maize straw) ($p < 0.01$). There was a tendency toward a better respiration rate in treatment with Jerusalem artichoke (faeces Ja). In treatments with pig faeces, there was 81% more respiration in treatments with maize straw compared with the treatments without maize straw (5967.2 and 3292.1 respectively). Total CO_2 is shown in table 5.5.

5.3.2.3 Mineral nitrogen

Total mineral nitrogen as well as ammonium (NH_4) and nitrate (NO_3) after 21 days of incubation is shown in Table 5.6. Total mineral nitrogen was higher only in the treatments with faeces Ja compared to the other treatments. The NO_3 was significantly higher only in the treatment with faeces Ja without maize straw. NH_4 was significantly higher in the treatment amended with faeces Ja and maize straw ($p < 0.05$).

Table 5.5. Effect of pig faeces and maize straw on microbial biomass and activity in the soil

Treatments	Adenylates nmol/g DM			Microbial biomass mg/kg^{-1}			Respiration µg CO_2/g DM
	ATP	At	AEC	Cmic	Nmic	Cmic/Nmic	CO_2
Soil without Faeces	3.0^{a}	4.8^{a}	0.79	178.6^{a}	41.3^{a}	4.3	161.9^{a}
Soil with Faeces WoF	7.5^{ab}	12.5^{ab}	0.73	902.7^{b}	229.1^{b}	3.9	3090.3^{b}
Soil with Faeces Tlr	9.2^{b}	15.0^{b}	0.74	922.1^{b}	251.6^{b}	3.7	2983.2^{b}
Soil with Faeces Ja	10.1^{b}	16.3^{b}	0.74	1099.2^{bc}	275.0^{b}	4.0	3802.9^{b}
Soil with Faeces WoF + maize straw	12.8^{c}	21.5^{c}	0.72	1661.8^{cd}	386.6^{c}	4.4	6188.3^{c}
Soil with Faeces Tlr + maize straw	10.9^{bc}	16.7^{bc}	0.74	1827.0^{d}	403.5^{c}	4.4	5251.7^{c}
Soil with Faeces Ja + maize straw	14.0^{c}	23.0^{c}	0.77	2088.7^{d}	463.9^{c}	4.4	6461.7^{c}
SED	1.57	2.62	0.03	230.3	34.4	0.26	378.1

Different letter between rows are statistically significant ($p < 0.05$).

Table 5.6. Effect of pig faeces and maize straw on mineral nitrogen in the soil

Treatments	Mineral Nitrogen (µg/g Soil DM)		
	NH_4	NO_3	Total
Soil without Faeces	2.26[a]	7.59[a]	9.85[a]
Soil with Faeces WoF	8.52[ab]	10.02[a]	18.53[a]
Soil with Faeces Tlr	6.24[ab]	11.90[a]	18.15[a]
Soil with Faeces Ja	8.63[ab]	18.95[b]	27.59[b]
Soil with Faeces WoF + maize straw	12.17[b]	6.92[a]	19.10[a]
Soil with Faeces Tlr + maize straw	5.83[ab]	6.65[a]	12.49[a]
Soil with Faeces Ja + maize straw	21.49[c]	11.81[a]	33.31[b]
SED	3.00	1.82	3.76

Different letter between rows are statistically significant ($p < 0.05$).

5.4 Discussion

5.4.1 Quality of pig faeces

The diet management had a significant effect on the dry matter of manure. The lower dry matter in faeces of pigs on plots with Jerusalem artichoke compared with the other treatments is in accordance of feeding high fibre diets. Choct and Kocher (2000) reported that the use of high fibre diets (i.e. non-starch-carbohydrates (NSP), specially those NSP soluble in water) increase the production of faeces by increasing the retention of water in gut. Similar results have been reported in sows (Tabeling et al., 2003). The reduction of 20% of concentrate diet could drive increased intake of Jerusalem artichoke available on the plot. That could probably explain the higher total nitrogen and carbon in faeces of pigs in the treatment with Jerusalem artichoke.

5.4.2 Adenylates in pig faeces

After 30 and 40 days of feeding Jerusalem artichoke, a higher microbial activity was found in the faeces of pigs compared to the control and the Turnip-like rape treatment ($p < 0.01$). The higher microbial activity can be explained by the fructans within Jerusalem artichoke. Fructans are fermentable carbohydrates that have a prebiotic activity and consist mostly of fructose and glucose molecules. Inulin is the active ingredient of fructans found in *Helianthus tuberosus* (Vijn and Smeekens, 1999). Prebiotics are nutrients that are used by specific bacteria to increase the chance to thrive in the intestine as opposed to probiotics that are foods that contains live bacteria. They selectively promote the growth and activity of beneficial bacteria (such as bifidobacteria and lactobacilli). Bifidobacteria can inhibit the growth of potential pathogens, stimulate components of the immune system, improve the bio-availability of certain nutrients such as calcium and aid the synthesis of B vitamins

(Jenkins et al., 1999). The increase in production of this beneficial bacteria results in an increased faecal biomass, decreased pH in large intestine and production of short-chain fatty acids.

Reduction of pathogens in pigs hind gut will reduce the risk of intestinal bacteria translocation. Intestinal bacterial translocation has been postulated as an important risk factor for the development of multiple organ failure (in absence of a definite focus of infection) (Lemaire et al., 1997). Stress during transportation of slaughter pigs can lead to an increased level of translocation of endotoxin from the gut into the systemic circulation (Zucker and Krüger, 1998). The content of fructans in *Helianthus tuberosus* may play an important role not only in relation to nutrient losses but to gut protection against potential pathogens.

The absence of bio-active substances in Turnip-like rape and the low amount available of this plant in the plots during the experiment can explain the low adenylates in faeces of pigs feed with Turnip-like rape. The interaction of the amount of concentrate diet and the available forage was identified as an important factor in relation of microbial activity in faeces of pigs.

5.4.3 Pig performance

The reduction of the amount of concentrate in the feed ratio of pigs kept outdoors had shown an increase of forage intake. Digestible energy content related to the amount of concentrate diet feed intake shows a regulation of grazing time of sows, the lower the concentrate diet the higher the grazing time (Santos-Ricalde and Lean, 2002).

Stern and Andresen (2003), keeping fattening pigs in outdoor foraging on a clover/grass pasture with 100 and 80% of the indoor recommended feed allowance, found lower daily weight gain in low level concentrate diet (811 and 686 g/day on the 100 and 80% levels, respectively). They also report that the reduction of feed allowance by 20% increased the nutrient intake from the herbage by 5%. The conditions of the present study compare to the clover/grass provided on the plots a better comparative nutritional value. The higher daily weight gain in the treatments with Jerusalem artichoke compared with the control showed the provision of nutrients to improve the pig performance. There is need for further investigations, including root-crop (i.e. Jerusalem artichoke) intake measurements.

5.4.4 Laboratory incubation of pig faeces in soil

Pig faeces addition over the microbial biomass and microbial activity.

The increase of microbial activity found in this study is in agreement with Chantigny et al. (2002). These authors found higher respiration (microbial activity) in soils incubated with pig slurry compared to a soil none amended. They also showed a higher microbial activity in pig slurry during the incubation compared to cattle manure or plant residues (alfalfa and maize).

The addition of reliable nutrients (i.e. glucose and amino acids) to the soil had showed an increase of the microbial biomass and activity (De Nobili et al., 2001). The faeces of pigs have high reliable nutrients for microbial growth such as NH_4; significantly higher compared to cattle manure (Chantigny et al., 2002). Carbon and N dynamics are closely linked during decomposition of animal manure (Chantigny et al., 2001). The authors report that the pig faeces showed an improvement of microbial activity even in low incubation temperature (0ºC).

So far no studies have been carried out on the effect of different pig faeces types influence the microbial growth. In the present study the addition of faeces increased the microbial biomass and activity. There was a tendency toward a better respiration rate and microbial biomass in treatment with Jerusalem artichoke (faeces Ja). That could be possible explained by the higher adenylates (microbial biomass) in this faeces of pig (faeces Ja) compared to the faeces WoF and Tlr.

Maize straw addition over the microbial biomass and microbial activity.

In the present study the increase of microbial activity was of 80% (3292.1 and 5967.2 µg CO_2/g DM for treatments with faeces amended and with faeces and maize straw amended). The microbial biomass and microbial activity in soil after 21 days incubation with faeces Ja showed a tendency to increased compared with the other faeces type (with or without the addition of maize straw). That was related to the high microbial biomass (adenylates) found in the faeces Ja. Additionally, the recently immobilized nitrogen due to incorporation into the microbial biomass is mineralized much more readily than the N in the older soil organic matter. In a study of Ocio et al. (1991) the addition of wheat straw increased 43% microbial biomass N during the first 5 days of incubation and remained at this level following 20 days.

Based on the information of this study is possible to identify two different sources of soil nutrients flow control. One is related to the short term regulation and the other more to the long term regulation. For the short term regulation the microbial activity in pig faeces was related to a increase of nutrients available (N_{min}) for microbial growth. In the long term the regulation was more related to the increase of carbon available for microbial biomass, this later associated to a long term regulation. This regulation is represented in the Fig 5.4.

There was a good agreement between the two methods for biomass measurement (adenylates and CFE), indicating that they are suitable for estimation of microbial biomass not only in soil but also in pig faeces.

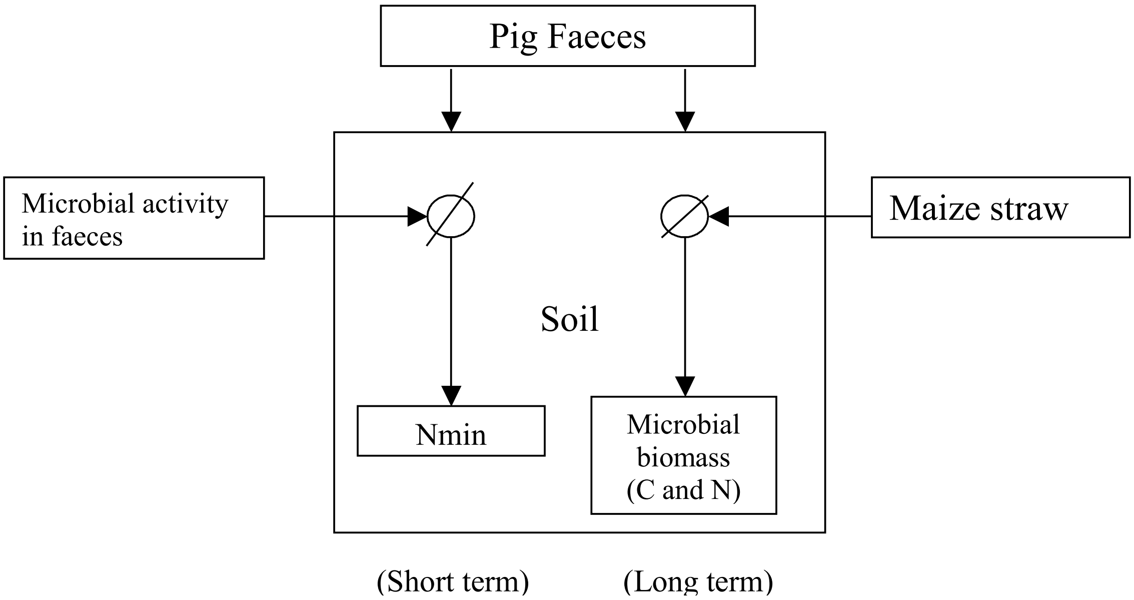


Fig 5.4. Regulation of pig faeces and maize straw on soil microbial biomass and Nmin in the soil

5.5 Conclusions

The offer of Jerusalem artichoke (forage and tuber) increased the nitrogen and carbon faeces excretion and increased the microbial biomass in pig faeces. This tends to improve the microbial activity in the soil and mineral nitrogen. The addition of maize straw also increased the microbial biomass in the soil. The addition of maize straw in soils incubated with faeces of pigs feed with Jerusalem artichoke increased the mineral nitrogen but more in the form of ammonium.

The reduction of concentrate diet combined with the availability of Jerusalem artichoke on the plots of pigs kept under outdoor increased the daily weight gain.

Chapter 6 Final considerations

Based on the information found out in this study the following considerations can be listed:

6.1 Pig potential and feed resources available

Results of the first experiment showed that Creole pigs had clearly lower nitrogen retention compared with the genetically improved pigs. However, the comparative high feed intake found in Creole pigs lead to the conclusion that nutrient retention potential of creole pigs can be fulfilled with fibrous diets. The substitution of maize in the pig diet by using an available feedstuff with no other use in the production system (i.e. mucuna bean), that in other condition will not have other value will contribute to use more maize for human consumption (i.e. farmer family). Based on these results and due to the high availability of forage feedstuffs further research is necessary to determine feeding strategies based on other feedstuffs available.

6.2 Pigs and crop rotation

At farm level the maize yield under milpa condition can be sustained by keeping pigs in rotation within the same area, which graze on the weeds and adds nitrogen to the soil (from faeces). The improvement of nutrients allocation by integrating pigs and crop production, provided not only a valuable source of nutrients for plant growth, but they have additional values by influencing weeds control. In the present study it was not possible to determine on which degree the improvement of maize yield is explained by the addition of nutrients through the faeces of pigs or the reduction of weeds biomass.

Considering the resources available in the milpa system and the low nutrient requirements of Creole pigs led to the conclusion that are better adapted to be keeping in rotation before crop cultivation in milpa system. Further improvements in maize cultivation should be explored by examining strategies to manipulate the concentrate diet offered to pigs kept in outdoor and the available weeds on the plot. It is important to emphasise in experiment pig rotation is the use not only of pig manure but also the benefits of rooting/foraging activity of the pigs over the reduction or control of weeds.

6.3 Diet management and quality of the manure

The first experiment showed that feeding pigs with high roughage feedstuffs in the diet (diet C) shifted the excretion of nitrogen from the urine towards the faeces. The result showed the same effect on Creole and genetically improved breeds. In concordance, in the third experiment under outdoor condition was determined that the quality of pig faeces can be influenced by reducing the concentrate diet and managing pig in plots with forage. It was found a potential to influence the soil microbial biology and an improvement of mineral nitrogen.

The quality of pig faeces showed a tendency to improve slightly the mineral nitrogen on the short term (21 days incubation).

The microbial biomass as a desirable aspect to improve the organic matter can be demonstrated only in long term experiments. Mäder et al. (1996) showed evidence that the soil microbial populations need more than 15 years to reach a new stable equilibrium at a higher level. These authors found differences between different fertilization methods, comparing organic, the combination of mineral and organic fertilization and exclusively mineral fertilizer in a three long-term field trials in three different soil and climate conditions.

It can be argued based on the results of experiment three (chapter 5) that the microbial activity in the treatment with pig rotation used in the second experiment (Chapter 4) could be improved by the addition of nitrogen to the soil from pig faeces. The need of test this hypothesis under the conditions of tropical climate and particularly under the conditions of small farmers with low external inputs would be of interest.

Based on the overall results of the three experiments, the strategies identified with potential to improve the efficient use of limited nutrients resources in milpa system are:

1) The use of Creole pig which have low N retention potential that can be covered by forage/fibrous diets.
2) Integrating pigs in a maize rotation within the same area. It provides input of nutrients through the pig faeces and simultaneously contributes to weed control.
3) The use of fibrous diets to influence the binding of nitrogen in microbial biomass and influence the soil microbial biomass.

The study found out an alternative to develop on integrated animal and crop production system for small-scale farmers to enhance production in a more ecological way. The potential of the strategies identified should be adapted to the particular conditions of peasant farmer by balancing the needs of nutrients for animal's growth and the flow of nutrients within the production system. It depends on the potential of breeds and the cross breeds (Creole x GIp), the farmers rear and the regional and seasonal availability of feedstuffs.

Summary

In the tropics the spatial separation of crops and animals often results in a one way flux of nutrients from the crop fields to the area where animals are kept in the home garden. Simultaneously, there is a tendency towards a reduction of the fallow period after slash and burn. Both factors cause a considerable reduction in the maize yield. Three experiments were carried out with the objective to study the nutrient flow and the interactions between the components of the production system (i.e. animal-plant-soil) to identify possibilities to improve the efficiency in the use of available nutrient resources in small pig production systems in the tropic area of Mexico.

In the **first experiment,** the digestibility and nitrogen balance in Creole (Cp) and genetically improved pigs (GIp) fed with low and high quality diets was evaluated. 16 Cp and 16 GIp pigs with a mean initial live weight of 40 kg were housed in metabolism crates. Four experimental diets were used: diet A) maize only; diet B) 25% of mucuna (*Stizolobium deeringianum*) beans previously boiled and dried + 75% of maize; diet C) 25% of grass (*Panicum maximum*) previously dried + 75% of maize, and diet D) balanced according to the recommendations of nutrient supply for growing pigs (NRC, 1998). The crude protein contents of the diets were 8.5 %, 12.5 %, 12.5 % and 16.0%, respectively. The pigs were allocated to one of four diets in a randomised block design with four blocks and one replication per treatment in each block. Data were analysed using the GLM procedure of SAS.

Cp pigs showed a higher feed intake than GIp pigs ($p < 0.05$). The diet C (with a high crude fibre level) reduced the digestibility of dry matter and NDF compared to the other three diets. This effect was seen in both breeds ($p < 0.01$). Cp pigs showed lower nitrogen retention in all diets compared to GIp pigs ($p < 0.01$). The GIp genotype showed the highest nitrogen retention when the high protein diet (D) was used, however the lowest when the other diets (A, B and C) were fed ($p < 0.01$). The diets B and C (with mucuna and grass) shifted the excretion of nitrogen from urine towards the faeces ($p < 0.01$). The results indicate that the use of low quality diets match better with the potential of Creole pigs' for nitrogen retention. There is no recommendation to use genetically improved breeds of pigs when only low quality feedstuffs are available.

The objective of the **second experiment** was to determine whether the use of pigs in a field rotation has a beneficial effect on maize yield. It encompassed the following treatments: traditionally slash and burn (S&B), keeping pigs before the cultivation of maize (PR) and a control treatment without pigs and without burn (WoPRB). Cp pigs were

fed with a diet of 75% maize and 25% heated mucuna bean containing 12.5% crude protein. The parameters measured were pig performance, weeds biomass, labour time in weed control, soil mineral nitrogen, and maize yield. S&B treatment was repeated twice, and PR and WoPRB three times. Pig performance was similar in the three treatments of each year. A reduction of maize yield was found in S&B and WoPRB ($p < 0.01$) and no reduction was found in PR compared to the previous year ($p > 0.05$). In the first year of the evaluation a lower weed biomass was found in PR compared to WoPRB ($p < 0.01$), the labour time for weed control was reduced in PR compared to WoPRB. No significant differences in weed biomass were found in the following year of the evaluation ($p > 0.05$). The slight increase of soil mineral nitrogen in PR treatment suggests an increase in the rate of nitrogen mobilization. The Creole pigs showed an acceptable performance level under outdoor conditions. The use of pigs in a field rotation system sustained the production of maize. This strategy can be expected to provide advantages in stabilizing maize yield without the use of slash and burn by influencing the weed biomass and the input of nutrients through the faeces.

The objective of the **third experiment** was to determine the effect of forage on the microbial biomass in pig faeces under outdoor conditions and the effect of different qualities of pig faeces on the microbial biomass in the soil. The experiment was based on the hypothesis that forage can improve the microbial biomass not only in pig faeces but also in the soil. A field and a laboratory incubation experiment was conducted. Treatments used for the field experiment were: group WoF (110% nutrient supply according to the recommendations by concentrate without forage in the plot), group Tlr (100% nutrient supply by concentrate and Turnip-like rape in the plot (*Brassica rapa var rapa*)), and group Ja (80% nutrient supply by concentrate and Jerusalem artichoke (*Heliantus tuberosus L.*) in the plot). Faeces of pigs from each treatment were sampled. 92 pigs (75 ± 10 kg initial LW) of cross bred (Hampshire x Pietrain) x (Duroc x German Landrace) and Pietrain x (Duroc x German Landrace) were used.

In the laboratory an incubation of the pig faeces with soil samples was carried out during 21 days in climate chamber. Treatments consisted of a mix of soil and faeces (WoF, Tlr and Ja) with and without maize straw and additional control treatment without faeces and without maize straw. Mineral nitrogen, carbon and total nitrogen of pig faeces after 30 days kept in outdoor and mineral nitrogen of soil incubated after 21 days were assesed. Adenylate concentration (as indicator of the microbial biomass) in pig faeces was measured at 0, 30 and 40 days. Adenylate, nitrogen and carbon concentration as well as

microbial activity were determined in the mixture of soil and faeces after 21 days incubation. Similar mineral nitrogen content was found in all faeces types ($p > 0.05$). The content of total nitrogen and carbon was significantly higher in faeces Ja, as well as ATP and total adenylates content at 30 and 40 days compared to the control group (faeces WoF) and faeces Tlr ($p < 0.01$). In laboratory incubation, the inclusion of pig faeces and maize straw increased the microbial biomass in soil ($p < 0.01$). There was a tendency toward an improvement of the microbial biomass when faeces from pigs fed with Jerusalem artichoke were used (faeces Ja). Microbial activity showed similar results. Mineral nitrogen was higher in soil incubated with faeces Ja.

The results indicate that the feeding of forage can increase the microbial biomass in pig faeces. This tends to improve the microbial activity and biomass in the soil.

The strategies identified to improve the use of available nutrients were:

i. use of pigs in rotation with maize production within the same area provide input of nutrients through the faeces of pigs and contribute to weed control,

ii. the potential of Creole pigs for N-retention can be used with forage/fibrous diets, and

iii. use of fibrous diets influences positively the nitrogen bound in the faeces and the soil microbial biomass and mineral nitrogen.

The strategies identified should be adapted to the particular conditions of each farm by balancing the needs of nutrients for the animals' growth and the flow of nutrients within the production system.

Keywords: Creole, improved breeds, pigs, low input system, outdoor production.

Zusammenfassung (German)

In den Tropen führt die räumliche Trennung der Pflanzen- und Tierproduktion häufig zu einem einseitigen Nährstofffluss von den Ackerflächen zu den Flächen, wo die Tiere gehalten werden. Gleichzeitig besteht eine Tendenz zu einer deutlichen Verkürzung der Brachflächenperiode nach Brandrodung. Beide Faktoren verursachen verminderte Erträge im Maisanbau. Das Ziel der Untersuchungen war es, die Nährstoffverwertung durch Schweine und die Interaktionen zwischen den einzelnen Elementen der Produktionssysteme (Tier-Pflanze-Boden) zu erfassen und die Nutzung von Nährstoffen der lokalen Ressourcen der kleinbäuerlichen Schweinehalter in den tropischen Gebieten Mexikos zu verbessern. Hierzu wurden drei Experimente durchgeführt.

Im **ersten Versuch** wurde die Verdaulichkeit und die Stickstoffbilanz bei kreolischen (KS) und genetisch verbesserten (GVS) Schweinen untersucht, die mit Futterrationen niedriger und hoher Qualität gefüttert wurden. 16 KS- und 16 GVS-Schweine mit einem durchschnittlichen Anfangsgewicht von 40 kg wurden in metabolischen Käfigen aufgestallt. 4 Versuchsrationen wurden geprüft: Ration A: nur Mais; Ration B: 25% Mucuna-Bohnen (*Stizolobium deeringianum*) vorher in Wasser gekocht und getrocknet + 75% Mais; Ration C: 25% Gras (*Panicum maximum*) zuvor getrocknet + 75% Mais; und Ration D: zusammengestellt nach den Versorgungsempfehlungen für wachsende Schweine (NRC, 1998). Die Rationen enthielten 8,5; 12,5; 12,5 bzw. 16,0% Rohprotein. Die Schweine wurden in 4 randomisierte Fütterungsgruppen mit einer Wiederholung unterteilt. Hierbei zeigten KS-Schweine eine höhere Trockenmasse (TM)-Aufnahme als die GVS-Schweine ($p < 0,05$). Die Ration C (mit hohem Rohfaser-Gehalte) verringerte die TM- und NDF-Verdaulichkeit im Vergleich zu den anderen 3 Rationen bei beiden Herkünfte ($p < 0,01$). KS-Schweine wiesen im Vergleich zu GVS-Schweinen eine geringere N-Retention bei allen Rationen auf ($p < 0,01$). Der GVS-Genotyp hatte die höchste N-Retention bei der ausgewogenen Ration (D), aber die niedrigste bei den anderen Rationen (A, B und C) im Vergleich zu den KS-Schweinen ($p < 0,01$). Die Fütterungsvarianten B und C (mit Mucuna-Bohnen und Gras) führten zu einer Verschiebung der N-Exkretion von Harn zu Kot ($p < 0,01$). Die Ergebnisse zeigen, dass Rationen geringerer Qualität besser an das genetische N-Retentionspotenzial der KS-Schweine angepasst sind als an das der GVS-Schweine. Die Ergebnisse legen den Schluss nahe, dass die KS-Schweine auf der Basis der in bäuerlichen Systemen verfügbaren Futtermittel eine effizientere Nährstoffnutzung erwarten lassen. Wenn nur Futtermittel geringerer Qualität zur Verfügung stehen, kann die Haltung von GVS-Tieren nicht empfohlen werden.

Im **zweiten Experiment** wurde untersucht, ob der Einsatz von Schweinen auf den Ackerflächen eine positive Wirkung auf die Ertragsleistung des Maisanbaus hat. Zu diesem Zweck wurden folgende 3 Varianten gewählt: traditionelle Brandrodung (BR); Schweinehaltung auf den Ackerflächen vor dem Mais-Anbau (SH); eine Kontrollvariante ohne Schweine und ohne Brandrodung (oSHoBR). Die KS-Schweine wurden mit einer Diät, bestehend aus 75% Mais und 25% Mucuna-Bohnen gefüttert. Die untersuchten Parameter waren: Gewichtszunahmen, Unkraut-Biomasse, Arbeitszeit für die Unkraut-Bekämpfung, Stickstoffgehalt im Boden und Ertrag des Maisanbaus. Die Variante BR wurde zweimal und die Varianten SH und oSHoBR dreimal wiederholt. Die Leistung der Schweine der Variante SH lagen zwischen den drei Wiederholungen des selben Jahres auf ähnlichem Niveau. Im Vergleich zum Vorjahr wurde eine Verminderung der Maisproduktion bei BR und oSHoBR ($p < 0,01$), aber nicht bei der Variante SH ($p > 0,05$) ermittelt. Eine geringere Unkraut-Biomasse ($p < 0,01$) und eine verkürzte Arbeitszeit für die Unkraut-Bekämpfung im ersten Jahr wurde bei der SH-Variante, verglichen mit oSHoBR-Variante ermittelt. Bezüglich der Unkraut-Biomassen wurden in den folgenden Jahren keine signifikanten Unterschiede festgestellt. Die geringfügige Erhöhung des Stickstoffgehaltes im Boden der SH-Variante wies auf eine N-Mobilisierung hin. Die KS-Schweine erreichten ein akzeptables Leistungsniveau. Aus den Ergebnissen wird geschlussfolgert, dass der Einsatz von Schweinen vor dem Maisanbau den Maisertrag stabilisierte. Diese Strategie lässt Vorteile gegenüber der Brandrodung bezüglich des Einflusses auf die Unkraut-Biomasse und des Inputs von Nährstoffen durch den Schweinekot erwarten.

Das Ziel des **dritten Versuches** war es, den Effekt der Verfütterung von Grünfutter auf die mikrobielle Biomasse im Schweinekot unter den Bedingungen der Freilandhaltung und den Effekt von unterschiedlichen Qualitäten von Schweinekot auf die mikrobielle Biomasse im Boden zu ermitteln. Der Versuch basierte auf der Hypothese, dass das Grünfutter die mikrobielle Biomasse nicht nur im Kot sondern auch im Boden verbessern kann. Zu diesem Zweck wurden ein Feld- und ein Laborversuch durchgeführt. Die Varianten für den Feldversuch waren: Gruppe WoF (110% Bedarfsdeckung über Kraftfutter gemäß den Versorgungsenphelungen und ohne Grünfutter auf der Versuchsfläche), Gruppe Ja (100% Bedarfsdeckung über Kraftfütter und Aufnahme von Stoppelrüben (*Brassica rapa*, *var. rapa*)) und Gruppe Tlr (80% Bedarfsdeckung über Kraftfutter und Aufnahme von Topinambur (*Helianthus tuberosus* L.)). Es wurden Kotproben von Schweinen der drei Varianten entnommen. Im Versuch wurden 92 Tiere (75 ± 10 kg Anfangslebendmasse) der genetischen Herkünfte (Hampshire x Pietrain) x (Duroc x Deutsche Landrasse) und Pietrain x (Duroc x Deutsche Landrasse) eingesetzt. Der Kot wurde mit Bodenproben im Labor inkubiert. Es wurden Mischungen von Bodenproben und Kot in drei Varianten hergestellt: a) mit Maisstroh, b) ohne Maisstroh und c) Bodenproben ohne Kot oder Maisstroh als Kontrollvariante. Dabei kamen die drei verschiedenen Kotvarianten zum Einsatz, so dass eine Gesamtzahl von 7 Varianten resultierte. Bestimmt wurden: Mineralstickstoff-, Kohlenstoff- und Gesamtstickstoffgehalt im Schweinekot nach 30 Tagen in Freilandhaltung und Mineralstickstoffgehalt in den inkubierten Bodenproben nach 21 Tagen. Die Adenylat-Konzentration (als Indikator der mikrobiellen Biomasse) im Schweinekot wurde nach 0, 30 und 40 Tagen gemessen. Im Boden-Kot-Gemisch wurden die Adenylat-Konzentration und der Kohlenstoff- und der Stickstoffgehalt der mikrobiellen Biomasse sowie die mikrobielle Aktivität nach 21 Tagen Inkubation bestimmt. Die Daten wurden mittels der GLM-Prozedur des Programmes SAS ausgewertet.

Der Gesamt-Stickstoff- und der Kohlenstoffgehalt sowie die Adenylat-Konzentration nach 30 und 40 Tagen waren signifikant höher in den Kotproben der Variante Ja, im Vergleich zu den Varianten WoF and Tlr ($p < 0,01$). Die mikrobielle Biomasse wurde durch die Vermischung von Bodenproben mit Kot und Maisstroh erhöht ($p < 0,01$). Es resultierte eine Tendenz hinsichtlich einer Verbesserung der mikrobiellen Biomasse, wenn der Boden mit Kot von Schweinen, die mit Topinambur gefüttert worden waren (Tlr), vermischt wurde. Die mikrobielle Aktivität wies zwischen den Varianten keine Unterschiede auf. Der Mineralstickstoffgehalt war bei mit Kot inkubierten Bodenproben C höher.

Als mögliche Strategien zur verbesserten Nährstoffnutzung von limitierten Ressourcen kommen in Betracht:

- Flächennutzung durch Schweine und Nährstoff-Input durch den anfallenden Schweinekot als Dünger mit folgendem Maisanbau innerhalb der gleichen Ackerflächen bei gleichzeitiger Erleichterung der Unkraut-Kontrolle,
- das genetische N-Retentionspotenzial von Kreol-Schweinen kann mit Futtermitteln geringerer Qualität genutzt werden,
- die Nutzung von faserreichen Futtermitteln erhöht die N-Bindung im Kot, die mikrobielle Bodenbiomasse und die Verfügbarkeit von mineralischem Stickstoff.

Diese Strategien müssen allerdings mit Hilfe von Bilanzierungen des Nährstoffbedarfs der Tiere und des Nährstoffflusses innerhalb eines Produktionssystems an die betriebs- und standortspezifischen Bedingungen angepasst werden.

Schlüsselwörter: Kreol Schweine, Low Input System, Freilandhaltung

Resumen (Spanish)

En el trópico, la separación espacial de la producción de cultivos y animales resulta en el flujo de nutrientes unidireccional del área de cultivos a los animales en el traspatio. Además, hay la tendencia hacia una reducción del tiempo de descanso del monte después de la quema. Ambos factores causan una considerable reducción del rendimiento de maíz. Se realizaron tres experimentos con el objetivo de estudiar el flujo de nutrientes en los cerdos y la interacción entre los componentes del sistema de producción (entre animal-planta-suelo) para identificar las posibilidades de mejorar la eficiencia en el uso de los recursos nutritivos disponibles en un sistema de pequeño productor en el trópico de México.

En el **primer experimento** se evaluó la digestibilidad y el balance de nitrógeno en Cp y GIp alimentados con dietas de baja y alta calidad. 16 Cp y 16 GIp cerdos con un peso vivo inicial (PVI) de 40 Kg. fueron mantenidos en jaulas metabólicas. Se utilizaron cuatro dietas experimentales: dieta A) solo maíz; dieta B) 25% de fríjol mucuna previamente cocido y secado + 75% de maíz; dieta C) 25% de pasto (*Panicum maximum*) previamente secado + 75% de maíz y dieta D) balanceada de acuerdo a los requerimientos de cerdos en crecimiento (NRC, 1998). El contenido de proteína cruda de las dietas fue de 8.5, 12.5, 12.5 y 16.0 % respectivamente. Los cerdos fueron distribuidos al azar a una de las dietas en un diseño de bloques al azar con cuatro bloques y una repetición por tratamiento en cada bloque. Los datos fueron analizados utilizando el procedimiento GLM de SAS. El consumo alimenticio más alto se encontró en Cp ($p < 0.05$). La dieta C (con nivel de fibra alto) redujo la digestibilidad de la materia seca y de FDN comparado con las otras tres dietas. Este efecto se observó en ambas razas ($p < 0.01$). Cp mostraron una baja retención de nitrógeno en todas las dietas evaluadas ($p < 0.01$). El genotipo GIp tuvo el mayor retención de nitrógeno con la dieta balanceada con alto contenido de nitrógeno (dieta D), no obstante fue menor con las otras dietas (A, B y C) ($p < 0.01$). Las dietas B y C (con mucuna y pasto respectivamente) cambiaron la excreción de nitrógeno de la orina a las heces ($p < 0.01$). Los resultados indican que el uso de dietas de baja calidad es más compatible con el potencial de retención de nitrógeno de los cerdos criollos. No se recomienda el uso de razas de cerdos genéticamente mejoradas cuando solo se tienen recursos alimenticios de baja calidad.

El objetivo del **segundo experimento** fue determinar si a través de la rotación de cerdos en una parcela se podría mejorar la producción de maíz. Consistió en los siguientes tratamientos: roza-tumba y quema tradicional (S&B), mantener cerdos antes del cultivo de

maíz (PR) y un control sin rotación de cerdos y sin quema (WoPRB). Cp fueron alimentados con una dieta con 75% de maíz y 25% de mucuna cocida con un contenido de 12.5 % de proteína cruda. Los parámetros medidos fueron comportamiento de cerdos, biomasa de la maleza, tiempo de labor para el control de las malezas, nitrógeno mineral en el suelo y rendimiento de maíz. El tratamiento S&B tuvo dos repeticiones, mientras que PR y WoPRB tres. El comportamiento de cerdos fue similar en los tres grupos de cada año. Se encontró una reducción del rendimiento de maíz en los tratamientos S&B y WoPRB ($p < 0.01$) y no se encontró reducción en PR comparado con el año previo ($p > 0.05$). El primer año de evaluación se encontró menor biomasa de la maleza en el tratamiento PR comparado con WoPRB ($p < 0.01$), el tiempo de labor para el control de maleza se redujo en PR comparado con WoPRB. No se encontraron diferencias significativas en la biomasa de las malezas en los siguientes años de evaluación ($p > 0.05$). El ligero incremento de nitrógeno mineral en el suelo en el tratamiento PR sugiere un incremento de la tasa de movilización de nitrógeno. Los cerdos criollos mostraron un comportamiento aceptable en exterior. El uso de la rotación de cerdos en una parcela sostuvo la producción de maíz. Esta estrategia puede proveer ventajas para estabilizar el rendimiento maíz sin el uso del fuego al influenciar la biomasa de las malezas y el ingreso de nutrientes a través de las heces de los cerdos.

El objetivo del **tercer experimento** fue determinar el efecto del forraje en la biomasa microbiana en las heces de cerdos manejados en exterior y el efecto de diferentes tipos de heces de cerdos en la biomasa microbiana en el suelo. La hipótesis del experimento fue que el forraje puede mejorar la biomasa microbiana no solo en la heces de cerdos si no también en el suelo. Se realizo un experimento de campo y de laboratorio. Los tratamientos de la parte de campo fueron: grupo 1 con 110% de las necesidades nutritivas recomendadas sin forraje en la parcela, grupo 2 con 100% de las necesidades nutritivas y Turmip like rape (*Brassica rapa* var *rapa*) sembrada en la parecela y grupo 3 con 80% de las necesidades nutritivas y Jerusalem artichoke (*Heliantus tuberosus* L.) en la parcela. Se tomaron muestras de las heces de los cerdos y fueron nombradas con las abreviaciones como heces WoF, Tlr y Ja respectivamente. Se utilizaron 92 cerdos (75 ± 10 kg de peso vivo inicial) de cerdos cruzados (Hampshire x Pietrain) x (Duroc x Landrace alemán) y Pietrain x (Duroc x Landrace alemán),

Las heces de los cerdos fueron incubadas en el laboratorio en una muestra de suelo durante 21 días en una cámara climática. Los tratamientos consistieron en la mezcla de suelo y heces WoF, Tlr y Ja con y sin la adición de paja de maíz y adicionalmente un tratamiento

control sin heces y sin paja de maíz. Se determinó el nitrógeno mineral, el total de carbono y de nitrógeno de las heces de cerdos después de 30 días mantenidos en exterior y el nitrógeno mineral de los suelos incubados durante 21 días. Se determinaron los adenilatos (como indicador de la biomasa microbiana) en las heces de cerdos a los 0, 30 y 40 días. Se determinaron también los adenilatos, la biomasa microbiana (nitrógeno y carbono) y la actividad microbiana se determino en el suelo después de 21 días de incubación. Los datos fueron analizados usando el procedimiento GLM de SAS. Se encontró similar contenido de nitrógeno mineral en todos los tipos de heces ($p > 0.05$). El contenido de carbono y nitrógeno total fueron significativamente más altos en las heces Ja, así como también el contenido de ATP y los adenilatos totales a los 30 y 40 días comparado con el grupo control (heces WoF) y las heces 2 ($p < 0.01$). En la incubación en laboratorio, la inclusión de heces de cerdos y paja de maíz incrementó la biomasa microbiana en el suelo ($p < 0.01$). Se observó una tendencia al incrementó de la biomasa microbiana con las heces de cerdos alimentados con Jerusalem artichoke (heces Ja). La actividad microbiana mostró similares resultados. El nitrógeno mineral fue más alto en el suelo incubado con heces Ja. Los resultados indican que la alimentación con forraje puede incrementar la biomasa microbiana en heces de cerdos. Esto tiende a mejorar la actividad microbiana y la biomasa en el suelo.

Las estrategias identificadas con potencial para mejorar el uso de recursos limitados fueron:

- El uso de cerdos en rotación con maíz contribuye al ingreso de nutrientes a través de las heces de los cerdos y al control de las malezas.
- El potencial de retención de nitrógeno de los cerdos criollos puede cubrirse con dietas con forraje o fibrosas.
- El uso de dietas fibrosas influye positivamente la fijación de nitrógeno en las heces y en la biomasa microbiana del suelo y en el nitrógeno mineral.

Las estrategias identificadas se deben adaptar a las condiciones particulares de cada granja tratando de balancear las necesidades de nutrientes para el crecimiento animal y el flujo de nutrientes dentro del sistema de producción.

Palabras claves: Criollo, razas mejoradas, cerdos, sistema bajos insumos, producción exterior.

References

Acosta-Bustillos L., Flores-Guido J. and A. Gómez-Pompa, 1998. Uso y manejo de Plantas Forrajeras para Cria de Animales dentro del solar en una comunidad Maya en Yucatan. In: Etnoflora Yucatanense, Fascículo 14.

Aggarwal R.K., Kumar P. and J. F. Power, 1997. Use of crop residue and manure to conserve water and enhance nutrient availability and perl millet yields in an arid tropical region. Soil and Tillage Research 41: 43-51.

Anderson S., Gündel S. and J. Jimenéz, 1994. Un modelo conceptual del manejo de agroecosistemas por la unidad productiva campesina en Yucatán, Mexico. Memorias del II Congreso Internacional de Investigación en Sistemas de Produccion Agropecuarios. CICA-UEAM, Toluca, México.

Anderson S., Keane B., Moguel J. and W. Trejo, 1998. Food, feed and forage: food security and innovations within campesino agriculture. Technical Report No.1 of the collaborative research project between Wye College and FMVZ-UADY in SE Mexico: Optimising livestock integration into small-scale low external input crop systems.

Anderson S., Ferráes N. and T. Rivera, 1999. La población de cerdo criollo en Yucatán, México: estado del impacto genético. In: Memorias del Seminario Internacional sobre Agroviodiversidad Campesina del 12 al 14 de mayo. Centro de Investigaciones en Ciencias Agropecuarias de la Facultad de Geografia de la UAEM, Toluca, México pp. 257-266.

Anderson S., Gündel, S., Pound B. and B. Triomphe, 2001. Cover crops in smallholders agriculture: Lessons from Latin America. Intermediate Technology Publications, London.

Anderson S., 2003. Animal genetic resources and sustainable livelihoods. Ecological Economics 45: 331-339.

Anon., 1992. Perspectivas del uso de razas autóctonas en la porcicultura rural. Porcirama, 17: 35-41.

Arora, S.K., 1995. Composition of legume grains. In: Tropical Legumes in Animal Nutrition (Editores D'Mello, J.P.F. and Devendra, C.). UK: Ed. CAB International, pp. 67-93.

Arulmozhi M. and K. Janardhanan, 1992. The biochemical composition and nutritional potential of the tribial pulse, *Mucuna monosperma* DC. ex Wight. Plant Foods for Human Nutrition 42: 45-53.

Bai, Q.Y., Zelles L., Scheunert I. and F. Korte, 1988. A simple effective procedure for the determination of adenosine triphosphate in soils. Chemosphere 17: 2461-2470.

Balloun S. L., 1980. Soybean Meal in Poultry Nutrition. Unite States of America: Ovid Bell Press, pp. 13-35.

Bakker G.C.M., Jongbloed R., Verstegen M.W.A., Jongbloed A.W. and M.W Bosch, 1995. Nutrient apparent digestibility and the performance of growing, fattening pigs as affected by incremental additions of fat to starch or non-starch polysaccharides. Animal Science 60: 325-335.

Becker B., 1996. Ethical norms and values behind the concept of sustainability. In: Nachhaltige Ressourcennutzung, Journal of Agriculture in the Tropics and Subtropics 56: 31-50.

Becker M. and K. Nehring, 1969. Handbuch der Futtermittel. Erster Band. Verlag Paul parey, Hamburg und Berlin.

Bezkorovainy A. 1989. Classification of Bifidobacteria. In: A. Bezkorovainy and R. Miller-Catchpole (Editors), Biochemistry and physiology of Bifidobacteria, CRC Press, Boca Raton, pp. 1-28.

BLF (Bundesministerium für Land- und Forstwirtschaft), 1991. Fachbeirat für Bodenfruchtbarkeit und Bodenschutz: Wirtschaftsdünger. Richtige Gewinnung und Anwendung. Wien.

Brandt M. 2001. Arbeitsbericht No 4: Bodenprofile der Hessischen Staatsdomäne Frankenhausen. Fachgebiet Bodenkunden, Universität Kassel pp. 34.

Brookes P.C., Landman, A., Pruden, G., and D.S. Jenkinson, 1985. Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method for measuring microbial biomass nitrogen in soil. Soil Biology & Biochemistry 17: 837-842.

Buckles D., Ponce I., Sain G. y Medina G., 1992. Tierra cobarde se vuelve valiente: Uso y difusión del frijol de abono (*Mucuna deeringiana*) en las laderas del Litoral Atlántico de Honduras. México, D.F. CIMMYT. pp. 1-35.

Budavari S., 1989. Merck Index: An encyclopedia of chemicals, drugs and biologicals. 11 ed. pp. 861-862.

Caamal A., Menesses L. and J.J. Jimenez-Osornio, 1996. El uso de *Stizolobium pruriens* y *Canavalia ensiformis* como cultivo de cobertura, para el control de arvenses en Yucatán, México. In: Nuevos Horizontes en Agricultura: Agroecología y desarrollo sostenible, Colegio de Postgraduados en Ciencias Agrícolas, México, pp. 307-310.

Caamal-Maldonado J. A., Jiménez-Osornio J. J., Torres-Barragán A. and A.L. Anaya, 2001: The use of allelophathic Legumes cover and mulch species for weed control in cropping systems. Agronomy Journal 93: 27-36.

Carbajal A. J., Lara, L.P.E., Maza, M.A. and P.I. Hurtado, 1987. Producción de semillas de dos leguminosas tropicales con y sin el uso de espaldera. Boletín informativo, I.T.A. No. 19, Tizimín, Yucatán. pp 1-4.

Ceccherini M.T., Castaltini M., Piovanelli C., Hastings R.C. McCarthy A.J., Bazzicalupo M. and N. Miclaus, 1998. Effects of swine manure fertilization on autotrophic ammonia oxidizing bacteria in soil. Applied Soil Ecology 7: 149-157.

Chantigny H.M., Angers D.A. and P. Rochette, 2002. Fate of carbon and nitrogen from animal manure and crop residues in wet and cold soils. Soil Biology and Biochemistry, 34: 509-517.

Chantigny H.M., Rochette P. and D.A Angers, 2001. Short-term C and N dynamics in a soil amended with pig slurry and barley straw: a field experiment. Canadian Journal of Soil science, 81: 131-137.

Chel-Guerrero L., Aguilar Marcos A. and A. Castellanos-Ruelas, 1983. Utilización digestiva de la alfalfa por el cerdo Pelon Mexicano. Técnica Pecuaría en México 44: 27-34.

Chinnamuthu C. R., 1996. Pigs manage the world's worst weed. In: LEISA Magazine: More than rice 12: 16.

Choc M. and A. Kocher 2000. Non-starch carbohydrates: Digestion and its secondary effects in monogastrics. Proceedings of the Nutrition Society of Australia, 24: 31-42.

CSIR (1962). The wealth of India: a dictionary of Indian raw material and industrial products. New Delhi, India: Council of Scientific and Industrial Research.

Daxenbichler M.E., VanEtten C.H, Hallinan E.A., Earlr F.R. and A.S., Barclay, 1971. Seeds as sources of L-Dopa, Journal of Medical Chemistry 14: 463-465.

De Wit J., van Keulen H. van der Meer H.G. and A.J. Nell, 1997. Animal manure: asset or liability?. In:World Animal Rewiew, 88.

Del Carmen J., Gernat A.G., Myhrman R. and L.B. Carew, 1999. Evaluation of raw and heated Velvet Beans (*Mucuna pruriens*) as feed ingredients for broilers. Poutry Science 78: 899-872.

De la Vega A., Giral F. and A Sotelo., 1981. Nutritional evaluation of the velvet bean (*Stizolobium cinerium*) alone and suplemented with methionine or wheat fluor. Nutrition Reports International 24: 817-823.

Delve R. J., Cadisch G., Tanner J. C., Thorpe W., Thorne P. J., and K. E. Giller, 2001. Implications of livestock feeding managements on soil fertility in the smallholder farming systems of sub-Saharan Africa. Agricultural Ecosystem Environment 84: 227-243.

De Nobili M., Contin M., Mondini M. and P.C. Brookes, 2001. Soil microbial biomass is triggered into activity by trace amounts of substrate. Soil biology and Biochemistry, 33: 1163-1170.

DLG (Deutsche Landwirtschafts- Gesellschaft), 1991. Futterwerttabellen- Schweine/erarb. von der Dokumentationsstelle der Universität Hohenheim. Unter Mitw. des Ausschusses für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie. 6., Aufl. Frankfurt am Main, DLG-Verlag. Pp. 22.

Duch-Gary J., 1991. Fisiografías del Estado de Yucatán. Su relación con la agrícultura. Universidad Autónoma Chapingo, México pp. 15.

Duke J.A., Reed C.F. and J.K.P Weder, 1981. *Mucuna spp*. In: Handbook of Legumes of World Economic Importance (Editor Duke J.A.). USA: Plenum Press. pp 170-173.

Duque A. D., 1993. Evaluación del Frijol Terciopelo (*Stizolobium derringianum*) en el control de Malezas en Cítricos y como Fuente de Proteína en la Ración de Pollos de Engorda. Tesis Maestría en Ciencia Animal D.G.E.T.A., I.T.A. No. 2. Conkal, Yuc.

Dyckmans J. and M. Raubuch, 1997. A modification of a method to determine adenosine nucleotides in forest organic layers and mineral soils by ion-paired reversed-phase high-performance liquid chromatography. Journal of Microbiological Methods, 30: 13-20.

EC regulation No 1084/1999 incorporated into No 2092/91 on organic production of agricultural products and indications referring on agricultural products and foodstuffs to include livestock production. Accessible at: www.europa.eu.int/eur-lex.

Escarzaga G. E. (1987). Determinación del potencial alelopático del "Nescafé" (*Stizolobium pruriens* L. Medic. Var. *Utilis* Wall ex wight), sobre cinco cultivos y tres malezas. Tesis Ing. Agr., ITESM Querétaro, Qro. 76 p.

Farke A and A. Sundrum, 2005. Fattening pigs in an outdoor system as a part of the crop rotation within organic farming: Growth performance and carcass yield. In: A. Sundrum and F. Weißmann, (eds.), Organic pig production in free range systems. Landbauforschung Völkenrode Special Issue, 281: 25-30.

Farnworth E. R., Jones J. D., Modler H. W. and N. Cave, 1993. The use of Jerusalem artichoke flour in pig and chicken diets. In. Fuchs (Editor). Inulin and Inulin-Containing Crops. Elsevier, Amsterdam, pp. 385-389.

Farnworth E. R., Modler H. W. and D.A. Mackie, 1995. Adding Jerusalem artichoke (*Heliantus tuberosus* L.) to weanling pig diets and the effect on manure composition and characteristics. Animal Feed Science and Technology, 55: 153-160.

Florez M. and G.A. Agráz, 1983. Ganado Porcino. Limusa. México D.F.

Frimmer M., 1973. Farmacología y Toxicología Veterinaria. México: Acribia. Pp. 341.

Friesecke H., 1984. Handbuch der praktischen Fütterung. BLV München.

Fuller M. F., McWilliam R., Wang T. C. and L. R. Giles, 1989. The optimum dietary amino acid pattern for growing pigs. “. Requirements for maintenance and for tissue protein accretion. Br. J. Nutr. 62: 255-267.

Gatel F. and F. Grosjean, 1992. Effect of protein content of the diet on nitrogen excretion by pigs. Livestock Production Science, 31: 109-120.

GfE (German Society of Nutrition), 1987. Gesellschaft für Ernährungsphysiologie der Haustiere/Ausschuß für Bedarfsnormen; Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere, No.4 Schweine; DLG-Verlag, Frankfurt/M, 112 pp.

Gobierno del Estado de Yucatán, 1983. Monografía Secretaria de Planeación, Mérida, Yuc., México, p. 406.

Graefe S., 2003. Crop and soil variability in traditional and modern mayan maize cultivation of Yucatan, Mexico. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 75: 72.

Graves A., Matthews, R. and K. Waldie, 2004. Low external input technologies for livelihood improvement in subsistence agriculture. Advances in Agronomy, 82: 473-555.

Gündel S., 1998. Participatory Innovation Development and Diffusion: Adoption and adaptation of introduced legumes in the traditional slash and burn peasant farming system in Yucatan, Mexico. Weikersheim: Margraf, Zugl. Humboldt-Universitát zu Berlin, Diss., pp. 133.

Henry Y., Arnal M., Obled C. and A. Rerat, 1988. Protein and amino acid metabolism as well as protein and amino acid requirement in non-ruminants. Wissenschaft Zeitschrift Rostock Universität, 37: 9-18.

Henry Y., Colleaux Y. and B. Séve, 1992. Effects of dietary level of lysine and of level and source of protein on feed intake, growth performance and plasma amino acid pattern in the finishing pig. Journal Animal Science, 70: 188-195.

Henry Y. and B. Séve, 1993. Feed intake and dietary amino acids balance in growing pigs with special reference to lysine, tryptophan and threonine. Pigs News and Information, 14: 35-43.

Hermansen, J. E. and T. Kristensen, 1998. Research and evaluation of mixed farming systems for ecological animal production in Denmark. Proceedings from workshop „Mixed farming systems in Europe“, Dronten, the Netherlands, 25-28 May, pp. 97-102.

Hernández- Xolocotzi E., Levy-Tacher, S., and E. Bello-Baltazar, 1994. La roza-tumba-quema en Yucatán. *In*: La milpa en Yucatán: un sistema de producción agrícola tradicional, Ed. Hernández- Xolocotzi E., Levy-Tacher, S., y Bello-Baltazar E. Volumen 1. Colegio de Postgraduados, México. pp. 35-86.

Illsley-Granich C., 1994. Vegetación y milpa en el ejido de Yaxcaba, Yucatán. In E. Hernandez-Xolocotzi, E. Bello Baltazar and S Levy-Tacher. La milpa en Yucatán: un sistema de producción agrícola tradicional. Colegio de Postgraduados, México, pp. 129-148.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1993. El sector alimentario en México. INEGI. Aguascalientes, México. pp. 292.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 2000. Anuario Estadístico de los Estados Unidos Mexicanos. INEGI. Aguascalientes, México. pp. 54.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 2002. El sector alimentario en México. INEGI. Aguascalientes, México. pp. 314.

Isermeyer H., 1952. Eine einfache Methode zur Bestimmung der Bodenatmung und der Carbonate im Boden. Zeitschrift für Pflanzenernährung und Bodenkunde, 56: 25-38.

Jenkins D.J.A., Kendall C.W.C. and V. Vuksan, 1999. Inulin, oligofructose and intestinal function. J Nutr., 129 (suppl):1431S-1433S.

Jenkinson D.S., 1966. Studies on the decomposition of plant material in soil. II. Partial sterilization of soil and the soil biomass. Journal of Soil Science, 17: 280-302.

Jongbloed A.W., 1984. The impact of animal husbandry on the environment. 35^{th} ann. Meet. EAAP The Hague. The Netherlands, 6-9 August, Commission on animal management and health.

Jörgensen R.G., 1995. Die quantitative Bestimmung der mikrobiellen Biomasse in Böden mit der Chloroform-Fumigations-Extraktions-Methode. Göttinger Bodenkundliche Berichte 104, 1-229.

Jöergensen R.G. and T. Mueller, 1996. The fumigation-extraction method to estimate soil microbial biomass: Calibration of the k_{EN} value. Soil Biology & Biochemistry, 28: 33-37.

Jost M., 1991. Weidehaltung von Schweinen. Schweizerische Milchzeitung, 39: 9.

Kay D.E., 1978. Food Legumes. UK: Tropical Products Institute, pp. 390-398.

Kennely J.J. and F.X. Aherne, 1980. The effect of fibre addition to diets formulated to contain different levels of energy and protein on growth and carcass quality of swine. Canadian Journal Animal Science 60: 385-393.

Kirchgessner M., Kreuzer, M., Machmuller A. and D.A. Roth-Maier, 1994. Evidence for a high efficiency of bacterial protein synthesis in the digestive tract of adults sows fed supplements of fibrous feedstuffs. Animal Feed Science and Technology, 46: 293-306.

Kreuzer M., Machmüller A., Gerdemann M.M., Hanneken H. and M. Wittmann, 1998. Reduction of gaseous nitrogen loss from pig manure using feeds rich in easily-fermentable non-starch polysaccharides. Animal Feed Science and Technology 73: 1-19.

Kröbel R., 2002. Sozio-ökonomische Rahmenbedingungen der Schweineproduktion im Dorf Kochol im Bundesland Yucatan in Mexico. Thesis in the department „Angewandte Nutztierethologie und artgerechte Nutztierhaltung", University of Kassel, Germany.

Kumar R. and J.P.F. D'Mello, 1995. Anti-nutritional substances in forage legumes. In: Tropical Legumes in Animal Nutrition (Editores D'Mello, J.P.F. and Devendra, C.). UK: CAB International, pp. 95-133.

Lara L.P.E. and L.A. Sansores, 1990. Comportamiento agronómico del frijol terciopelo (*S. deeringianum*), en el Oriente de Yucatán. Memorias: I Congreso de Investigación. D.G.E.T.A., I.T.A. No 20, Aguascalientes. Ags. pp. 125.

Lara L.P.E. and M. J. G. Escobedo, 1991. Efecto de la fertilización fosforada y la densidad de siembra en el rendimiento del frijol terciopelo (*S. deeringianum*), en Yucatán. Memorias: I Congreso Regional de Investigación. D.G.E.T.A., I.T.A. No. 2, Conkal, Yucatán, pp. 55.

Laurena A.C., Jamela M.A., Revilleza H.R., and E.M.T. Mendoza, 1994. Polyphenols, phytate, cyanogenic glycosides, and trypsin inhibitor activity of several Philippine indigenous food legumes. Journal of Food Composition and Analysis, 73: 194-202.

Lemaire L.C.J.M., Wagensveld B.A., van Gulik T.M., Dankerts J., Gouma D.J. and J.J.B. van Lanschot (1997). Bacterial translocation via the thoracic duct in a porcine model of hepatic ischemia/reperfusion injury. Accessible at website: http://www.ssat.com/cgi-bin/97ddw/ddw79.cgi?affiliation.

Lemus-Flores C., Ulloa-Arvizu R., Ramos-Kuri M., Estrada F. J. and R.A. Alonso, 2001. Genetic analysis of Mexican Hairless Pig Populations. Journal of Animal Science, 79: 3021-3026.

Lenis N.P., Bikker P. Van der Meulen J., van Diepen J.Th.M., Bakker J.G.M. and A.W. Jongbloed, 1996. Journal Animal Science 74: 2687-2699.

Liener I. E., 1989. Antinutritional factors. In: Legumes: Chemistry, Technology, and Human nutrition. (Editor: Metthews R. H.). USA: Marcel Dekker, pp. 339-382.

Levy-Tacher S and E. Hernández Xolocotzi, 1992. La sucesion secundaria en yucatán y su manejo. In: D. Zizumbo-Villareal, Ch. H. Rasmussen, L.M. Arias-Reyes and S. Terán-Contrers Ed., La Modernización de la milpa en Yucatán: utopía o realidad. pp. 203-214.

Lopez-Morales J. R., Martinez-Gamba R. and G. Salinas-Ramos, 1999. El cerdo Pelón Mexicano, Antecedentes y Perspectivas. Ciencia y Cultura Latinoamericana, México, pp. 78.

Ly J., Diéguez, F.J., Martínez R. M. and A. García, 1998. Digestion of a diet very high in fibre in Cuban Creole pigs. Animal Feed Science and Technology, 72: 397-402.

Ly J., Ty C. and P. Samkol, 2003. N balance studies in young Mong Cai and Large White pigs fed high fibre diets based on wheat bran. Livestock Research for Rural Development (15) 1. Available at: http://www.cipav.org.co/lrrd15/1/ly151.htm.

Machin D.H., 1990. Alternative feeds for outdoor pig production. In: B.A. Stark, D.H. Machin and J.M. Wilkinson Editors; Outdoor pigs: principles and practices. Chalcome publication; pp. 103-115.

Mäder P., Pfiffner L., Fliessbach A., von Lützow M. and J.C. Munch, 1996. Soil ecology-The impact of organic and conventional agriculture on soil biota and its significance for soil fertility. In: Fundamentals of Organic Agriculture, IFOAM, Editor: Troels V. Ostergaard. Copenhagen

McDowell R.E., 1993. Animal genetic resources and sustainable production systems in Latinamerica. In: Memoria Simposio sobre los recursos genéticos animales en América Latina (Proceeding symposium about animal genetic resources in Latinamerica). ALPA; CATIE, FAO; Santiago; Chile, pp. 53-74.

Méndez M.D., 1997. Proyectos para su rescate Cerdo Pelón Mexicano. Nuestro Acontecer Porcino, 5: 60-63.

Moya-García X., 1999. Turning the Tortilla Upside Down, a Study of the Endogenous Development Potential in Local Agricultural and Organizational Practices of two Mayan Villages in Yucatan Mexico. Thesis at Wageningen Agricultural University, Wageningen, The Netherlands, pp. 208.

Mucheru M., Mugendi D.N., Micheni A., Mugwe J., Kung'u J.B., Otor S. and J. Gitari, 2004. Improved food production by use of soil fertility amendment strategies in the central highlands of Kenya. In: A. Bationo (Ed.) Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa. pp. 583-592.

NRC (National Research Council), 1998. Nutrient Requirements of Poultry. 9th rev. ed. USA. National Academy Press. Washington, D.C. pp. 26-27.

Ocio J.A., Matinez J. and P.C. Brookes, 1991. Contribution of straw-derived N to total microbial biomass N following incorporation of cereal straw to soil. Soil Biology and Biochemistry 23: 655-659.

Odriozola M., Zuzuarregui J. and M. Sierra-Castro, 1969. Estabulación del cerdo Ibérico. Instituto Nacional de Colonización, Ministerio de Agricultura, Madrid, España.

Olaboro, G. Okoto, M.W., Mugerwa J.S. and J.D. Latshawa, 1991. Growth-Depressing factors in velvet beans fed to broiler chicks. East African Agricultural and Forestry Journal 57: 103-110.

Parr W.H., 1988. The small-scale manufacture of compound animal feed. Overseas Development Natural Resource Institute Bulletin 9: 64-70.

Pfeiler U., 1999. Ergebnisse von Untersuchungen zur Bodenbelastung bei der Freilandhaltung von Schweinen. Dissertation zur Erlangung des akademischen Grades doctor rerum agriculturarum an der Landwirtschaftlich-Gärtnerischen Fakultät der Humboldt-Universität zu Berlin, pp. 110.

Piloto J.L., Vilda-Figuroa M., Macias M., Rosabal M. and J. Ly, 1998. A note on the use of Jerusalem artichokes (*Helianthus tuberosus* L.) in diets for growing pigs. Journal of Animal and Feed Science, 7: 213-217.

Powell J. M. and T. O. Williams, 1993. Livestock, nutrient cycling and sustainable agriculture in west African Sahel. International Institute for Enviroment and Development, London, Gatekeeper Series No 37.

Preston, R. T., 1991. Environmental implications of animal agriculture: the need for integrated systems and the modelling of energy flow. In: Isotope and related techniques in animal production and health, IAEA and FAO Vienna, Austria, pp. 233-252.

Pusztai A., 1985. Constraints on the nutritional utilization of plant proteins. Nutrition Abstracts and Reviews, 55 : 363-369.

Rajaram N. and K. Janardhanan, 1991. The biochemical composition and nutritional potential of the tribal pulse *Mucuna gigantea* (Willd) DC. Plant Foods for Human Nutrition, 41: 45-51.

Ravindram V. and G. Ravindram, 1988. Nutritional and anti-nutritional characteristics of mucuna (*M. utilis*) bean seeds. Journal of the Science of Food and Agriculture 46: 71-79.

Reed J. D., 1986. Relationships among soluble phenolics, insoluble proanthocyanins and fibre in East African browse species. J. Range Manag. 39: 5-7.

Ruíz B and R. Belmar, 1999. Evaluación del Frijol Terciopelo (*Stizolobium deeringianum*) sin tratar y tratado como ingrediente en dietas de cerdos. Memorias: XXXV Reunión Nacional de Investigación Pecuaria, Mérida, Yucatán, México. pp. 222.

Salas N. L. F. and C.J.C Segura., 1990. Valor alimenticio del frijol terciopelo (*Stizolobium deeringianum*) en dietas para pollos de engorda. En: Memorias de la XV convención nacional ANECA, Cancún, Quintana Roo. Tomo II, pp. 163-168.

Sánchez P.A., 1981. Suelos del trópico: carcaterísticas y manejo. IICA (Instituto Interamericano de Cooperación para la Agricultura) San José, Costa Rica, pp. 625.

Santos R., 1999. The effect of energy supply during pregnancy on productive performance, grazing behaviour and forage intake of sows kept in an outdoor system under tropical conditions. PhD Thesis Wye College, University of London, pp. 208.

Santos-Ricalde R.H. and I.J. Lean, 2002. Effect of feed intake during pregnancy on productive performance and grazing behaviour of primiparous sows kept in an outdoor system under tropical conditions. Livestock Production Science 77: 13-12.

SAS Institute Inc., 1986. SAS User's Guide: Statistics. Cary, NC.

Souza H. B. A. Souza P. A. Faleiros R. R. S. and J. F.Durigan, 1991. Caracterizaçâo física e avaliaçâo química e bioquímica de grâos de mucuna Anâ (*Stizolobium deeringianum*). Alimentos e Nutriçâo 3: 29-38.

Somda Z.C., Powell J. M., Fernández-Rivera S. and J. Reed, 1995. Feed factors affecting nutrient excretion by ruminants and fate of nutrients when applied to soil. In: J. M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (Eds). Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of sub-Saharan Africa. Volume II: Technical Papers. Proceedings of an International Conference held in Addis Ababa, Ethiopia, 22-26 November 1993. ILCA (International Livestock Centre for Africa), Ethiopia; pp. 227-243.

Sundrum A., 2001. Organic livestock farming a critical review. Livestock Production Science 67: 207-215.

Stern S. and N. Andresen, 2003. Performance, site preferences, foraging and excretory behaviour in relation to feed allowance of growing pigs on pasture. Livestock Production Science 79: 257-265.

Tabelin R., Schwier S. and J. Kamphues, 2003. Effect of different feeding and hausing conditions on dry matter content and consistency of faeces in sow. Journal of Animal Physiology and Animal Nutrition 87: 116:121.

Terán S. and Ch. Rasmussen, 1992. La milpa de los Mayas. La agrícultura de los mayas prehispánicos y actuales en el noreste de Yucatán. México: Ed. Danida. Mexico, pp. 349.

Torrallardona D., 1999. Reduction of nitrogen excretion in pigs, improvement of precision in nutrient requirements. In: Brufau J. and Tacon A. (ed.) Feed manufacturing in the mediterranean region: Recent advances in research and technology Zaragoza: CIHEAM-IAMZ, Conference of Feed Manufacturers of the Mediterranean, 1998/03/25-27, Reus, Spain. pp. 265-274.

Trejo L. W., 1998. Evaluación nutricional del frijol terciopelo en la alimentacion de pollos de engorda. MSc Thesis, Facultad de Medicina Veterinaria y Zootecnia de la Universidad Autónoma de Yucatán, pp. 35.

Trejo L.W., Solorio J. and R. Belmar, 1999a. Evaluación de la aceptación del frijol terciopelo (*Stizolobium deeringianum*) y albizia (*Albizia lebbeck*) en dietas para pollo. Memorias: XXXV Reunión Nacional de Investigación Pecuaria, Mérida, Yucatán, México. pp. 201.

Trejo L.W., Belmar R. and S. Anderson, 1999b. Evaluación nutricional del frijol terciopelo (*Stizolobium deeringianum*) crudo y tratado en dietas para pollo de engorda. Memorias: XXXV Reunión Nacional de Investigación Pecuaria, Mérida, Yucatán, México. pp. 207.

Trejo L.W. and R. Belmar, 2000. Evaluación de la aceptación del frijol terciopelo (*Stizolobium deeringianum*) y canavalia (*Canavalia ensiformis*) en pollos. Memorias: XXXVI Reunión Nacional de Investigación Pecuaria, Hermosillo, Sonora, México. pp. 184.

Trejo, L. W. Santos, R., Hau, E., Olivera, L., Anderson, S. and R. Belmar, 2004. Utilisation of mucuna beans (*Mucuna pruriens* (L.) DC ssp *deeringianum* (Bart) Hanelt) to feed growing broilers. Journal of Agriculture and Rural Development in the Tropics and Subtropics 105, 155-164.

Vaarst M., Hovi M., Sundrum A., Younie D. and S. Padel, 2003. Sustaining animal health and food safety in European organic livestock farming. Presentation at 54th annual EAAP Meeting, Rome, 31st August.

Van Bruchem J., Verstegen M.W.A. and S. Tamminga, 1999. From nutrient fluxes in animals to nutrient dynamics and health in animal production systems. In: Proceedings 5th EAAP symposim on livestock farming systems: Integrating animal science into the search for sustainability. Posieux, Switzerland, pp. 28-48.

Van Bruchem J., Schiere H., van Keulen H., 1999. Dairy farming in the Netherlands in transition towards more efficient nutrient use. Livestock Production Science 61: 145-153.

Van Keulen H., van der Meer H.G. and J. M. Imke de Boer, 1996. Nutrient balances of livestock production systems in the Netherlands. In: Utilization of local feed resources by dairy cattle (A. F. Groen and J. Van Bruchem, eds). EAAP Publication No. 84, pp. 3-18.

Varel V.H. and J.T. Yen, 1997. Microbial perspective of fibre utilisation by swine. Journal of Animal Science 75:2715-2722.

Vijn I and S. Smeekens, 1999. Fructan: more than a reserve carbohydrate? Plant Physiol. 120: 351-360.

Whitehead D.C., 1995. Grassland Nitrogen. CAB international, UK, pp. 397.

Wu, J., Joergensen R.G., Pommerening B., Chaussod R. and P.C. Brookes, 1990. Measurement of soil microbial biomass C by fumigation-extraction - an automated procedure. Soil Biology & Biochemistry, 22: 1167-1169.

Yazawa K., Imai K. and Z. Tamura, 1978. Oligosaccharides and polysaccharides specifically utilizable by Bifidobacteria. Chem. Pharm Bull, 26: 3306-3311.

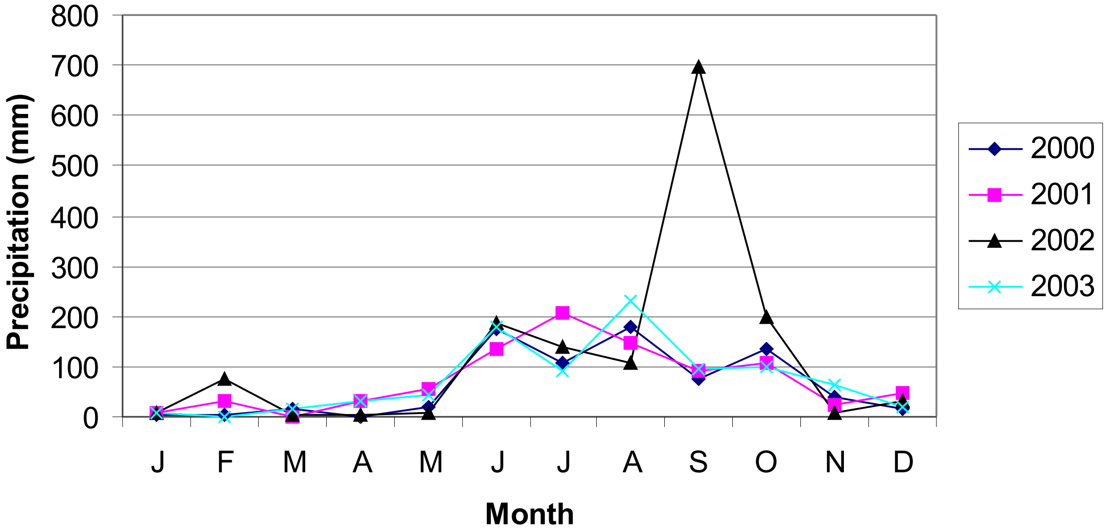
Zucker B.A. and M. Krüger (1998). Auswirkungen von Transportbelastungen auf den Endotoxingehalt im Blut von Schlachtschweinen. Berl. Mün. Tierärztl. Wsschr., 111: 208-210.

Appendices

Appendix one: Main Crops Planted in the Milpa System.

Classification	Common name	Scientific name
Cereal	Maize	*Zea maize*
Cucurbitaceous	Squash	*Curcubita spp.*
Legumes	Common beans	*Phseolus vulgaris L.*
	Lima beans	*Phaseolus lunatus*
	Cowpea	*Vigna unguiculata*
	Pigeonpea	*Cajanus indica*
Tubercles	Winged Yam Aki makal	*Dioscorea alata L.*
	Kukut makal	*Xanthosoma yucatanense Engler.*
	Sweetpoteto	*Ipomea batatas (L.) Lam.*
	Jícama	*Pachirrhizus erosus (L.) Urban*
	Cassava	*Manihot esculenta Crantz*

Appendix two. Precipitation during the fourth years of evaluation of the experiment two in Yucatan, Mexico (CNA, 2004).



Appendix three: Calendar activities in the Milpa system under slash and Burn.

Activities	Jul	Ago	Sep	Oct	Nov	Dic	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic	Ene	Feb
Piece of land selection in the forest		---	---	---	---	---	---	---	---	---	---									
Breach (milpa 1st year)		---	---	---	---	---	---	---	---	---	---									
Measurement (milpa 1st year)		---	---	---	---	---	---	---	---	---	---									
Clearance of the forest with axe (milpa 1st year in thick Forest)		---	---	---	---	---	---	---	---	---	---									
Enclosure (thick Forest)			---	---	---	---	---	---	---	---	---									
Clearance of the forest with machete (milpa 1st year in underbrush)								---	---											
Slash (milpa 2nd and 3th year)								---	---	---	---									
To clean a border surrounding the milpa									---	---	---									
Burning of fields										---	---									
Sowing time											---	---	---	---	---	---				
Weed control													---	---						
To bend the maize plants																---	---			
Harvesting																		---	---	---
Storage of the yield																		---	---	---
Fallow period																				

Source: Teran and Rasmussen (1992).

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