Sweet Potato Leaves for Growing Pigs

Biomass Yield, Digestion and Nutritive Value

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Abstract

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The aim of the present studies was to evaluate the potential of using sweet potato leaves (*Ipomoea batatas* (L.) Lam) as a protein source in diets for growing pigs.

A number of sweet potato varieties were evaluated with respect to the biomass yield of the leaves, stems and tubers under different leaf harvesting intervals and defoliation techniques with the aim of selecting the best varieties for forage production. The biomass yields of leaves, stems and tubers were found to vary according to variety, season and defoliation technique. The best options in terms of leaf and stem production were a cutting interval of 20 days and a defoliation of 50% of the total branches. Defoliation reduced tuber production. Sweet potato leaves (SPL) had a crude protein (CP) content of 25.5-29.8% in dry matter, which was markedly higher than in the stems.
The leaves can be preserved as feed for pigs by ensiling with either cassava root meal, sweet potato root meal or sugarcane molasses as additives. The optimum level of additive is 60 g kg^{-1} of the wilted sweet potato leaves. The digestibility in growing pigs of dry matter, organic matter (OM) and CP of ensiled sweet potato leaves was high, but that of crude fibre was low.
Sweet potato leaves can be used for feeding pigs in fresh, dry and ensiled forms. The total tract and ileal digestibility values of CP, OM and neutral detergent fibre (NDF), and ileal digestibility of amino acids were not different among fresh, dry and ensiled sweet potato leaves. The mean ileal and total tract digestibility of the CP of sweet potato leaves was 74% and 76%, respectively.
Sweet potato leaves are high in protein content compared to other protein-rich forages. Lysine is the first limiting amino acid. Growing pigs fed sweet potato leaves with addition of synthetic lysine had daily live-weight gains of 536 g day^{-1}, which was similar to that of pigs fed a control diet with fish meal as the protein source (542 g day^{-1}). However, without addition of lysine to the SPL diet daily live-weight gain was only 482 g day^{-1}.

It is concluded that SPL can be considered as a potentially valuable protein source for pigs. The leaves can be used fresh, dried or as silage, and can replace fish meal and groundnut cake as a protein source for growing pigs under small farm conditions in central Vietnam.

Key words: Biomass yield, Sweet potato leaves, Silage, Growing pigs, Ileal digestibility, Performance, Carcass characteristics.

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Affectionately dedicated to
my parents, my wife Dao Thi Phuong,
my daughter Quynh Anh and my son Minh Duc.

Contents

Appendix

Paper I-IV

The present thesis is based on the following papers, which will be referred to in the text by their Roman numerals.

I. An, L.V., Frankow-Lindberg, B.E. and Lindberg, J.E. 2003. Effect of harvesting interval and defoliation on yield and chemical composition of leaves, stems and tubers of sweet potato (*Ipomoea batatas* L. (Lam.)) plant parts. *Field Crops Research 82, 49-58*.

II. An, L.V. and Lindberg, J.E. 2004. Ensiling of Sweet Potato Leaves (*Ipomoea batatas* (L.) Lam) and the Nutritive Value of Sweet Potato Leaf Silage for Growing Pigs. *Asian-Australian Journal of Animal Sciences 17(4), 497-503*.

III. An, L.V., Hong, T.T.T. and Lindberg, J.E. 2004. Ileal and total tract digestibility in growing pigs fed cassava root meal diets with inclusion of fresh, dry and ensiled sweet potato leaves. *Animal Feed Science and Technology 114, 127-139.*

IV. An, L.V., Hong, T.T.T., Ogle, B. and Lindberg, J.E. 2004. Utilisation of ensiled sweet potato leaves as a protein supplement in diets for growing pigs. *Tropical Animal Health and Production. (In Press).*

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Introduction

Animal production is increasing globally to meet the demands for meat and milk in human diets. In developed countries, pig diets are based on cereals as the dominant energy source, and a substantial part of the essential amino acids is provided from protein rich feedstuffs, sometimes with supplementary synthetic amino acids. However, in developing countries, there is still a shortage of both energy sources and feedstuffs with an acceptable protein content and quality for animal production. In view of the world-wide demand for additional feed sources, the exploitation of traditional crops, which often are grown with low inputs, and are largely adapted to the climatical conditions of the developing countries would be a step towards better resource utilisation.

One traditional crop in tropical countries is the sweet potato (*Ipomoea batatas* L. (Lam.)), which originated from Central America. Sweet potato is extensively grown in many countries, especially in China and Southeast Asia. In Vietnam, sweet potato is the third most important crop after rice and maize and occupied 245,000 ha in 2001 (Statistical Yearbook, 2002). Sweet potato is usually the main food crop in areas where rice production is limited, but at present it is more commonly used for livestock; both tubers and vines are used for pigs, chickens and cattle (Woolfe, 1992). Sweet potato based pig production systems are very common in Vietnam and play an important role in the economies of small farmers (Peter, 1998).

Sweet potatoes can be planted for either tubers and/or forage production, depending on purpose and season. The yields of these parts also vary as a result of different climate and soil conditions (Woolfe, 1992; Hartemink et al., 2000). Sweet potato tuber DM consists mainly of starch and is therefore considered as an energy source, while the leaves have a high protein content and can therefore be used as a protein source for livestock (Zhang and Xie, 1990; Dominguez, 1992; Woolfe, 1992; Moat and Dryden, 1993; Ishida et al., 2000).

So far, research on sweet potato has mainly focussed on tuber production. There are very few reports on the production of leaves and their nutritive value in pigs. The vines comprise both the leaves and stems. The crude protein content of the leaf part is between 26 % to 33 % of DM, while the CP content of the stem is 10 % to 14 % (Woolfe, 1992; Ishida et al., 2000). Therefore, if the leaves are separated from stems, they have a high value as a protein source for pigs.

The potential of using different forages as feed for growing pigs has been studied extensively. Lindberg and Cortova (1995) showed that lucerne leaf

meal was well utilised in barley-based diet for growing pigs. Also, lucerne, white cover, red clover and perennial ryegrass meals may have a potential as energy and protein sources in modern pig meat production (Lindberg and Andersson, 1998; Reverter et al., 1999). Phuc and Lindberg (2000) suggested that cassava leaves could be used to improve the dietary protein supply in tropical conditions. An investigation on sun-dried sweet potato vines (Domínguez and Ly, 1997) reported however that the proportion of sweet potato vine in diets for pigs should be low to avoid a negative effect on nutrient digestibility and these authors also called for new methods to improve the digestibility of this by-products.

Aims of the thesis

The aims of the present studies were:

- To investigate the biomass yield of the leaves, stems and tubers of sweet potato varieties under different harvesting intervals and defoliation techniques,
- To identify a suitable preservation method of sweet potato leaves with respect to the nutritive value,
- To measure the ileal and total tract digestibility of sweet potato leaves in growing pigs, and
- To evaluate the utilisation of sweet potato leaves as a protein source for pigs under farm conditions.

Background

Livestock production in Vietnam

Livestock plays an important role in farming systems as it provides meat and milk for human consumption, income for farmers and manure for cropping. At present, the rapid increase in the population of Vietnam together with the economic development have led to an increase in demand for food generally, and animal protein in particular. According to the Statistical Yearbook (2002) the population growth rate in Vietnam was 1.7 % per year during the period from 1992-2001, and the average annual economic growth rate was about 7.4 %. Thus, the livestock sector has to be developed, both in terms of quantity and quality, to meet demands (Table 1).

Table 1. Animal production in Vietnam between 1992-2001 (Statistical Yearbook, 2002)

Year	Cattle*	Buffalo*	Pigs*	Poultry**	Goats, sheep*
1992	3202	2886	13892	125	312
1993	3333	2960	14874	133	353
1994	3467	2977	15588	138	428
1995	3639	2962	16306	142	550
1996	3800	2954	16922	151	513
1997	3905	2944	17636	161	515
1998	3987	2951	18132	166	514
1999	4064	2956	18886	179	471
2000	4128	2897	20194	196	543
2001	3896	2819	21741	216	561

* Thousand head
** Million head

The numbers of small ruminants, poultry and pigs have increased markedly during the last 10 years while the numbers of cattle have increased less and the number of buffaloes has remained the same. Animal production in Vietnam is mainly based on smallholder farming. In rural areas, pigs and poultry are kept for cash income while cattle and buffaloes are used for draught power. The number of each kind of animal kept in each farm is small because feed supply is limited. Recently, improved dairy cows were introduced to Vietnam but these animals are only kept close to the big cities such as Hanoi or Ho Chi Minh City where there is a ready market for milk.

Pigs are the most popular animal in Vietnam and pig production from small-scale farms accounts for over 75% of the pork production in the country (Statistical Yearbook 2002). Due to the high cost of commercial feed, farmers use crops and crop by-products available at farm level, such as cassava root meal, rice bran, maize and sweet potatoes. These feedstuffs are normally rich in carbohydrate, but low in protein content.

The Mong Cai is an indigenous pig breed in Vietnam that has good characteristics with regards to reproduction, is adapted to the hot climate and is tolerant of high fibre diets. Due to the low daily live weight gain and high fat content in the carcass, crossbreeding programs with the Large White and other exotic boars have been followed to improve productivity and meat quality, with the Mong Cai used as the mother pig. In this study (Paper II, III and IV), crossbred fattening pigs (Large White and Mong Cai) were used, as they are very common in rural pig production in Vietnam.

Livestock – crop production systems

Livestock production is closely linked to the cropping systems in Vietnam. The integration of crop and animal production is well developed in the small-holder farming systems of Asia (Devendra and Thomas, 2002). The complementarity in resource use in these systems is such that the outputs from one sector are used as inputs for the others; for example, livestock supply manure and draught power for crop production and the crop residues can be used as feed for animals. The use of animal manure in crop farming contributes to the maintenance of soil fertility and reduces the input costs (Devendra and Thomas, 2002).

Vietnam has a typical Asian agriculture, in which crop – livestock systems are dominant. Rice is the most important crop for food production and can be cultivated 2 or 3 times per year. In this production system, cattle and buffaloes are used for land preparation and traction. Pigs are kept at each farm to supply manure for the rice field. Rice straw is the major conserved feed for cattle and buffaloes, especially in the dry season, while rice bran is the main feed for pigs. Other annual crops such as cassava, sweet potato and various vegetables are also planted to produce food and income, and the by-products are used for feeding animals.

In general, feeding systems for livestock are based on locally available feed resources such as rice straw, rice bran, sugar cane tops, sweet potato vines, cassava root meal, and agro-industrial by-products from marine food processing and brewing. Commercial feeds are rarely used because these are expensive. The proportion of commercial feed used is about 20 % of the total, while the remaining 80 % is mainly crop residues and farm by-

products, which are often of poor quality and low nutritional value. The question is how to improve the nutritional quality of diets in small-farmer systems and thus improve the production capacity of the animals. It is also important that farmers can adopt a practice easily and that this will increase their net income.

Sweet potato

Introduction

The sweet potato, *Ipomoea batatas* L. (Lam.), is a dicotyledonous plant which belongs to the morning-glory family (*Convolvulaceae*). It was domesticated more than 5000 years ago, and originated from Central America. The crop was introduced into China in the late 16th century and spread rapidly throughout Asia and Africa during the 17th and 18th centuries. Sweet potato is an important crop in many areas of the world, and today is cultivated in over 100 countries, and ranks among the five most important food crops in the tropical areas where a high population of the world's poorest people live (Woolfe, 1992). About 80% of the sweet potato in the world is grown in Asia, under 15 % in Africa and about 6% in the rest of the world (Horton, 1988). With the advantages of sweet potato cultivation and its high nutritive value, the sweet potato has been developed as an alternative crop to supply food for human and livestock demands in both fresh or processed form.

In Vietnam, sweet potato production decreased during the 10 years from 1992 to 2001 in terms of cultivated area (Table 2). The main reason for the decline may have been the increase in rice production as a result of the economic policy reforms of the government. Rice is the main food crop and production was insufficient for domestic demand before 1990. However from 1991 onwards production improved because agricultural land was allocated to individual farmers for 20 years. With increasing rice production, sweet potato production decreased.

Table 2. Sweet potato production in Vietnam between 1992 and 2001 (Statistical Yearbook, 2002)

Year	Area (ha)	Yield (ton/ha)	Production (tonnes)
1992	404900	6.64	2593000
1993	387100	6.21	2404800
1994	343700	5.55	1905800
1995	304600	5.54	1685800
1996	302700	5.61	1697000
1997	267200	6.33	1691000
1998	253500	6.02	1526100
1999	270200	6.46	1744600
2000	254300	6.33	1611300
2001	244600	6.76	1653500

Biomass yield

Sweet potato produces a high amount of biomass, which depends on the season, climate, fertiliser application, time of harvesting, defoliation and purpose of use. The productive potential of different varieties of sweet potato is from 3 to 4 ton/ha of root (DM) and the foliage production can be from 4.3 to 6.0 ton DM/ha/crop (Ruiz et al., 1980). The biomass yield of sweet potato decreases after the first season due to poor nutrient supply and diseases, thus cultivation of this crop should be in rotation with other crops in the field (Hartemink et al., 2000).

Compared to other common root crops, average root production of sweet potatoes is similar to that of cassava and lower than that of yam (Okigbo, 1986). However, the leaf biomass yield of sweet potato is higher than that of these crops, as sweet potato leaves can be harvested many times throughout the year (Dahniya, 1981; Hong et al., 2003).

Chemical composition

Both the root and the leaf parts of sweet potato can be used as food for humans and animals. The chemical composition of these parts is quite different. The roots or tubers have a high moisture and low dry matter content. The average dry matter content is approximately 30 %, but varies depending on variety, climate and harvesting time. The chemical composition of sweet potato root is shown in Table 3.

Table 3. The chemical composition (% in DM) of sweet potato roots (Woolfe, 1992)

	Average	Range
Starch	70	30-85
Total sugars	10	5-38
Total protein (N x 6.25)	5	1.2-10
Lipid	1.5	1-2.5
Ash	3	0.6-4.5
Total fibre	10	-
Vitamins and other components	<1	-

In many areas, sweet potato leaves are consumed and varieties are grown which are suitable for harvesting both root and leaves, or for harvesting leaves only. In contrast to sweet potato root, there is little information about the chemical composition of sweet potato green parts (including stem, petiole and leaf). Sweet potato leaves have a low dry matter content, but a high crude protein and fibre content. The chemical composition of sweet potato green parts is presented in Table 4 and Table 5.

Table 4. Plant components (% of plant DM), dry matter (DM) content (%) and chemical composition (% of DM) (Woolfe, 1992)

Portion	Weight	DM	Crude Protein	Crude fibre	Starch	Sugars	Ash
Total [a]		12.5	20.9	14.9	3.7	8.8	13.5
Stem [a]	26.0	9.6	13.6	20.7	3.9	12.6	13.8
Petiole [a]	23.9	7.9	12.7	16.6	4.5	11.0	18.3
Leaf [a]	50.1	16.3	28.6	11.1	3.2	6.0	10.9
Total [b]		6.6	20.7	15.0	3.6	13.0	16.7
Stem [b]	24.4	7.9	14.1	20.8	3.4	16.8	14.9
Petiole [b]	37.9	5.9	13.3	17.1	4.0	15.7	22.3
Leaf [b]	37.7	6.5	32.4	9.2	3.4	7.8	12.2

[a] Average of three lines with similar DM content
[b] Line CN 1508-93 with low DM content

Table 5. The essential amino acid composition of sweet potato root and leaves and other food plants (g/16 g N) (Woolfe, 1992)

Food	His	Ile	Leu	Lys	Met + Cys	Phe + Tyr	Thr	Trp	Val
Sweet potato roots	1.7	4.4	6.0	4.0	2.5	6.9	4.4	1.4	5.9
Cassava root	2.1	2.8	4.0	4.1	2.7	4.1	2.6	1.2	3.3
Maize meal	2.7	3.7	12.5	2.7	3.5	8.7	3.6	0.7	4.9
Sweet potato leaves	3.4	4.8	8.1	3.8	2.9	7.8	4.5	0.88	9.1
Cassava leaves	2.2	4.9	8.6	6.2	2.8	9.4	4.7	1.5	5.7

Utilization of sweet potato

Sweet potato is not only used for human consumption but also for animal feed, because of its nutritional advantages. In the tropical countries, sweet potato is used both directly as a fresh or processed food and indirectly as animal feed (Woolfe, 1992). The sweet potato root consists mainly of starch and thus has a high digestible energy content. Similarly to cassava root meal, it has low protein, fat and fibre levels. The vines have high fibre and protein content, with about 18.5 % CP (Dominguez, 1992), while the leaves have a CP content of 25.6 to 32.4 % in DM (Woolfe, 1992; Ishida, 2000). In some areas, for example Korea, Japan, Vietnam and China, the top of the sweet potato is also used for human consumption (Villareal et al., 1985; Peter et al., 2000). The NDF content of sweet potato vines is about 26 % (Dominguez, 1992).

According to Ishida et al. (2000), the above-ground parts of sweet potato, such as leaves, stalks and stems have a high nutritive value. In particular, leaves contain a large amount of protein with a high amino acid score. All

parts are rich in dietary fibre, particularly stems, with soluble and insoluble dietary fibre. Contents of minerals and vitamins such as A, B_2, C, and E are high in leaves in comparison with other vegetables. For this reason, both roots and vines are used as a protein and vitamin source for pigs, poultry, rabbits and cattle (Mora et al., 1992; Wethli and Paris, 1995; Ali et al., 1999; Chen et al., 1977).

Sweet potato as a feed resource for livestock

Sweet potato is used as a livestock feed in many developing countries. According to international statistics about one third of the sweet potato production in developing countries is used for animal feed. In Asian countries such as China, Indonesia, South Korea, Philippines, Taiwan, and Vietnam, the sweet potato is used in both root and vine form. Normally, roots are used for pigs and vines for cattle. Some farmers in China and the Philippines prefer to boil the roots first and then use them as a pig feed in order to improve the digestibility (Scott, 1992). Sweet potato leaves have been evaluated as a feed to replace imported dried alfalfa in poultry feed, and a diet including green leaves had 15% lower feed conversion compared to other treatments (Wethli and Paris, 1995). When sweet potato vine meal replaced lucerne meal at 0, 40, 80, 120 and 160 g/kg diet, broilers grown to 21 days showed no differences in growth rate, food intake or food conversion efficiency (Farrell et al., 2000). A considerable amount of research has been published on using sweet potato roots for pigs, and for example were evaluated in a digestibility trial fed either raw or cooked, peeled or non-peeled. Peeling significantly increased the digestibility of crude protein, ether extract and crude fibre, but had no effect on digestible and metabolizable energy, or on total digestible nutrients. Cooking did not significantly affect the utilization of energy, but increased the digestibility of the nutrients (Oyenuga and Fetuga, 1975). Dominguez (1992) found that the inclusion of fresh sweet potato vines (10 % of DM) to a diet of cooked sweet potatoes and soya bean meal lowered the digestibility of all nutrients in growing pigs. According to Backer et al. (1980) in a feeding trial with growing cattle, treatments with 0:100, 25:75, 75:25, 50:50, and 100:0 ratio of tubers to sweet potato forage supplemented with urea to provide 0, 18, 35, 53 and 71 % of total nitrogen, respectively, resulted in live weight gains that did not differ significantly between treatments. Average live weight gain was 0.767 kg/day.

Ensiling sweet potato leaves

Silage is the material produced by the controlled fermentation of a crop of a high moisture content. Ensiling is the name given to the process of fermentation in preserving green crops. The first essential objective in preserving crops by natural fermentation is the achievement of anaerobic conditions (McDonald et al., 1991). The most efficient way is to store the material in a hermetically sealed container. Under these conditions the oxygen trapped in the herbage is rapidly removed by respiratory enzymes in the plant. The silage must be kept under anaerobic conditions because when the oxygen is in contact with the herbage for any period of time, aerobic microbial activity occurs and the material decays to a useless and frequently toxic product. The second objective in preserving crops by natural fermentation is to discourage the activities of undesirable micro-organisms such as clostridia and enterobacteria. Clostridia are usually present on harvested forage in the form of spores and only grow under strict anaerobic conditions (McDonald et al., 1991). The growth of these organisms is undesirable because they produce butyric acid and degrade amino acids, which lessen the nutritive value of the silage. The enterobacteria are non-spore forming, able to grow in both aerobic and anaerobic conditions, ferment sugars to acetic acid, and also have the ability to degrade amino acids. Therefore, one way of inhibiting the growth of these undesirable micro-organisms is to promote lactic acid fermentation. Lactic acid bacteria are also present on harvested crops and ferment the sugars in the crops to a mixture of acids, but predominantly lactic acid. The lactic acid produced increases the hydrogen ion concentration to a level that inhibits undesirable bacteria and therefore, the silage is preserved in a good condition.

Silage additives

The aim of using silage additives is to support the fermentation process of the lactic acid bacteria, in order to produce a well preserved silage. Silage additives can be classified into two main groups: stimulants and inhibitors. Fermentation stimulants include lactic acid bacteria and carbohydrate sources, such as glucose, sucrose, molasses, cassava, potatoes and cereals. The fermentation inhibitors are normally acids and other chemical products. These additive groups are concerned with fermentation control and act either by encouraging lactic acid fermentation or by inhibiting microbial growth. A basic requirement for all additives is that they are non-toxic to humans and animals, and have no adverse effect on the digestibility of animals (McDonald et al., 1991).

Evaluation of nutritive value

Chemical composition

The potential of a feedstuff for animals can be evaluated on the basis of its chemical composition, which traditionally comprises the content of moisture, ash, crude protein (CP), ether extract (EE), nitrogen-free extract and crude fibre (CF).

In the developing countries, feeds for animals at the farm level are normally poor in protein but high in fibre content. Sweet potato forages are available farm products that have high crude fibre contents (Dominguez and Ly, 1997).

Digestibility

Foods for animals are mainly organic materials which have to be broken down into simple components in the digestive tract before they can pass through the mucous membrane of the alimentary canal into the blood and lymph. The former process is called "digestion" and the passing of digested nutrients through the mucous membrane is called "absorption". The digestion processes are grouped into mechanical, chemical and microbial, respectively. The mechanical activities are mastication and the muscular contractions of the alimentary tract. The chemical action occurs by the secretion of enzymes. In pigs, the mechanical and chemical digestive processes mainly occur in the front parts of the digestive tract, while the microbial processes happen mainly in the large intestine by the action of micro-organisms.

The value of feed to animals can be determined by the changes in the amounts of the nutrients made available through the digestion and absorption processes in the digestive tract.

Total tract digestibility

Measuring the digestibility of feed for all species of animals is based on the input of feed and output of faeces. Normally, in a digestibility trial, male pigs are preferred to females because it is easier to separate faeces and urine (McDonald et al., 1995). Nutrient digestibility of any given feed can be calculated as follows:

$$\text{Nutrient digestibility (\%)} = \frac{\text{Nutrient consumed (g)} - \text{Nutrients in faeces (g)}}{\text{Nutrients consumed (g)}} \times 100.$$

In a traditional digestibility trial, the feed under investigation is given to the animal in a known amount and the output of faeces is collected and measured. However, special methods can be used for measuring digestibility, such as the indicator method. The indicator should not be toxic, not affect the animal physiology and not affect gastrointestinal tract secretion, digestion, and absorption. Most importantly the indicator should not be absorbed or metabolised within the gastrointestinal tract. Another important point concerning the indicator is that it must be distributed evenly throughout the feed. Indicators used for digestibility studies include acid insoluble ash (silica) or indigestible acid-detergent fibre as an internal marker, or an added chemical, such as chromium oxide (Cr_2O_3) as an external marker.

Ileal digestibility and cannulation techniques

Determination of ileal digestibility provides more detailed information on the utilization of a feed than total tract digestibility. In monogastrics, the main site of absorption of nutrients is the small intestine. The undigested food is excreted in the faeces. However, not all the faeces are undigested food residues. Part of the faeces are enzymes and other substances that are secreted into the gut, as well as microbes produced in the gut. This leads to an underestimate of the food actually absorbed by the animal. Total tract digestibility is therefore not a good estimate of the food absorbed in the small intestine.

Several methods have been developed to collect digesta from the terminal ileum. In all the pigs are surgically fitted with cannulas in the gastrointestinal tract. Ileal cannulation techniques include T-cannulas (Jørgensen et al., 1985), ileo-caecal re-entrant cannulas (Easter and Tanksley, 1973; Van Leeuwen et al., 1988), ileo-rectal shunt technique (Laplace and Darcy-Vrillon, 1989) and post-valvular T-caecum cannulas (Van Leeuwen et al., 1988).

In the current thesis (Paper III) the Post-valvular T-caecum cannula (PVTC) technique was used. In this method the caecum is removed and the T-cannula is joined with the remnants of the caecum directly opposite the ileo-caecal valve. When the cannula is open the ileo-caecal valve protrudes into the cannula and thus digesta can be collected (Van Leeuwen et al., 1991).
In Paper III chromium oxide was used as digesta flow maker and the digestibility of the diets at each sampling site was calculated using the indicator technique (Sauer et al., 2000) according to the equation:

$$CAD_D = 1- (DC_F \times I_D)/(DC_D \times I_F)$$

where

CAD_D = coefficient of apparent digestibility of dietary component in the assay diet
DC_F = dietary component concentration in ileal digesta or faeces (g kg^{-1})
I_D = indicator concentration in the assay diet (g kg^{-1})
DC_D = dietary component concentration in the assay diet (g kg^{-1})
I_F = indicator concentration in ileal digesta or faeces (g kg^{-1})

Ileal digestible amino acids

Amino acid digestibility values can be determined according to the ileal or faecal analysis methods. The ileal analysis method should be considered as an improvement of the faecal analysis method. A proportion of the dietary protein can not be digested in the small intestine and moves to the large intestine. In this part of the digestive tract, a part of the protein can be fermented by the microflora. The nitrogen will be either absorbed in the form of ammonia or in microbial protein. The remainder will be excreted in faeces. Bacterial fermentation in the large intestine is shown by the large amount of bacterial nitrogen in faeces. Ileal collection eliminates the hind-gut as a source of error and is justified as absorption from the large intestine give little or no contribution to the protein status of animal (McDonald et al., 1995). Therefore, ileal digestibility has the advantage over faecal digestibility because the values more closely reflect digestibility to the point where absorption of amino acids is completed (Van Leeuwen et al., 1991; Batterham, 1994; Sauer et al., 2000).

There is considerable interest in what form the ileal digestibility measurement should be – apparent or true digestibility. Apparent digestibility measures both the digestibility of amino acids in the feed and those contributed from endogenous sources, while true digestibility includes a correction for endogenous secretions (Batterham, 1994). Apparent digestibility values are affected by the level of crude protein in the diet. As the crude protein level in the diet increases, the proportion from endogenous sources decreases, and the apparent digestibility of the diet increases. Thus, the proportion of amino acids actually digested is underestimated in diets with low protein content when using apparent digestibility. However, true digestibility values are not affected by the crude protein content in diet. Correction for the endogenous contribution can be estimated by the use of a protein-free diet or feeding graded levels of the test protein and extrapolating back to zero (Low, 1982). Recent methods include the use of ^{15}N to label the amino acids in the feed or the pig so that the undigested can be distinguished from the unabsorbed endogenous secretions (Huisman et al., 1992; Dehareng et al., 2001), and

the use of homoargrinine to estimate lysine digestibility (Hagemeister and Erbersdobler, 1985; McNeilage, et al., 2001). Lysine in a feed is converted to homoarginine by a guianidination process. Homoarginine is absorbed and is immediately reconverted to lysine so that the pig does not suffer a lysine deficiency. Any homoargine remaining in the terminal ileum is thus of dietary origin and is a reflection of the true digestibility of lysine.

A number of different types of study have been undertaken to determine the usefulness of ileal digestibility values and the results are not always in agreement. Comparisons have been made between ileal and faecal values. Some of studies have shown little or no advantage of ileal over faecal digestibility (Van Barneveld et al., 1994; Rowan et al., 1994). However, ileal digestibility values are the preferred system for measuring amino acid digestibility because the faecal values could have been modified by microbial activity (Batterham, 1994; Boisen and Moughan, 1996; Boisen et al., 2000). Use of ileal digestibility values in diet formulation improves the accuracy of formulation and prediction of animal performance (Williams, 1995).

Ideal protein concept

The quality of dietary protein is indicated by the presence and relative proportions of all the essential amino acids. The ideal protein is defined as the perfect ratio among the essential amino acids required for maintenance and production (Boisen et al., 2000).

Generally, animal proteins are rich in lysine and have higher biological values than plant proteins, which are often low in lysine, tryptophan, and methionine. For example, maize protein can support adequate growth of pigs only after supplementation with both tryptophan and lysine. Soybean is limiting in methionine, while fishmeal is high in both lysine and methionine (McDonald et al., 1995).

The ideal protein is conceived as providing the essential amino acids in the proportions required by the pig and of having the correct balance between the essential and non-essential amino acids. The amino acid requirements of farm animals are influenced by many different factors including animal characteristics (weight, daily gain, sex, genotype), environment and health status (Moughan 1989; Fuller, 1994; Boisen et al., 2000). However, most changes in amino acid requirements do not lead to changes in the relative proportion of different amino acids (Boisen et al., 2000). The balance of amino acids in the ideal protein and the amino acid profile of the ideal protein are presented in Table 6 and Table 7, respectively.

Table 6. Recommended balance of amino acids (g/kg) in an ideal protein for pigs (McDonald et al., 1995)

Lysine	70	Leucine	70
Methionine + cystine	35[a]	Histidine	23
Threonine	42	Phenylalanine + tyrosine	67[b]
Tryptophan	10	Valine	49
Isoleucine	38	Non-essential amino acids	596

[a] At least half should be methionine.
[b] At least half should be phenylalanine

Table 7. Amino acid profile (relative to lysine) of an ideal protein for growing pigs (Boisen et al., 2000)

	A	B	C	D	E
Lysine	100	100	100	100	100
Methionine + cystine	50	55	59	60	50
Threonine	60	64	75	65	66
Tryptophan	15	16	19	18	18
Isoleusine	55	61	61	60	50
Leucine	100	80	110	100	100
Valine	70	64	75	68	70
Histidine	33	29	32	32	33
Phenylalanine + tyrosine	96	88	122	95	100
Arginine	-	42	-	42	-

A: ARC (1981); B: NRC (1998); C: Fuller et al. (1989); D: Chung and Baker (1992); E: Cole and Van Lunen (1994).

Effect of dietary fibre on digestibility in pigs

Dietary carbohydrates constitute a major fraction of the diet for pigs and consist of mono-, di- and oligosaccharides and two broad classes of polysaccharides – starch and non-starch polysaccharides (Bach Knudsen and Jørgensen, 2001). Starch and disaccharides are mainly broken down by a combination of salivary, pancreatic and mucosal enzymes in the small intestine with the end products (glucose, galactose and fructose) absorbed into the portal vein. No enzymes in the small intestine of pigs can cleave the bondings in some oligosaccharides and non-starch polysaccharides. These carbohydrates can be broken down by microbial fermentation in the large intestine. The end products of microbial fermentation of carbohydrates are short-chain fatty acids and lactic acid, which are absorbed to the animal. Factors that influence the breakdown of non-starch polysaccharides in the large intestine include the retention time, age and weight of the animal and the microbial composition.

The term dietary fibre, in older literature, is used for crude fibre (CF), neutral detergent fibre (NDF) and acid detergent fibre (ADF). According to Bach Knudsen (1997) and Souffrant (2001) dietary fibre is defined as a heterogenous mixture of structural and non-structural polysaccharides and

lignin and is not digested by endogenous secretions by the pig, but efficiently by the microbial flora. Dietary fibre can be measured by either enzymatic-gravimetric or enzymatic-chemical methods (Bach Knudsen and Jørgensen, 2001; Bach Knudsen et al., 1997).

Dietary fibre is generally considered as a fraction with a low energy content, and in the pig causes regular peristaltic action that avoids the possibility of constipation (Wenk, 2001).

In growing pigs, digestibility coefficients of dietary fibre average 0.4-0.5 but they range from around zero in high lignin and water-insoluble dietary fibre sources (e.g. wheat straw) to 0.8-0.9 in fibre sources with high pectin or water-soluble dietary fibre levels (e.g. sugar beet pulp or soybean hulls) (Noblet and Le Goff, 2001). The digestibility of dietary fibre is lower in young animals than in adult animals and the negative effects of dietary fibre on the digestibility of energy and nutrients are highest in young animals (Bach Knudsen and Jørgensen, 2001). Chabeauti et al. (1991) found that in diets with similar amounts of non-starch polysaccharides, plant cell walls from sugar beet pulp and soya bean hull diets were highly digestible (0.69 and 0.74 for total non-starch polysaccharides, respectively) while those from wheat bran and wheat straw diets were low (0.51 and 0.30 for total non-starch polysaccharides, respectively). Similar results were also given by Freire et al. (2000) and Galassi et al. (2004). Therefore, it is not only the level of dietary fibre that is important, but also the type or source of fibre plays a significant role in digestion and absorption.

Summary of materials and methods

Plant material (Paper I, II, III, and IV)

In Paper I, 15 varieties of sweet potato were investigated. Fourteen of these varieties were received from the National Root Crops Institute in Hanoi, Vietnam, where sweet potato varieties are bred for planting throughout the country. One variety was collected from a farmer's field at the experimental site, here called “Local”. This local variety has been used by farmers in the area for a long time and is one of the main varieties for both tuber and forage production purposes. In Paper II, III and IV, the local variety was used, as this variety gives a high biomass yield of both tuber and root, and is adapted to the climate conditions in the area.

Harvesting interval and defoliation (Paper I)

Defoliation was carried out by harvesting the vines by hand, with different harvesting intervals and different harvesting proportions. The defoliation treatments were as follows:

H15: harvesting every 15 days (a total of four harvests)
H20: harvesting every 20 days (a total of three harvests)
H30: harvesting every 30 days (a total of two harvests)
H120: no harvest during the growth period (only one harvest of vines at 120 days)

At each harvest, fifty percent of the total branches were cut at 10 cm distance from the main stems. In treatments H15, H20 and H30, the first harvest was performed 60 days after planting. The final harvest of vines and tubers for all treatments was at 120 days after planting. The experiment was conducted as a block design with 3 replicates.

Different proportions of the plant were harvested as follows:

C25: 25% of the total number of branches were harvested
C50: 50% of the total number of branches were harvested
C75: 75% of the total number of branches were harvested
C100: all branches were harvested

The first, second and third harvests were at 60, 90 and 120 days after planting, respectively. Prior to harvesting, the number of branches was counted on an individual plant basis. The experiment was conducted as a block design with 3 replicates.

In all experiments, at each harvest, the material was manually partitioned into leaves and stems (including petioles) that were weighed separately. At the final harvest all branches were collected and partitioned into leaves and stems and the tubers were also collected and weighed. At each harvest, sub-samples of about 500 g of leaves and stems, and at the final harvest also of tubers, were taken for chemical analyses.

Ensiling methods (Paper II, III, and IV)

In Paper II, sweet potato leaves were harvested at 60 days after planting. The vines were manually separated into leaf and stem parts, and only the leaf part was used for ensiling. Leaves were chopped into small pieces of 2-3 cm and spread out on the floor overnight for wilting to reduce the moisture content. Cassava root meal (CRM), sweet potato root meal (SPM) and sugar cane molasses (Mo) were used as additives in making silage of sweet potato leaves (SPL). CRM, SPM and Mo were added at 0, 30, 60 and 90 g kg^{-1} (air-dry weight of additive to pre-wilted weight of SPL). The experiment was designed with 3 additives and 4 treatments (one control without additive and three additive levels)

In Paper III and IV, cassava root meal was used as an additive at 60 g kg^{-1} of the wilted weight of the leaves and with 5 g kg^{-1} salt added. The mixture was kept in sealed air-tight plastic bags with a capacity of 30 kg.

Balance trial (Paper II)

Four castrated male pigs (Large White x Mong Cai) were used to study the total tract digestibility of dietary components and nitrogen (N) utilisation of diets with inclusion of ensiled SPL. The pigs were from the same litter and had an average initial body weight of 31.8 ± 0.7 kg. The experiment was conducted as a 4 x 4 Latin square, with a total length of 40 days, comprising four periods of 5 days adaptation to the diets and 5 days of quantitative collection of faeces and urine. The diets were based on cassava root meal with inclusion of protein from either fish meal (C) or SPL ensiled with either CRM (D1), SPM (D2) or Mo (D3).

Ileal and total tract digestibility (Paper III)

Four thirteen-weeks old crossbred (Large White x Mong Cai) castrated male pigs from the same litter, with an average body weight of 25.4 ± 0.6 kg were used. The pigs were vaccinated against pasteurellosis and hog cholera, and surgically fitted with a post-valve T-caecum cannula (Van Leeuwen et al., 1991) and kept for two weeks to recover from surgery before the experimental diets were introduced. Four cassava root meal basal diets were formulated to have 120 g crude protein kg^{-1} DM. The casein diet (CAS) was formulated with inclusion of casein and three other diets with inclusion of fresh sweet potato leaves (FSP), dried sweet potato leaves (DSP) and ensiled sweet potato leaves (ESP), which were the sole protein sources. Daily feed intake was calculated at 4 kg/100kg of body weight for each individual animal at the start of each experimental period and the refusals were recorded. The pigs were fed twice per day at 06.00 h and 18.00 h with the daily allowance equally divided between the two meals. The experiment was designed as a 4 x 4 Latin square and lasted 48 days, comprising four periods. Each experimental period consisted of 12 days of which 5 days were for adaptation to each diet, 4 days for collection of faeces, followed by 1 day for collection of ileal digesta, 1 day rest and a 2nd day for collection of ileal digesta.

Feeding trials (Paper IV)

In Experiment 1, twelve female and twelve castrated male crossbred pigs (Large White x Mong Cai) with an initial body weight of 15.9 ± 1.2 kg and of similar age were used. The pigs were allocated randomly by sex into 4 groups, with each group consisting of 6 pigs (3 males and 3 females). They were kept individually in pens at the experimental farm and fed the different experimental diets three times per day. Four experimental diets

were formulated in which the protein source was from fish meal (FM), groundnut cake (GC), ensiled sweet potato leaves (SP) and ensiled sweet potato leaves with lysine (SPL). All the diets were isonitrogenous (14% CP for 15 to 50 kg, and 12% CP for 50 to 90 kg live weight) and had the same calculated content of metabolisable energy (ME). The ME content was adjusted by adding soybean oil. The synthetic lysine was thoroughly mixed with the diet (0.45 % and 0.36 % of DM for the two periods from 15-50 kg and from 50-90 kg, respectively). The feed allowance was at 4 kg/100 kg of body weight, divided equally each day into three meals (07.00h, 14.00h and 21.00h). In Experiment 2, sixteen crossbred pigs (Large White x Mong Cai) with an initial body weight of 18.4 ± 1.0 kg were allocated to 4 farms, with 4 pigs in each. At each farm, two pigs were kept in one pen, and one pair fed the experimental diet (SPL) and the other the fish meal diet (FM). The pigs were weighed monthly during the 3 months of the experiment.

Chemical analyses (Paper I, II, III and IV)

Samples for chemical analyses were dried at 60^{o}C for 24 hours and ground to pass a 1mm sieve. Dry matter (DM) was determined by drying at 105^{o}C for 24 hours to a constant weight. The content of crude protein (CP) was measured by the Kjeldahl method as N x 6.25 using Cu as a catalyst (AOAC, 1990). Amino acids (AA) were analysed according to Spackman et al. (1958) on an ion-exchange column using HPLC. Neutral detergent fibre (NDF) was determined according to Robertson and Van Soest (1981) and acid detergent fibre (ADF) according to Goering and Van Soest (1970). Chromium was determined by atomic absorption spectrometry after ashing according to Fenton and Fenton (1979).

Statistical analyses

The data were subjected to analysis of variance (ANOVA) by using the General Linear Model (GLM) procedure of Minitab (1998). When the F test was significant ($P<0.05$) Tukey's test for paired comparisons was used to compare means.

Summary of results

Biomass yield and chemical composition of sweet potato

The results from Paper I showed that there were significant differences ($P<0.001$) in leaf, stem, and tuber yields and leaf to stem ratio between sweet potato varieties. Leaf DM yield ha^{-1} of the local variety, T2(20), AB95002, 69-1, KL7, and KB1 was significantly greater than that of the other varieties. The stem DM production ha^{-1} showed the same pattern as that of the leaves. The leaf to stem proportion differed between varieties and varied between 42 and 53 % ($P<0.001$). The local variety, TQ1, K51 and KB1 had significantly greater tuber yields, producing more than 3.0 tonnes of tuber DM ha^{-1} in 120 days.

Harvesting interval of vines affected leaf, stem and tuber DM yield and leaf to stem proportion. Treatment H120 resulted in a significantly lower leaf yield than other treatments, while treatment H20 resulted in the highest leaf DM yield in both experiments ($P<0.001$). Tuber DM yield was significantly influenced ($P<0.001$) by harvesting interval, with treatment H15 giving the lowest, and treatment H120 the highest tuber DM yield. Harvesting proportion of vines affected leaf ($P<0.05$), stem ($P<0.01$) and tuber ($P<0.01$) yields. Leaf and stem DM production was highest at C50 and smallest at C100. Tuber production decreased with increasing harvesting proportion of vines.

The CP content of sweet potato leaves ranged from 25.5 to 29.8% in DM. The CP content of the stem fraction was only 11.5 to 13.7 % in DM. The ADF and NDF contents of the leaves varied between 13.6 and 19.9 %, and 23.5 and 29.8 % of DM, respectively.

Ensiling sweet potato leaves

In Paper II, the level of CRM, SPM and Mo added affected the silage composition and the changes with time of ensiling of pH, DM, CP and NH_3-N. Generally, the pH decreased rapidly during the first week and then remained stable until 8 weeks at all levels of additive addition. Increasing the level of additive decreased pH. The CP content was lower at day 56 than at the start in all treatments ($P<0.05$). Increasing the inclusion of CRM, SPM and Mo decreased the CP content ($P<0.05$) of the silage. With the addition of Mo the NH_3-N content was lower ($P<0.05$) than in the control treatment.

Balance trial

The daily intake of CF was higher in ensiled SPL diets than in the control diet without SPL ($P<0.05$). There were no differences in daily intakes of DM, CP and OM between the diets. Total tract apparent digestibility (TTAD) of DM, OM, CP and CF were not different between the SPL diets ensiled with different additives ($P>0.05$), while the TTAD of DM, OM and CP were higher in the control diet than in ensiled SPL diets. The N retention for the control diet with fish meal was higher than for ensiled SPL diets ($P<0.05$). There were no differences in N retention between the ensiled SPL diets.

Ileal and total tract digestibility of sweet potato leaves

There were no significant differences ($P>0.05$) in the ileal digestibility of OM between diets (Paper III). However, differences were found for CP and NDF ileal digestibility between the CAS and FSP, DSP and ESP diets. The CAS diet was high for CP and low for NDF digestibility ($P<0.01$). The total tract digestibility of OM, CP and CF were different between diet CAS and diets FSP, DSP, ESP ($P<0.01$). The ileal and total tract digestibility of OM, CP, CF, NDF and ADF was not different between sweet potato diets ($P>0.05$). There were no differences in the ileal digestibility values of most of the amino acids between the sweet potato leaf diets ($P>0.05$). The CP digestibility coefficients of sweet potato leaves were 0.74 in ileal and from 0.75 (dry sweet potato leaves) to 0.77 (ensiled sweet potato leaves) in total tract.

Performance of growing pigs fed sweet potato leaves

There were significant differences ($P<0.05$) in feed intake, final weight, daily live weight gain and feed conversion ratio (FCR) among the experimental diets (Paper IV). However, the growth performance, feed intake and feed conversion ratio were not different between FM and SPL diets. Daily live weight gains of pigs on the FM, GC, SP and SPL diets were 542, 464, 482 and 536 g, respectively ($P<0.05$). Feed conversion ratio was highest (3.8 kg feed/kg gain) for SP and lowest (3.5 kg feed/kg gain) for FM ($P<0.05$).

General discussion

Biomass yield

The study of the effect of harvesting interval and defoliation on biomass yield of sweet potato (Paper I) showed that generally, defoliation affected tuber production more than either leaf or stem production. This can be explained by the strong correlation that exists between leaf area/leaf growth and tuber yield (e.g. Mannan et al., 1992; Kakaty et al., 1992). In the present study, removal of up to 50% of the vines at an interval of 30 days was found to result in a reduction of tuber yield of about 20%, while greater proportions of vines removed reduced tuber yield by almost 50%. Similar results have been reported by others (e.g. Dahyniya, 1981; Nguyen and Bautista, 1999). Leaf yield, on the other hand, was little affected by either harvesting interval or harvesting proportion of vines. Thus, the need for tuber production will be the main factor to consider when deciding on how to harvest sweet potato vines for forage purposes.

Our results are in agreement with Gomes and Carr (2001), who reported on the biomass yield of sweet potato at different cutting intervals in Mozambique (14-day, 28-day and no cutting of vines). The results showed that the biomass yield of leaves increased when the frequency of vine harvesting increased, with the 14-day interval giving a higher leaf production than the 28-day and no cutting treatments. The root yield was highest without vine cutting.

Similar findings have been reported for cassava (Dahniya et al., 1981; Lockard et al., 1985; Simwambana et al., 1994; Hong et al., 2003). The cassava fodder yield was affected by the subsequent cutting, and the highest biomass yield of leaves was found with cutting intervals of 60 and 45 days. Studies on the effects of harvesting interval on the biomass yield of other forages such as *Chamaecytisus palmensis* (Assefa, 1998), *Gliricidia sepium* (Garcia et al., 2001), and *Pueraria lobata* (kudzu) (Terrill et al., 2003) also reported that the biomass yield of these forages depends on the harvesting interval.

Chemical composition

Chemical composition of leaves, stems and tubers differs in sweet potato (Göhl, 1981; Woolfe, 1992; National Institute of Animal Husbandry, 1995). In the present study (Paper I), leaves had superior contents of DM and CP compared with stems, these results being in agreement with Woolfe (1992) and Ishida et al. (2000). In sweet potato vines the CP content in DM ranges from 16 % to 29 % (Farrell et al., 2000; Hartemink, et al., 2000; Dung, 2001), which is comparable to our findings of 19 % to 22 %. Similar

results were reported by Zhang and Xie (1990) who analysed 31 sweet potato varieties from China, Japan and other countries.

Studies on plants that are used for forage production purposes in Vietnam showed that sweet potato leaves have a potential as a source of protein for livestock (Phuc, 2000; Dung, 2001), with a relatively high content of CP and low content of fibrous constituents. We also found the content of fibrous components in leaves to be rather low, which is in agreement with other authors (Woolfe, 1992; Ishida et al., 2000). The marked difference in fibre content between leaves and stems is well known and has also been demonstrated for temperate legumes (e.g. Demarquilly and Jarrige, 1974). The fibre content of sweet potato leaves is lower than that in other tropical forages, such as water spinach (*Ipomoea batatas*), leucaena leaves (*Leucaena leucocephala*), groundnut foliage (*Arachis foliage*) and cassava leaves (*Manihot esculenta*) (Phuc, 2000).

The sum of AA in leaves as a percentage of CP was high, but the level of lysine was low compared with the ideal protein for pigs (ARC, 1981). The AA profile is comparable to other tropical forages, such as cassava leaves (*Manihot esculenta*), water spinach (*Ipomoea aquatica*) and duckweed (*Lemna minor*), but it is poorer than in soybean meal (Phuc et al., 2001). Sweet potato vines and lucerne meal (*Medicago sativa*) have the same CP level in DM, which is lower than that in sweet potato leaves and cassava leaves (Table 8).

Table 8. Chemical composition (g/kg DM) of sweet potato vines, sweet potato leaves, cassava leaves and lucerne meal

	Sweet potato vines[a]	Sweet potato leaves[b]	Cassava leaves[c]	Lucerne meal[a]
ADF	364	185	221	352
NDF	498	275	321	397
Lignin	54	(-)	(-)	69
Ash	178	(-)	87	100
CP	191	268	264	182
OM	822	(-)	913	900

[a] Farell et al. 2000
[b] Paper I
[c] Phuc and Lindberg 2001
(-) not determined

Ensiling

Several methods for preserving sweet potato are being applied, including sun-drying, which is often used in the tropical countries. Sweet potato roots and vines can be preserved under sun-drying to give sweet potato root meal or sweet potato leaf meal and these feeds are commonly used in some rural areas. However, sweet potato leaves are normally more abundantly available in the wet season when sun-drying is unsuitable. Ensiling forages to be preserved as feed for animals is recommended (McDonald et al., 1991), and the chemical composition of some ensiled foliages is shown in Table 9.

Table 9. Nutritive values of some ensiled foliages

	Sweet potato leaves(*)	Cassava leaves (**)	Red clover (***)
pH	3.95	4.0	4.0
DM (g/kg)	342	462	203
CP (g/kg)	231	200	173
CF (g/kg)	125	-	217
N-NH_3 (gNH_3/kgtotal N)	36	40	51

(*): Paper II, 60 g of cassava root meal/kg pre-wilted sweet potato leaves
(**): Ly (2002) cassava leaves harvested at 8 weeks
(***): Lättemäe et al. (1996), 40 liters of sugar beet molasses/ton of fresh matter

In all experiments (Paper II, Paper III and Paper IV) the pre-wilted sweet potato leaves were successfully preserved as silage. However, without additives (Paper II) the fermentation processes were slow, resulting in a high pH during the first and second weeks of ensiling compared to the other treatments. This can be explained by the low level of water soluble carbohydrate (WSC) in sweet potato leaves. Woolfe (1992) reported that sweet potato leaves contain about 78 g sugars and 34 g starch kg^{-1} DM. Also, McDonald et al. (1991) indicated that the WSC contents of tropical forage species are generally considered to be lower than those of temperate species. It should also be noted that the sweet potato leaves were pre-wilted, which increased the DM content from 156 to 293 g kg^{-1} and should have contributed to creating conditions for an efficient fermentation process.

Cassava root meal, sweet potato root meal and sugar cane molasses can provide a source of potentially available energy for growth of the lactic acid bacteria (McDonald et al., 1991). The pH at day 7, when additives were used, was markedly decreased in the present study (Paper II) and supports the contention that they provided easily available substrates that supported the fermentation. This finding is in accordance with a number of earlier studies where carbohydrate-rich materials have been used as additives in an attempt to improve both the fermentation process and the

nutritional value of silage (McDonald et al., 1991; Sibanda et al., 1997; Jaurena and Pichard, 2001). Increasing levels of additive to the pre-wilted SPL increased the DM content, in accordance with earlier findings where molasses and cereal grains have been used as silage additives (Abou-Raya et al., 1973; Moseley and Ramanathan, 1989; Lättemäe et al., 1996; Sibanda et al., 1997).

The CP content was highest in the untreated silage, and decreased with increasing inclusion of the additives (Paper II). This should be expected as CRM, SPM and Mo only contain 20 to 30 g CP kg^{-1} DM. The CP content of the silage did not change during the first 2-3 weeks of ensiling, but there were significant decreases at day 56 in all treatments. If good fermentation conditions are provided, only minor effects on the silage protein content should be expected (McDonald et al., 1991). An ideal silage fermentation process is dominated by lactic acid bacteria, which have limited capacity for amino acid synthesis and a low ability to ferment amino acids (McDonald et al., 1991). The low content of NH_3-N in this experiment (Paper II), less than 60 g kg^{-1} N in all treatments, was comparable to grass silage produced in England and Wales (Haigh, 1996a; Haigh, 1996b).

Ileal and total tract digestibility

As indicated above, sweet potato leaves have high CP and amino acid contents and should be considered as a potential feedstuff for monogastrics, especially for growing pigs.

In growing pigs, the total tract digestibility coefficients of dietary fibre are normally between 0.40 and 0.60, but range from around zero to 0.90 depending on fibre source. The variation in digestibility can be explained by differences in the chemical structure and level of water soluble/insoluble fibre contents (Noblet and Le Goff, 2001). A part of the dietary fibre can be digested before the end of the ileum (Graham et al., 1986; Jørgensen et al., 1996; Anderson and Lindberg, 1997; Phuc and Lindberg, 2000) while the main part is fermented by micro-organisms in the hindgut, with a subsequent production of volatile fatty acids.

In the present study (Paper III), total tract digestibility coefficients of sweet potato leaves were 0.55 – 0.57 for NDF and 0.32 – 0.36 for ADF, which are in agreement with reported values for a range of feedstuffs (Table 10) Noblet and Perez (1993). Similar results were also reported by Phuc and Lindberg (2000) for cassava leaves, groundnut foliage and leucaena leaves. There were no differences in digestibility coefficients of CF, NDF, ADF between fresh, sun-dried and ensiled sweet potato leaves. Total tract digestibility coefficients of ensiled sweet potato leaves are comparable to other ensiled feeds (Table 10 and Table 11).

Table 10. Total tract digestibility coefficients of crude fibre in growing pigs

	Ensiled sweet potato leaves [a]	Ensiled cassava leaves [b]	Other [c]
Crude fibre	0.61	0.39	0.38
NDF	0.55	0.30	0.54
ADF	0.32	0.24	0.37

[a] : Paper III, for sun-dried sweet potato leaves
[b] : Phuc and Lindberg (2000), for sun-dried cassava leaves
[c] : Noblet and Perez (1993), mean of 114 dietary samples

Table 11. Digestibility coefficients of dietary components in growing pigs

	Fresh SPL [a]	Dried SPL [a]	Ensiled SPL [a]	Dried cassava leaves [b]	Ensiled cassava leaves [b]	Groundnut foliage meal [b]	Leucaena leaf meal [b]
Ileal							
OM	0.83	0.84	0.82	0.41	0.42	0.55	0.44
CP	0.74	0.74	0.74	0.37	0.37	0.43	0.39
NDF	0.23	0.24	0.25	0.26	0.23	0.49	0.24
Total tract							
OM	0.88	0.85	0.88	0.54	0.59	0.64	0.53
CP	0.76	0.75	0.77	0.45	0.46	0.47	0.42
CF	0.61	0.61	0.62	0.50	0.59	0.51	0.54
NDF	0.57	0.55	0.56	0.23	0.31	0.58	0.27
ADF	0.36	0.32	0.36	0.20	0.21	0.46	0.18

[a]: Paper III
[b]: Phuc and Lindberg, 2000

The inclusion of sweet potato leaves in the diet reduced the ileal and total tract digestibility of CP and OM (Paper III). This can be explained by the increase in fibre content of the diets and was in agreement with studies on inclusion of tropical foliages (Phuc and Lindberg, 2000), as well as temperate forages (Lindberg and Andersson, 1998) and other fibre-rich feedstuffs (Wenk, 2001) in diets for growing pigs. A likely explanation for the reduced digestibility of protein and amino acids in fibre-rich diets is that amino acids are bound to or encapsulated in the cell wall and that fibre will stimulate secretion of endogenous nitrogen. Also, a high content of insoluble fibre in the digesta increases the peristaltic action of the gut and, therefore, reduces the transit time, which may lead to an impaired digestibility. Jørgensen et al. (1996) reported that a high fibre diet (268 versus 59 g crude fibre (CF) kg^{-1} DM) resulted in a five to six fold increase in the flow of digesta through the terminal ileum of growing pigs. In the present study (Paper III), the coefficient of apparent ileal digestibility (CIAD) of OM was unaffected by an increase in dietary fibre content (84 versus 145-157 g NDF kg^{-1} DM), while there was a reduction of the CIAD

(-0.12 units) and coefficient of apparent total tract digestibility (CTTAD) (-0.11 units) of CP.

There were no differences in CIAD and CTTAD of dietary components between sweet potato leaf diets (Paper III), suggesting that the preservation methods used resulted in products that were nutritionally similar, and not different from the fresh material. This was in agreement with Phuc and Lindberg (2000), reporting similar nutritive values of sun-dried and ensiled cassava leaves in growing pigs. Compared with other tropical forage sources studied in growing pigs, such as cassava leaves, groundnut foliage and leucaena leaves (Phuc and Lindberg, 2000), and leucaena meal (Ly et al., 1998), sweet potato leaves showed a higher CIAD of CP than the forages mentioned above. Also, there were no differences in CIAD of AA between fresh, dried and ensiled sweet potato leaves, with the possible exception of lysine. The reduction of ileal AA digestibility in sweet potato leaf diets (Paper III) could be due to an increase in the ileal flow of AA related to the properties of the feedstuff. The changes in the ileal flow of AA could be the result of the increase of fibre in the diet (Boisen and Moughan, 1996; Jondreville et al, 2000). Similar results were found in growing pigs when including temperate forage meals in barley-based diets (Reverter and Lindberg, 1998; Reverter et al., 1999).

Nutritive value

Domínguez and Ly (1997) included sweet potato vines in diets for growing pigs and reported that due to the high fibre content, the vines had a low CP digestibility. The chemical composition of CP and CF of different parts of sweet potato vines differs considerably. The CP content of the leaves ranges from 26.5 % to 32.5 %, according to variety (Woolfe, 1992; Ishida et al., 2000; Paper I), while the CP content of the stems is only 10.4 % to 14.1 % (Woolfe, 1992; Paper I). Similarly, the CF content of the sweet potato leaves and stems was reported to be 11.1 % and 20.7 %, respectively (Woolfe, 1992). Therefore, inclusion of both leaf and stem parts in diets for pigs would result in poor growth performance. In our experiments (Paper II, III, IV), sweet potato leaves were separated from stems before ensiling with cassava root meal. The nutritive value of the sweet potato was thus improved, with the leaf silage containing 22.7 % CP and 12.5 % CF.

The amino acid composition of sweet potato leaves in the present study (Paper I and III) is comparable to the results of other authors (Woolfe, 1992; Ishida et al., 2000) and is similar to cassava leaves, groundnut foliage and lucerne meal (Phuc and Lindberg, 2001) (Table 12).

The growth performance experiments (Paper IV) showed that when the CP of the diet is provided from sweet potato leaves plus lysine, the daily gain

and feed conversion were similar to those of pigs given diets with fish meal, and better than for pigs fed sweet potato leaves only or groundnut cake. This can be explained by the fact that although sweet potato leaves are relatively rich in protein, lysine is the first limiting amino acid (Woolfe, 1992), and supplementation of lysine would have increased the utilization of CP and amino acids.

Table 12. Amino acid contents (g/16 g N) in sweet potato leaves, cassava leaves, groundnut foliage and leucaena leaves

	Sweet potato leaves [a]	Cassava leaves [b]	Groundnut foliage [b]	Leuceana leaves [b]	Sweet potato leaves [c]
Essential AA					
Arginine	5.2	5.9	5.2	5.7	(-)
Histidine	2.1	1.9	1.9	2.0	3.4
Isoleucine	3.7	4.4	3.7	4.1	4.8
Leucine	8.5	8.0	7.0	7.9	8.1
Lysine	4.3	5.6	4.1	5.8	3.8
Methionine	1.2	1.5	0.9	1.2	2.9
Phenylalanine	7.0	5.7	5.4	5.6	7.8
Threonine	5.1	4.0	4.0	4.0	4.5
Tyrosine	4.1	4.0	3.8	4.3	(-)
Valine	5.7	5.3	5.1	5.3	9.1
Non-essential AA					
Alanine	5.4	5.7	4.9	5.5	(-)
Aspartic	10.7	9.7	9.9	9.0	(-)
Glutamic	10.9	11.2	9.9	10.0	(-)
Glycine	3.8	4.1	4.2	4.3	(-)
Proline	3.9	3.6	4.7	4.0	(-)
Serine	4.1	4.7	4.3	4.4	(-)
Total AA	88.7	85.3	79.0	83.3	

[a]: Paper III
[b]: Phuc and Lindberg 2001
[c]: Woolfe 1992

Several experiments that evaluated forages for growing pigs indicated that forages could partly replace cereals without reducing the performance. Ensiled sugar beet-pulp was included at 100 g/kg DM diet without affecting the growth performance of fattening pigs, while increasing the level to 200 g/kg DM diet reduced feed intake but made no difference to carcass quality (Scipioni and Martelli, 2001). Lindberg and Anderson (1998) reported that including 10 % and 20 % of forage meals of white clover, lucerne, red clover and perennial rye grass in barley based diets for growing pigs resulted in reduced digestibility of OM, but increased the digestibility of CF. These authors concluded that forage meals could be used to a limited extent as a protein source for pigs. Our results are in agreement with Phuc et al. (2000), who concluded that cassava leaves can be used as a protein supplement in growing pig diets and that ensiled or

dried cassava leaves are potentially useful feed resources in developing countries.

Conclusions

- Sweet potato varieties differ with respect to root and/or forage production potential and the growth performance of the plant depends on season. Of the different sweet potato varieties examined, the local variety appeared to be the best adapted to the climatic conditions in central Vietnam and this variety had the best potential for both tuber and forage production.

- In order to optimise the biomass yield of sweet potato for forage production, it should be harvested at intervals of about 3 weeks, and the leaf defoliation should be 50% of the total above-ground green part.

- The chemical composition of sweet potato forage varies between leaves, stems and vines. When using sweet potato forage for monogastric animals, especially for pigs, the leaves should be separated from the vines to reduce the fibre content of the diet.

- Sweet potato leaves can either be fed fresh, dried or ensiled, as the preservation method had no affect on the nutritive value. However, in the humid tropical countries, where sweet potato leaves can not be conserved by sun-drying in the harvesting season, the ensiling method is recommended.

- The nutritional properties of the sweet potato leaves indicate that they have the potential to improve dietary protein and amino acid supply in low fibre diets for pigs.

- Sweet potato leaves can be used as a protein-rich feedstuff for pigs. However, supplementation of sweet potato leaf diets with lysine will improve the nutritive value for growing pigs.

Implications

Sweet potato is a traditional food crop that grows well in different soil types and climatic conditions in the tropics. In order to supply feed for animals in smallholder farming systems in Vietnam, sweet potato can be

planted for forage production. Sweet potato forage is a potential feed source for pigs and ruminants. The leaves should be removed from the stems and are used for pigs, and the stems for cattle or buffaloes.

Due to the unbalanced amino acid content in sweet potato leaves, diets for pigs that include sweet potato leaves should be supplemented with sufficient lysine to improve the nutrient value.

Future research

Studies on the growth of sweet potato foliage should be continued to identify the potential forage production at different times of the year, particularly in the feed-shortage seasons.

On-farm applied research should be carried out to develop appropriate technologies for the preservation and utilisation of sweet potato leaves as animal feed in collaboration with farmers.

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