ROOT CROPS IN THE DIETS OF GROWING PIGS

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P BOYD (NOTTINGHAM UNIVERSITY)
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Abstract

General Introduction

Concluding Discussion

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ROOT CROPS IN THE DIETS OF GROWING PIGS

by

Philip Anthony Boyd

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Nottingham University
School of Agriculture
Sutton Bonington
Loughborough
Leics LE12 5RD

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ABSTRACT

Experiments were conducted to evaluate fodder beet and sweet potato as components of the diets of growing pigs. Metabolism trials 1 A and 1 B were designed primarily to study the dietary energy values of fresh and dried fodder beet and sweet potato. Drying the root crops had no effect on the digestibility or metabolisability of the gross energy of either fodder beet or sweet potato. However, improvements in the digestibility of dietary acid detergent fibre were recorded following processing for both root crops. Digestible energy (DE) and metabolisable energy (ME) values of 13.72 MJ /kg DM DE and 13.70 MJ /kg DM ME were determined for fodder beet and 13.80 MJ /kg DM DE and 11.39 MJ /kg DM ME determined for sweet potato.

Growth trial 1 examined the performance of growing pigs fed nutritionally balanced diets containing varying proportions of fresh and dried fodder beet up to 413 g/kg of the total diet (on a dry matter basis). Feed DM intakes were maintained across treatments, indicating that under the feeding regime used, the bulky nature of the root crop did not limit nutrient intakes. Significant deteriorations in growth performance were recorded as fodder beet supplied increasing proportions of the total diet. Daily liveweight gains decreased from 0.786 to 0.728 kg /day and feed conversion ratios increased from 1.987 to 2.102 as the level of dietary fodder beet increased from 151.0 t0 413.0 g/kg DM. Increasing dietary fodder beet rates were also associated with reduced fat deposition and deteriorations in killing out proportion.

Direct substitution of fresh fodder' beet for increasing amounts of a balanced compound diet in growth trial 2 impaired the growth performance of growing pigs, the more so as the fodder beet supplied increasing proportions of the total diet. Voluntary feed intakes of the fodder beet fed pigs were slightly reduced relative to

the compound fed controls, although these reductions may have been associated with nutrient imbalance. Carcass quality in terms of lean and fat deposition significantly deteriorated as fodder beet supplied increasing proportions of the total diet. Increasing proportions of dietary fodder beet were again associated with reductions in killing out proportion, as in growth trial 1, with the reductions largly attributable to significantly increased stomach and large intestinal weights. Although substituting fodder beet for the compound diet reduced costs /kg liveweight gain, economic performance, measured as returns / pig place / year, deteriorated as the root crop supplied increasing proportions of the total diet.

Growth trials 3 and 4, conducted in the Solomon Islands, investigated the protein and amino acid supplementation of diets containing a high proportion of fresh sweet potato. Provision of a meal supplement containing 350 g crude protein /kg DM in combination with the sweet potato resulted in the best growth performance with daily liveweight gains and feed conversion ratios markedly improved relative to controls receiving no protein supplementation ; 0.560 cf 0.033 kg/day and 2.570 cf 7.703 respectively. Intakes of essential amino acids were still sub-optimal when the supplement containing 350 g crude protein /kg DM was fed in combination with sweet potato and therefore growth trial 4 was designed to investigate responses to supplementation of this diet with synthetic amino acids. Methionine supplementation significantly improved growth performance and carcass quality relative to unsupplemented controls and pigs fed diets containing supplementary lysine. Improved growth performance with methionine supplementation was also associated with reduced costs /kg liveweight gain (1.687 cf 2.043 SI $ /kg) and increased returns / pig place / year (564.0 cf 402.0 SI $) relative to unsupplemented controls.

Chapter 1

GENERAL INTRODUCTION

1.1. GENERAL INTRODUCTION

In recent years there has been a growing trend throughout the world towards feeding compound diets based primarily upon cereals to growing pigs and breeding stock. As humans are in direct competition for these crops, their price fluctuates with changing human demand and at times this can render pig keeping a rather marginal activity, particularly in developing countries.

Alternative feeds to cereals are available throughout the world however, and their use in pig diets could be of considerable economic advantage. In this context root crops are a possibility both in temperate and tropical regions and are already utilized to a limited extend in certain production systems. A full appreciation of the value of root crops as components of pig diets is not yet apparent, however, and therefore production efficiency tends to be low when these materials are utilized.

Increased information about the ability of pigs to utilize root crops would improve efficiencies of production where these materials are already fed and enable an assesement to be made of the value of root crops as alternatives to cereal based diets.

This thesis is an account of studies into the utilization of two root crops, fodder beet and sweet potato, by growing / finishing pigs. These root crops were selected for evaluation because they were considered representative of the two main types of root crops ; sugar-rich and starch-rich respectively.

Experiments were designed to characterise the nutrient composition of the root crops and to study both the metabolism of the nutrients supplied by them and consequences of their use in terms of subsequent animal growth and carcass quality. An assesement of economic performance related to the presence of fodder beet and sweet potato in growing pig diets was also conducted. The experiments reported are concerned solely with the utilization of sweet potato and fodder beet roots, although other parts of the plants (vines and leaves) may also be of value in pig nutrition.

Experimental evaluation of fodder beet was conducted entirely at the University of Nottingham, whereas research into the utilization of sweet potato was undertaken both at the University of Nottingham and under tropical conditions in the Solomon Islands.

A review of the literature was conducted before the experimental work with the following objectives :-

- to assess the current importance of root crops in animal nutrition.
- to investigate the composition of fodder beet and sweet potato and determine how this might affect their use in pig diets.
- to compare results from previous experiments conducted to determine the value of root crops, particularly fodder beet and sweet potato, in animal feeding.

1.2 PRODUCTION AND UTILIZATION OF ROOT CROPS

1.2.1. Classification of root crops

Agriculturalists generally classify all crops where the edible organ (root, stem or tuber) is subterranean as 'root crops'. The true root crops, which include carrots, parsnips, swedes, turnips, mangolds, sugar beet and fodder beet are characterised by having high sugar contents in the organic matter, (principally sucrose, with small quantities of glucose and fructose), whereas the main tuber crops; potatoes, yams, taro, cassava and sweet potato, have either starch or fructan, instead of sucrose, as the main storage carbohydrate.

Roots crops are also loosely classified according to the climates in which they are grown. Fodder beet and most of the sugar-rich roots are regarded as temperate crops, whereas sweet potato and the tuberous starch crops (with the exception of the potato) are regarded as tropical crops Sweet potato, *Ipomea batatas (Lam) L.*, is a herbaceous perennial vine belonging to the family Convolvulaceae. Several hundred cultivars are known, with great variation found in both form and growth habit. The primary product from sweet potato is the starchy tuber, which is formed by a thickening of parts of the adventitious roots close to the subterranean part of the stem, or at the nodes which rest on the soil.

Fodder beet, *Beta vulgaris crassa*, belongs to the family Chenopodiaceae and, although a biennial, is usually harvested after the first year. A number of varieties of fodder beet exist which are intermediate in character between mangolds and sugar beet. All are grown for their swollen roots, which have high sugar contents and are used primarily as a stock feed.

1.2.2. **Agronomy**

Different root crops have specific environmental requirements although in some cases these may be similar between species. Temperate root crops generally require cool, moist conditions, light / medium free draining soils with a pH between 6.0 - 7.0 and a moderate rainfall of approximately 50 to 75 cm during the growing season (Knott, 1955).

The tropical root crops require higher temperatures (20 - 25 degrees C) for optimum growth and are unable to tolerate frost. Optimum soil pH and quality are more variable between these species, with cassava able to tolerate a wide range of conditions, due primarily to the penetrative ability of its feeder roots. An annual rainfall of 100 - 150 cm is considered ideal for cassava, sweet potatoes and yams, whereas taro requires 250 cm per year for highest yields (Kay, 1973).

The tropical root crops and potato are usually propagated vegetatively, using vine cuttings or whole tubers harvested from the previous year, whereas the sugar-rich temperate crops are grown from seeds, which are generally produced by specialist plant breeders.

Ideal conditions for the cultivation of fodder beet and sweet potato are summarized in table 1.1.

1.2.3. Origins of root crops

European agriculture and the early civilisations of the Meditteranean and Far East developed using grain crops as the staple carbohydrate food (Coursey and Haynes, 1970). Vegetatively propagated root and tuber crops were virtually unknown in the traditional food patterns of Western Europe until the potato was introduced from the Americas in the sixteenth century. At approximately the same time fodder beet was developed from the wild sea beet for use as an animal feed in Central Europe (Gill and Vear, 1980) and from this sugar beet was developed some 200 years later, as alternatives to cane sugar were sought.

In contrast, certain areas in the humid lowland tropics have evolved highly organised societies where all food production systems have been based on vegetatively propagated root crops. Examples of such societies are found in parts of West Africa, Melanesia and Polynesia (Coursey and Haynes, 1970).

The origins of the tropical root crops have been discussed in detail by Coursey and Haynes (1970). Cassava and sweet potato both originated in the Americas but were spread to the Pacific thousands of years ago and further afield more recently. Yams originated in West Africa, South East Asia and the Carribean and, although varieties are now spread throughout most tropical regions, these areas still account for the majority of world production.

Table 1.1 Optimum Environmental Conditions for Sweet Potato and Fodder Beet Cultivation

	Fodder Beet	Sweet Potato
Temperature	15 - 23 °C	24 °C or higher
Annual Rainfall	50 - 75 cm	75 - 100 cm
Soil	Light/medium	Light sandy
	free draining	free draining
	6.5 - 7.0	5.6 - 6.6

Sources of Information :-

(1973)

MAFF (1985)

1.2.4. Current distribution

Root crops are now widely distributed throughout the world wherever conditions for their cultivation are suitable. As well as environmental effects, distribution patterns are also influenced, to a certain degree, by cultural and economic factors.

The starchy root crops, with the exception of the potato, are located in either tropical (cassava, yam, sweet potato, taro), humid subtropical (sweet potato, taro), subtropical (sweet potato), or warm temperate (sweet potato) regions of the world (Kay, 1973).

The potato and sugar-rich root crops are located in cooler temperate regions or at higher altitudes in tropical areas.

1.2.5. Production of root crops

The most recent Food and Agriculture Organization figures estimate total world root crop production at 866 million tonnes (FAO, 1988). Almost every country in the world is reported to grow one or more root crop and a total of 55 million hectares were under cultivation to these crops in 1988.

The tonnage of cereals (wheat, rice, barley, maize, rye, oats, sorghum and millet) grown in 1988 was double the total root crop production (1743 cf 866 million tonnes) and the ratio of cereals to root crops has increased by five per cent over the last ten years. Food and Agriculture Organization figures show that total world root crop production has risen by 30 per cent over the last three decades, however, due primarily to a 63 per cent increase in sugar beet and an 82 per cent increase in cassava production. Sugar beet production has risen primarily as a result of improved husbandary techniques, which have allowed large scale production and enabled developed countries, particularly within the European Economic

Community (EEC), to strive for self sufficiency in refined sugar. Cassava production increased mainly as a result of greater human demand, but was also partly due to an increased use of this material in animal diets. Increased production of cassava specifically for use as an animal feed occurred primarily in Thailand and to a lesser extent in Indonesia, both countries exporting large quantities of dried cassava pellets to the European market during the 1960's, 1970's and early 1980's (Coursey, 1983).

Developing countries (including the centrally planned economies of Asia) accounted for 65 per cent of the total world production of starchy root crops (cassava, yams, taro, potato and sweet potato) with only potato grown in significant amounts outside of these areas.

The developed economies of Europe, North America, and the USSR produced 87 per cent of the world's sugar rich root crops (principally sugar beet) and total production of this crop in 1988 was 295 million tonnes from 8.5 million hectares.

Horton, Lynam and Knipscheer (1983) listed China (potatoes and sweet potatoes), USSR (potatoes and sugar beet), Poland (potatoes), Nigeria (yams and cassava) and Brazil (cassava), as the world's five most important root crop producers.

Sugar beet was grown in the greatest quantity throughout the world in 1988 followed by potato, cassava, sweet potato, yams, carrots and taro (FAO, 1988).

The Food and Agriculture Organization does not provide figures for the annual world production of turnips, swedes, parsnips or fodder beet. However, a total of 2.9 million hectares of these crops were estimated to be under cultivation in Europe and the USSR, which are regarded as the main producing areas (Lee, 1988).

The production of fodder beet and other root crops for animal consumption has declined substantially in the last 20 years, both within the EEC and in countries belonging to the Council for Mutual Economic Assistance (Lee, 1988), with an expanding forage maize crop and increased reliance on cereals responsible for this reduction.

Table 1.2 summarizes world root crop production figures for 1988.

1.2.6. Utilization of root crops

Root crops are grown throughout the world primarily as a source of human food (Coursey, 1983; Horton *et al.*, 1983) but are also used to a lesser extent for a variety of other purposes.

1.2.6.1. *Human food*

Root crops are considered to be of greater significance in human nutrition in developing countries than in the more developed nations. Coursey and Haynes (1970) suggested that root crops could be regarded as the staple food for approximately 400 million people within the tropics, whereas cereal grains and animal products were considered to be the most important food in the developed countries.

The importance of root crops in human nutrition also varies significantly within the classification of developing countries. Lucas (1968) calculated the proportion of the diet supplied by root crops in various countries throughout the world and suggested that this type of crop was of most importance in Africa, followed by South America and then the Far East. Other reports suggest that root crops also contribute substantially to the total diet in parts of Melanesia and Polynesia (Lambert, 1970; Bradbury, Baines, Hammer, Anders and Millar, 1984; Lin, Huang and Huang, 1988).

Root crops are usually regarded as being almost pure carbohydrate, providing energy-yielding ingredients but little else to the diet. Although this is their primary role, some root crops are better sources of protein than is

Table 1.2 Number of Countries Producing Root Crops and Root Crop Production (tonnes) in 1988.

	Sugar Beet	Potato	Sweet Potato	Cassava	Yam
No. countries producing root crops					
World	42	130	106	95	43
Market economies					
Developed	20	28	6	0	2
Developing	13	91	96	92	41
Centrally planned economies					
European	8	7	0	0	0
Asian	1	4	4	3	0
Root crop production (10^6 tonnes)					
World	295	270	130	138	24
Market economies					
Developed	136	71	2	0	0
Developing	22	45	15	132	24
Centrally planned economies					
European	124	122	0	0	0
Asian	13	32	113	6	0

Source of Information :-
FAO (1988)

often appreciated. Payne (1969) showed that yams, potatoes and wheat had similar levels of utilizable proteins for humans, providing calculations were on a dry matter (DM) basis and sweet potato cultivars with crude protein contents as high as 118.0 g/kg (DM basis) have been reported (Purcell, Swaisgood and Pope, 1972). Crude protein contents of cassava, most cultivars of sweet potato and the sugar rich temperate root crops are very low, however, and other sources of protein are usually required for satisfactory growth and good health in human populations. Further details on the nutrient composition of fodder beet and sweet potato are given in section 1.3.

The production of root crops for human consumption in developed countries is generally conducted on a large scale by relatively few producers. These root crops are marketed mostly by specialist companies and sold either fresh or in a variety of processed forms. In contrast, root crops in developing countries were essentially products of subsistance agriculture until two or three decades ago, with a large proportion of the crop being consumed by the farmers and extended family. Recent trends towards urbanization, however, have resulted in an increased proportion of the tropical roots now being transported and sold in urban markets. This has resulted in some difficulties as root crops are not easily transported in hot conditions and deteriorate rapidly after harvest. Processing of root crops to remove a high proportion of their water content prior to transport would alleviate many technical problems (Coursey, 1983) but most producers and consumers in developing countries have so far been reluctant to accept such methods.

1.2.6.2. *Animal food*

Root crops are used throughout the world as feed for classes of farm livestock. However, the importance of these crops in animal nutrition varies considerably, both between animal species and in different areas of the world.

In the developed countries of Northern Europe, the sugar rich root crops are grown primarily as a ruminant feed (Lee, 1988), with fodder beet, mangolds, turnips and swedes all used in the production of both meat and milk. Fodder beet and sugar beet are also used as pig feeds in Eastern Europe and the USSR (Symons, 1972) but in most other European countries the use of these materials in non-ruminant nutrition is minimal.

Thirty percent of the world potato crop is used for animal feed (Horton *et al.*, 1983), but in most developed countries only surplus or damaged potatoes not required for human consumption are fed, and only in Eastern Europe, particularly Poland and the USSR, are large quantities of potatoes still grown specifically for animal feed. Potatoes are used for feeding all classes of livestock but are considered particularly suitable for the nutrition of non-ruminants (Whittemore, 1977).

Climatic conditions in most parts of the United States are more suited to growing maize and sorghum than root crops and therefore, apart from a small amount of sweet potatoes in southern areas, these materials are not grown specifically for use as animal feed.

By-products from the sugar manufacturing industries, beet tops, beet pulp and beet molasses, are used extensively in both Europe and North America and although these materials are used primarily as ruminant feeds, recent work has shown that they may also be of value in non-ruminant diets (Close, Longland and Low, 1989; Bulman, Longland, Low, Keal and Harland, 1989).

Although root crops are widely used as animal feeds in developed countries, they tend to be of secondary importance to other crops, especially in non-ruminant nutrition. In certain tropical and semi-tropical areas, however, where the production of grain crops is limited, root crops are becoming increasingly important in expanding livestock industries.

Small scale livestock production based on root crops surplus to the family or village requirement has been practiced for years in many tropical and semi- tropical countries (Kimber, 1972; Pond and Maner, 1974; Coursey, 1983; Nwokolo, 1990) but estimates of total production from such systems are very difficult to establish.

Most non-ruminant livestock production enterprises, conducted on a large scale within the tropics, have previously relied on sorghum and maize as the main dietary energy sources. However, substantial increases in animal production generally and poultry production in particular in these areas, during the last 20 years, has resulted in increased interest in root crops as an alternative energy source in animal diets (Gomez, Santos and Valdivieso, 1985). This is particularly evident in South America (especially Brazil), where up to 40 per cent of the total cassava production has been used in animal nutrition (Phillips, 1974) and in South East Asia (China, Taiwan and South Korea) where large quantities of sweet potato are grown specifically for animal feed (Devendra and Fuller, 1979; Horton *et al.*, 1983).

Sweet potatoes and cassava are the only tropical root crops used to any extent in animal nutrition, as yams and taro require considerably more cultivation and are regarded as too valuable a human food. These crops are fed to both ruminants and non-ruminant animals in the tropics but, as cattle and sheep production is usually based on extensive areas of pasture land, the majority of sweet potato and cassava grown for feed is used in non-ruminant diets. Sweet potato and cassava are usually dried and ground into meal for inclusion in poultry diets, whereas pigs are generally fed fresh, dried or ensiled roots (Devendra and Fuller, 1979; Gomez *et al.*, 1985; Nwokolo, 1990).

As well as increased usage in the producer countries, large quantities of cassava have been dried and exported from the tropics, for use as animal feed, during the last

20 years (Coursey, 1983). This increased trade in dried cassava products was primarily between Thailand and certain member states of the EEC and was due to factors in the Common Agricultural Policy of the EEC, which allowed substitutes for highly priced grains to be imported into the community at low rates of duty. The introduction of import quotas has restricted the amounts of cassava now entering the EEC and unless other markets are exploited, the production of dried cassava pellets for animal feed can be expected to decrease.

1.2.6.3. *Industrial uses*

Tropical and temperate root crops are also used to a very limited extent in the production of non-food industrial products.

Approximately two per cent of the world potato crop, one per cent of the world cassava crop and less than one per cent of the world sweet potato crop is used in the manufacture of industrial starch, which is used primarily in the textile, paper and adhesive industries (Phillips, 1974; Horton *et al.*, 1983; Coursey, 1983).

Cassava, sweet potato, potato, fodder beet and sugar beet have also been used to produce ethanol (Kay, 1973; Coursey, 1983; Nwinyi, 1987; Geng, Hills, Johnson and Sah, 1989) but this process is of very minor importance and would not be expected to increase unless oil prices rose dramatically in relation to the price of these feed crops.

1.3. NUTRIENT CONTENT AND DIGESTIBILITY OF SWEET POTATO AND FODDER BEET

1.3.1. Proximate analysis

The nutritive value of a food is determined largely by its chemical composition which, at its most basic level, can be represented by proximate analysis.

Tables 1.3 and 1.4 compare published data on the proximate compositions of fodder beet and sweet potato. The data shown indicates that the composition of both root crops is very variable, which could pose problems if these materials are to be included in carefully formulated diets. For example, if a value of 88g crude protein/kg was used in formulating a diet containing 500 g/kg sweet potato, but the sweet potato used only contained 20g crude protein /kg, there would be a shortfall of 34g crude protein /kg, enough potentially to impair the performance of growing pigs.

The nutrient composition of root and tuber crops varies both between cultivars, as a result of genetic factors, and within cultivars, as a result of environmental factors. Splittstoesser (1977) reported that, frequently, environmental influences exceed cultivar differences and therefore variations within a cultivar are often greater than between cultivars.

The variability in composition of fodder beet and sweet potato should be borne in mind when including these materials in balanced diets and, for increased accuracy of diet formulation, determined values for proximate constituents, rather than average values, should always be used.

1.3.2. Dry matter content

Dry matter contents of sweet potato vary from 190 - 500 g/kg (Kay, 1973) and are higher than most cultivars of

Table 1.3 The Proximate Composition of Fodder Beet (g/kg DM except where stated)

Dry Matter (g/kg fresh)	Crude Protein	Ether Extract	Crude Fibre	Ash	Nitrogen Free Extract	Reference
159.0	76.0	4.0	59.0	90.0	775.0	Clarke et al. (1987)
214.0	67.0	2.0	50.0	82.0	799.0	Clarke et al. (1987)
203.0	55.0	3.0	50.0	52.0	840.0	Clarke et al. (1987)
193.0	73.0	8.0	56.0	43.0	820.0	Just et al. (1983)
197.0	84.0	1.0	59.0	82.0	774.0	Castle (1955)
	64.0	3.0	38.0	43.0	777.0	Castle et al. (1952)
182.8	62.9	2.6	56.0	81.3	797.0	MAFF (1990)

not stated

Table 1.4 The Proximate Composition of Sweet Potato (g/kg DM except where stated).

Dry Matter (g/kg fresh)	Crude Protein	Ether Extract	Crude Fibre	Ash	Nitrogen Free Extract	Reference
254.0	51.2	3.9	31.5	19.7	893.7	Lim Han Kuo (1967)
300.0	109.0	3.0	30.0	39.0	819.0	Devendra and Gohl (1970)
394.0	88.0	6.0	24.0	21.0	861.0	Devendra and Gohl (1970)
306.0	55.6	13.1	42.5	35.9	856.2	Cullison (1979)
288.0	20.8	13.9	20.8	34.7	930.6	Eusebio (1980)
320.0	39.0	16.0	38.0	34.0	873.0	McDonald et al. (1981)
332.0	45.2	9.0	48.2	30.1	867.5	Murthy and Swaminathan (1954)
400.0	58.0	5.4	12.0	39.0	885.6	Oyenuga and Fetuga (1975)

fodder beet, which are reported to range from 140 - 220 g/kg (McDonald, Edwards and Greenhalgh, 1981).

Total dry matter content as well as dry matter composition of fodder beet and sweet potato is influenced by cultivar, environment and stage of maturity at harvest (Kay, 1973; Aerts, Cottyn, De Brabander, Boucque and Buysse, 1979)

The high water content of fodder beet and sweet potato, results in low nutrient concentrations in these materials. As the nutrient concentration of a feed decreases an animal has to consume more of that feed to obtain the same level of nutrients. For example, if sweet potato is used to replace maize at 500 g/kg of a growing pig's diet, a reduction in dry matter content of the potato used, from 500 g/kg to 300 g/kg, would result in the pig having to eat 44 per cent more fresh material, to achieve the same dry matter intake.

Increased feed intakes by pigs, in response to decreasing nutrient concentrations, are only possible up to a certain point, (Cole, Duckworth, Holmes and Cuthbertson, 1967; Cole, Hardy and Lewis, 1972; Franck, Aherne and Jensen, 1983; Cole and Chadd, 1989) which is determined partly by physical limitations of the gastrointestinal tract (Houpt, 1984; Henry, 1985; Rayner and Gregory, 1989). Limited gastrointestinal capacity may restrict the amount of fodder beet or sweet potato which is consumed by growing pigs and therefore the nutritional value of these materials could be partly influenced by their dry matter content.

Experimental work reported in the literature suggests that the inclusion of fodder beet and sweet potato in growing pig diets does result in reductions in total daily dry matter intakes (Fagan, 1954; Devendra, 1963; Springhall, 1969; Rerat and Henry, 1964; Malynicz, 1971; Pond and Maner, 1974). However, in all these experiments, other factors apart from the bulk of the root crops could also have affected feed intakes and therefore it is apparent that further work is required to determine the effect of fodder beet and sweet potato bulk on daily feed intakes.

1.3.3. Nitrogen free extract

The nitrogen free extract (NFE) component of plant materials is very complex and can contain varying proportions of starch, fructans, pectins, cellulose, hemicellulose, lignins, organic acids, tannins, pigments and water soluble vitamins (McDonald *et al.*, 1981). Tables 1.3 and 1.4 show that, on a dry matter basis, the NFE is the principle component of sweet potato and fodder beet roots. This fraction is not determined analytically, but calculated by subtracting the sum of the amounts of moisture, ash, ether extract, crude protein and crude fibre (g/kg fresh weight) in these materials, away from 1000.

The NFE component of sweet potatoes is composed primarily of starch (Kay, 1973) and in fodder beet it consists primarily of water soluble carbohydrates (Clarke, Givens and Brunnen, 1987). Small quantities of water soluble carbohydrates are also present in sweet potato roots (10 - 20 g/kg, fresh weight basis) and levels increase slightly during storage and substantially (up to 130 g/kg of the fresh weight) when the potato is cooked (Hammet and Barrentine, 1961).

1.3.3.1. *Digestibility of nitrogen free extract*

Digestibility values quoted in the literature for the NFE component of sweet potato and fodder beet are a measure of the digestibility of the principle constituent in the NFE of each root crop, i.e. starch or water soluble carbohydrates.

1.3.3.1.1. *Sweet potato*

Growing pigs digest the NFE component of raw sweet potato roots with a high degree of efficiency, with coefficients of digestibility ranging from 0.94 to 0.98, reported in the literature (Oyenuga and Fetuga, 1975; Just, Jorgensen, Fernandez and Bech-Andersen, 1983).

Starches are classified into either A or B types, depending on their crystalline ultra-structure, as determined by X-ray diffractometry. Sweet potato, cassava and cereal grain starches, are all classified as A types, whereas starch granules from potato and most species of yam are classified as B types (Gallant, Bewa, Buy, Bouchet, Szylit and Sealy, 1982). The A type starches are reported to be more efficiently digested in animals than the B type starches. Work conducted by Baker, Nazr, Morrice and Bruce (1950) using laboratory rats, showed that maize, rice and cassava starch (A types) were digested in the small intestine, whereas the starch from the potato and yam (B types), was digested predominantly in the large intestine. These studies did not investigate the site of digestion of sweet potato starch which, although a type A starch, is reported to be digested slightly less efficiently than cereals and cassava starch, although more efficiently than potato and yam starch (Dreher, Dreher and Berry, 1984). Although sweet potato starch is digested slightly less efficiently than cereal starches, Gallant *et al.* (1982) and Szylit, Durand, Borgida, Atinkpahoun, Prieto and Delort-lavel (1978) reported that all type A starches were highly susceptible to alpha-amylase and therefore it is likely that sweet potato starch is also digested predominantly in the small intestine. Results from an earlier experiment (Morimota and Yoshida, 1954) also suggested that sweet potato starch was digested in the small intestine, as growing rats fed *ad libitum* starch from potato had enlarged caeca, which indicated high levels of microbial digestion, whereas those fed cereal or sweet potato starch did not

1.3.3.1.2. *Fodder beet*

The water soluble carbohydrates (WSC) in the NFE of fodder beet roots consist primarily of sucrose (970-980g/kg) and very small quantities of glucose and fructose (Quinn, Wright and Woods, 1980). Sucrose is rapidly digested by the enzyme sucrase in the small intestine of pigs and the glucose and fructose formed are actively transported across the intestinal epithelium into the portal blood stream. However, the extent of sucrose digestion in the small intestine is thought to be related to the absolute amounts of the disaccharide present in the digesta. Cunningham, Friend and Nicholson (1963) reported ileal digestibility coefficients of between 0.72 and 0.95, according to the amount of sucrose ingested. The lower digestibility at higher sucrose intakes, was thought to occur because the enzymic potential of the animal was not sufficiently adapted to the high quantities ingested. Any sucrose escaping enzymic digestion in the small intestine would be rapidly fermented by microbes in the caecum and large intestine, however, and therefore faecal digestibility coefficients for the WSC/NFE component of fodder beet roots would be expected to be very high. Just *et al.* (1983) and Janas, Mikolajczak and Podkowka (1984) reported digestibility coefficients of between 0.96-0.97 for the NFE component of fodder beet roots; however no values for the actual digestibility of WSC were reported.

1.3.4 Fibre

The fibre content of fodder beet and sweet potato, that is, the mixture of substances derived primarily from the plant cell walls, is generally low, but as with other proximate constituents, variations between cultivars does occur, (table 1.3). Although the crude fibre content of most cultivars of fodder beet varies between 40.0 - 60.0 g/kg DM, values as high as 126.0 g/kg DM have been reported (Robles and Aguilera, 1974). Jarrige and Fauconneau (1973) and Clarke *et al.* (1987) showed that the fibre content in fodder beet roots was negatively correlated to the total dry matter content, but no similar relationship was reported in the literature for sweet potato.

Fodder beet and sweet potato fibre consists mainly of cellulose and hemi-cellulose (primary cell walls), which are readily broken down and fermented by the intestinal micro-organisms present in the gut of pigs (Chesson, 1990). Growing pigs are therefore able to digest the fibre in these root crops relatively efficiently and digestibility coefficients of 0.74 - 0.83 and 0.79 - 0.81 have been calculated for fodder beet and sweet potato fibre respectively (Oyenuga and Fetuga, 1975; Just *et al.*, 1983; Janas *et al.*, 1984).

Although the crude fibre content of fodder beet is generally low, it is higher than in wheat or maize and therefore if fodder beet is used to replace these cereals at high levels in growing pig diets, total dietary fibre levels will be increased. Small increases in dietary crude fibre levels have been shown to decrease the digestibilities of dry matter and protein (Cranwell, 1968; Kuan, Stanogias and Dunkin, 1983; Stanogias and Pearce, 1985) and, although these decreases are not as pronounced with highly digestible fibre (Nordfelt, 1954), substituting fodder beet for cereals, in pig diets, may cause a reduction in the value of other dietary ingredients. Most sweet potato cultivars have similar crude fibre levels to cereal grains and therefore fibre per se is unlikely to exert an influence if this root crop is substituted for cereals in growing pig diets.

1.3.5. Protein content

1.3.5.1. *Crude protein*

The crude protein content of most cultivars of sweet potato varies between 45 - 70 g/kg on a dry matter basis (Kay, 1973), although values as high as 118.0 g/kg have been reported (Purcell *et al.*, 1972). Similar levels of crude protein (45 - 90 g/kg DM) are reported for most cultivars of fodder beet (Castle, Foot and Rowland, 1952; Clarke *et al.*, 1987) although exceptional values (125 g/kg dry matter) have also been recorded (Castle *et al.*, 1952).

As growing pigs (15 - 50 kg liveweight) require a minimum of 230g ideal protein per day for maximum levels of growth performance (ARC, 1981); feeding solely sweet potato or fodder beet to these animals would result in severe protein deficiencies. For example, a growing pig would have to consume over 3 kg of sweet potato dry matter / day (if the root crop contained 70g crude protein / kg DM) to obtain the recommended protein intake. Obviously for a pig weighing less than 50 kg this amount is considerably above its maximum feed intake capacity (Cole *et al.*, 1967; ARC, 1981; Chadd, 1990). Sweet potato and fodder beet protein is also deficient in certain essential amino acids (section 1.3.5.3.) and therefore even if feed intake capacity was not limiting, protein supply from these materials would still be sub-optimal. As severe deficiencies (or excesses) of any essential amino acid result in reductions in feed intake (Robinson, Holmes and Bayley, 1974; Robinson, 1975; Montgomery, Flux and Carr, 1978; Sparkes, 1982) feeding solely sweet potato or fodder beet to growing pigs would have an adverse effect on feed consumption levels.

Fodder beet and sweet potato would therefore be used primarily as a source of energy-yielding ingredients in pig diets, and would require additional protein supplementation if maximum levels of growth performance were to be achieved.

1.3.5.2. *Digestibility of crude protein*

The literature suggests that fodder beet and sweet potato protein is only poorly digested by the growing pig. The low coefficients of digestibility reported for these materials may partly be a reflection of their low protein contents, as metabolic faecal nitrogen losses will assume a larger proportion of the total protein intake. There is little agreement between workers on the digestibilities of fodder beet or sweet potato protein, with digestibility coefficients of 0.36 (Schneider, 1947), 0.30 (Danilenko and Bogdanov, 1962), 0.57 (Rerat and Henry, 1965a) and 0.58 (Just *et al.*, 1983) reported for fodder beet protein and 0.28 (Pond and Maner, 1974), 0.57 (Rose and White, 1980) and 0.66 (Just *et al.*, 1983) reported for sweet potato protein. Variation in the protein content of the root crops may account for these differences, as metabolic faecal nitrogen would then assume variable proportions of the total protein intake.

Low digestibility of sweet potato protein has also been attributed to the presence of trypsin inhibitors in the tubers (Yeh, Wung, Lin and Kuo, 1978). Bradbury, Hammer, Nguyen, Anders and Millar (1985) reported considerable variation in the trypsin inhibitor content of a number of sweet potato cultivars (0.26 - 43.6 trypsin inhibitor units / g fresh sweet potato) and therefore the differences in digestibility of sweet potato protein reported in the literature, could possibly also be attributed to different levels of this anti-nutritional factor.

The antinutritional effects of trypsin inhibitors are discussed further in section 1.3.10.2.

1.3.5.3. *Amino acid composition*

Although fodder beet and sweet potato are used primarily as a source of energy-yielding ingredients in pig nutrition and only contribute small amounts of protein to the diet, a consideration of their amino acid composition is included in this literature review for the sake of completeness.

Many sweet potato cultivars are used extensively in human nutrition, as well as for animal feed, and therefore substantially more information is available on their composition than is reported for fodder beet.

Table 1.5 presents published values for the essential and some non-essential amino acids contained in fodder beet and sweet potato.

The value of a particular protein source is dependent partly on its digestibility and also on the balance of its constituent amino acids. A useful basis for the evaluation of the balance of amino acids in fodder beet and sweet potato is that of the 'ideal protein' (Cole, 1979) whereby the levels of essential amino acids are expressed as a proportion of the lysine content. An ideally balanced protein for growing pigs (Ideal Protein), has been proposed (ARC, 1981) and contains essential amino acids in the proportions shown in table 1.6. Comparing the balance of amino acids in fodder beet or sweet potato, with the ideal protein, will highlight deficiencies or imbalances in these materials, which may need to be borne in mind and corrected during diet formulation. Table 1.6 indicates that whilst the amino acid balance of fish meal closely resembles that specified by the ideal protein, that of fodder beet or sweet potato does not. From the data presented, it would appear that lysine is likely to be the first limiting amino acid in both fodder beet and sweet potato, as all other amino acids are present in greater proportions to lysine than the ideal protein recommendations. However, a number of other reports suggest that methionine / cystine or tryptophan are in the greatest deficit in sweet potato protein (Purcell *et al.*, 1972; Splittstoesser and Martin, 1975; Cheng, 1978; Bradbury *et al.*, 1984) which indicates variations in the amino acid composition of this material.

Reports also indicate variation in the amino acid content of fodder beet roots, between cultivars (Jarrige and Fauconneau, 1973) and as a result of different environmental conditions (Filip'ev, Abrashina and Krishtopa, 1982). General predictions about imbalances, deficiencies or the biological value of fodder beet or sweet potato protein are therefore not really valid.

In most situations fodder beet and sweet potato would be fed to pigs in combination with other protein sources, such as fish or soya bean meal, and the specific amino acid imbalances or deficiencies in their protein would be of minor significance. However, in certain areas of the world, for example Melanesia, very little additional protein would be provided with the sweet potato, and therefore the amino acid profile of the root crop could exert an influence on pig performance.

1.3.6. Oil content

Tables 1.3 and 1.4 indicate that the oil contents of sweet potato and fodder beet are very low and vary slightly between different cultivars. Energy is stored principally as carbohydrate in root crops and therefore small variations in a minor nutrient are not likely to have any significant effect on pig nutrition. The small quantities of ether extract from root crops also appear to be poorly digested by the pig, with estimated digestibility coefficients of 0.01 for sweet potato and -0.81 for fodder beet roots quoted by Just *et al.* (1983). These values reflect the low levels of ether extract in both root crops as endogenous losses will assume a large proportion of total intake and are likely to be associated with large error values.

Table 1.5 : Amino Acid Composition of Fodder Beet and Sweet Potato (g/16g Nitrogen).

	Fodder Beet			Sweet Potato			
	1	2	3	4	5	6	7
Lysine	4.3	3.3	2.9	6.8	5.3	4.6	6.5
Methionine	1.4	1.0	1.0	2.6	2.8	1.5	2.5
Cystine	1.4	1.1	0.7	0.4	0.6	0.0	1.6
Threonine	2.1	2.7	2.4	5.5	5.9	4.8	4.6
Leucine	3.6	3.4	3.5	7.8	8.3	7.7	8.7
Isoleucine	3.6	2.2	2.2	5.3	10.1	4.8	5.3
Tyrosine	5.4	2.1	2.4	5.2	5.6	1.2	3.6
Phenylalanine		2.0	1.4	6.7	7.0	4.5	6.0
Tryptophan	0.7	0.6	0.8	1.1	1.2	-	-
Histidine	1.4	1.8	1.4	-	-	-	-
Valine	3.6	3.2	2.9	6.8	7.8	6.9	7.9
Arginine	2.9	3.3	1.8	-	-	-	-
Alanine	-	2.7	3.5	5.2	5.6	-	6.1
Glycine	-	2.4	2.2	4.3	5.1	-	2.6
Proline	-	-	2.1	5.4	4.3	-	4.3
Serine	-	3.4	2.9	5.1	5.8	-	5.5
Aspartic acid	-	7.5	7.4	14.3	16.5	-	13.0
Glutamic acid	-	19.6	21.7	8.6	9.5	-	11.7

not determined

1. I.N.R.A. (1984)
2. Buglem, B.O. Personal communication
3. Just *et al.* (1983)
4. Purcell *et al.* (1972) - Jewel cultivar
5. Purcell *et al.* (1972) - Julian cultivar
6. Splittstoesser, Martin and Rhodes (1973)
7. Nagase (1957)

Table 1.6 : Evaluation of The Relative Proportions of Essential Amino Acids in Fodder Beet and Sweet Potato.

	Fodder Beet			Sweet Potato				Ideal Protein	Fish Meal
	1	2	3	4	5	6	7	8	9
Lysine	100	100	100	100	100	100	100	100	100
Methionine and Cystine	67	63	57	44	64	33	63	50	50
Threonine	50	83	81	81	111	104	71	60	54
Leucine	83	104	119	115	157	167	134	100	95
Iso-leucine	83	68	76	78	191	104	82	55	60
Phenylalanine and Tyrosine	117	127	128	175	238	98	148	96	96
Tryptophan	17	19	28	16	23	-	-	15	15
Histidine	33	54	48	-	-	-	-	32	33
Valine	83	98	100	100	147	150	122	70	69
Arginine	67	100	62	-	-	-	-	-	74

not determined

1-7. see table 1.5.
8. ARC (1981)
9. Just *et al.* (1983

1.3.7. Energy

Proximate analysis has shown that fodder beet and sweet potato roots have high levels of carbohydrate but very low levels of crude protein. The principle use of these materials, as feeds for pigs, is therefore as a source of dietary energy-yielding ingredients and their value will depend on the availability of that energy and the efficiency with which it can be utilized.

1.3.7.1. *Gross energy*

Gross energy (GE), the total energy yielding potential of a feed, is of little practical use to the nutritionist in diet formulation, unless the proportion of GE available to the animal for maintenance and production is known. Table 1.7 summarizes published data on the dietary energy values of fodder beet and sweet potato.

1.3.7.2. *Digestible energy*

The digestible energy (DE) contents of fodder beet and sweet potato compare reasonably with cereals when expressed on a dry matter basis, however, high moisture levels in the fresh root crops result in markedly lower DE values, when these are expressed on an as fed basis (table 1.7). Therefore if fodder beet or sweet potato are used instead of cereals in growing pig diets, substantially more food (on a fresh weight basis) will have to be consumed, if the animal is to obtain the same digestible energy intakes. Although it is widely accepted that pigs adjust their feed intakes in response to changing dietary energy concentrations (Cole, *et al.*, 1967; Sparkes, 1982; Taverner, Campbell and Biden, 1984; Savidge, Cole and Lewis, 1984; Campbell and Taverner, 1986) increased feed consumption in response to decreasing dietary energy

Table 1.7 : Dietary Energy Values of Fodder Beet and Sweet Potato Roots.

	Fodder Beet		Sweet Potato			Barley	Wheat	Maize
	1	2	3	4	5	6	7	8
Gross Energy (MJ/kg DM)	16.6		17.4	16.8	16.7	18.5	18.6	18.8
Digestible Energy (MJ/kg DM)	14.4	13.2	16.0	15.9	15.9	14.8	16.0	14.8
Digestible Energy (MJ/kg fresh)	2.8	2.9		6.4	5.5	12.8	13.7	12.8
Metabolisable Energy (MJ/kg DM)	14.2		15.9	15.0				

- not stated

1. Just *et al.* (1983)
2. Halley (1982)
3. Just *et al.* (1983)
4. Oyenuga and Fetuga (1975)
5. Rose and White (1980)

6 - 8. Just *et al.* (1983)

concentrations is only possible up to a certain point (Cole *et al.*, 1972; Franck *et al.*, 1983). If root crops are to be efficiently utilized, a greater understanding of the effects of decreasing dietary energy concentrations when these materials are included in growing pig diets is therefore required.

The apparent DE content of sweet potato is higher than that of fodder beet due to slightly higher levels of oil in the sweet potato tubers and a more efficient digestion of the gross energy by the growing pig. Just *et al.* (1983) quoted gross energy digestibilities of 0.87 and 0.92 for fodder beet and sweet potato respectively, with the difference in efficiency of digestion probably attributable to the higher levels of crude fibre in the fodder beet roots.

1.3.7.3. *Metabolisable energy*

The metabolisable energy (ME) values of fodder beet and sweet potato for growing pigs have only occasionally been presented. Just *et al.* (1983) quoted values of 14.22 MJ/kg DM for fodder beet and 15.88 MJ/kg DM for sweet potato roots. Oyenuga and Fetuga (1975) reported similar ME values for raw and cooked sweet potato tubers, 15.04 and 15.06 MJ/kg DM, respectively.

The ME / DE ratios of fodder beet and sweet potato were very high in both of these reports (0.94 - 0.99), which indicates that very little of the root crop protein was used for energy-yielding purposes. Poor quality protein, with unbalanced amino acids, would be expected to decrease the ME value (and consequently the ME / DE ratio) and therefore in these experiments, either the amino acids in the root crops were well balanced or, more likely, their levels were too low to exert an influence, which could be detected accurately.

1.3.8. Vitamins

Reports on the vitamin contents of sweet potato and fodder beet are very limited and therefore the results from only three studies are presented in table 1.8. The data indicates that the vitamins in sweet potato, with the exception of riboflavin, are present in sufficient quantities to meet the dietary requirements of growing pigs, as specified by ARC (1981). Carotene, a precursor of vitamin A, is also found in sweet potato tubers, particularly in deep coloured varieties, where levels as high as 7 mg/100 g have been reported (Chadha and Dakshinamurthy, 1965). Thiamine, riboflavin, pantothenic acid, nicotinic acid and pyridoxine are only present at very low levels in fodder beet, and therefore additional vitamin supplementation would be required, to avoid deficiencies and poor health, if this root crop was included in growing pig diets.

1.3.9. Minerals

Information on the mineral composition of fodder beet and sweet potato is similarly limiting, but that available is presented in table 1.9. Compared with the published requirements (ARC, 1981), fodder beet and sweet potato appear to be deficient in the macro-minerals, calcium and phosphorus, and several of the trace elements (zinc, iodine, selenium and fluorine). However, providing diets containing fodder beet or sweet potato are correctly supplemented with a vitamin / mineral premix, no deficiencies or health problems should arise.

Table 1.8 : Vitamin Content of Fodder Beet and Sweet Potato Roots (mg/kg).

	Fodder Beet	Sweet Potato		
	1	2	3	4
Thiamine	0.14	0.85	0.73	0.90
Nicotinic Acid	1.80	7.70	6.56	6.00
Riboflavin	0.30	0.25	0.41	0.50
Pantothenic Acid	1.20	-	-	9.40
Pyridoxine	0.36	-	-	3.20
Tocopherol	-	-	-	40.00
Ascorbic Acid	-	-	-	220.00
Choline	-	-	-	3.50
Biotin	-	-	-	0.43

not stated

1. Hoff-Jorgensen, Moustgaard and Moller (1952)
2. Bradbury and Singh (1986) - Papua New Guinea variety
3. Bradbury and Singh (1986) - Solomon Islands variety
4. Crosby (1964)

Table 1.9 : Mineral Content of Fodder Beet and Sweet Potato Roots.

		Fodder Beet			Sweet Potato		
		1	2	3	4	5	6
Ca	%	0.16	0.05	0.05	0.02	0.03	-
P	%	0.03	0.03	0.03	0.06	0.05	-
Mg	%	0.02	0.03	0.05	0.01	0.02	0.08
K	%	-	0.28	0.22	0.34	0.37	0.49
Na	%	-	0.03	0.04	-	0.01	0.30
Cl	%	-	-	0.05	-	-	-
Cu	mg/kg	-	1.93	-	-	-	8.90
Mn	mg/kg	-	4.44	14.90	-	-	5.60
Zn	mg/kg	-	4.44	-	-	-	11.80
Fe	mg/kg	-	56.70	-	-	-	60.00

stated

1. Clarke *et al.* (1987
2. Just *et al.* 1983)
3. ARC (1976)
4. Picha (1985)
5. Kay (1973)
6. FAO (1975)

1.3.10. Anti-nutritional factors

1.3.10.1. *Fodder*

The majority of reports in the literature suggest that fodder beet is a safe and palatable feed for growing pigs (Braude and Mitchell, 1949; Dunkin and Cooper, 1949; Dunkin, 1952; Longwill, 1955 ; Rerat and Henry, 1964, 1965 and 1965a) although some workers have observed an increased incidence of scouring when this material was fed (Inglis, 1953; Fagan, 1954; Baxter, 1956).

Oxalic acid has been regarded as a possible toxin in fodder beet roots (Baxter, 1956) with levels of between 3.0 - 6.0 g/kg of the root dry matter reported (Burba and Nitzschke, 1974). Cooper and Johnson (1984) suggested that oxalic acid levels in excess of 100 g/kg of the dry matter would be required to make a plant potentially dangerous and therefore oxalic acid may not have been causing the scouring reported in the literature.

Freshly harvested fodder beet roots can contain high levels of nitrates, which have an irritant action and are known to cause scouring in farm animals (Cooper and Johnson, 1984). Fagan (1954) reported increased scouring when pigs were fed fodder beet which contained high levels of nitrates and observed that the digestive disturbance ceased within two days when fodder beet with very low nitrate levels was substituted. It is therefore possible that nitrates, rather than oxalic acid, were the cause of the scouring observed in other experiments.

1.3.10.2. *Sweet potato*

The main anti-nutritional factors in sweet potato roots are trypsin inhibitors (TI), the presence of which were first reported by Sohonnie and Bhandarker (1954). The TI content of sweet potato varies widely between cultivars, with values of 0.26 - 43.6 TI units /g fresh sweet potato reported (Bradbury *et al.*, 1985).

Trypsin inhibitors reduce the efficiency of protein digestion and can result in amino acid deficiencies if inhibition is very severe. Yeh (1983) reported slower growth and a lower protein efficiency ratio when uncooked sweet potato roots were fed to growing pigs at rates in excess of 250 - 300 g/kg of the total diet, but these were improved by subjecting the sweet potato to 588 - 784 K Pa pressure at 164 - 175 °C, which eliminated trypsin inhibitor activity (TIA) completely. This process, known as 'popping' would probably not be practical on a large scale, or under normal farm conditions, however, other methods of processing have also been shown to reduce TIA in sweet potato. Lin *et al.* (1988) fed either raw or ensiled sweet potato roots to growing rats and found TIA was lowest with longer periods of ensilage, which also resulted in significantly improved growth performance. The protein in sweet potato is partially hydrolysed during ensilage and as the trypsin inhibitor is itself a protein, with a precise three dimensional structure (Lakowski and Sealock, 1971), this alteration will reduce its inhibitory cababilities.

Trypsin inhibitor activity is also reportedly reduced by cooking sweet potatoes, with 90 per cent of original TIA lost at temperatures in excess of 90 °C, in most cultivars (Dickey and Collins, 1984).

Other reports in the literature suggest that raw sweet potato is relatively efficiently utilized by the growing pig (Bishop, 1957; Calder, 1960; Koo and Kim, 1974) and therefore any decision on whether to use processing to reduce the TIA will depend on present levels of pig performance, TI levels in the sweet potato and the costs associated with the processing.

1.4. THE VALUE OF ROOT CROPS IN PIG FEEDING

1.4.1. Feeding trials with growing / finishing pigs

Experiments conducted to evaluate root crops as feeds for pigs differ widely in design, although one of two basic approaches have generally been followed. In nearly all reported experiments the root crops have been fed in combination with a compound diet, either by limiting the amount of compound fed and allowing *ad libitum* access to the root crop, or by substituting the root crop for another ingredient already present in the compound diet.

The technique of restricting the amount of compound fed, whilst allowing *ad libitum* access to the root crop is known as the Lehmann method of feeding and this approach has been most widely used when evaluation of fodder beet and sweet potato has been reported in the literature.

1.4.1.1. *Addition of root crops to basal diets*

The Lehmann method of feeding, named after the German scientist who developed it, involved feeding increasing amounts of basal diet up to a certain liveweight, usually 22 - 27 kg, and then maintaining this level constant, whilst allowing *ad libitum* access to the root crop (or other feed of low nutrient concentration) from then until slaughter.

Tables 1.10 and 1.11 summarize the feed intake and growth performance responses observed in previous studies when fodder beet and sweet potato were fed using modifications of this method. Although statistical analysis was not performed in some of these experiments, the data presented still provide useful information, which can be used to assess the potential of fodder beet and sweet potato, when fed with limited quantities of compound diet.

Table 1.10 : Addition of Fodder Beet to Basal Diets : Effect on Feed Intakes, Liveweight Gains and Feed Conversion Ratios.

	1 *	2*	3	4	5
Weight Range (kg)	29-100	25-100	70-97	58-96	30-90
Level of Meal Fed (kg DM/day)					
Controls	2.01	1.97	2.58	2.45	2.09
Lehmann System	1.14	0.99	1.13	1.10	1.18
Average Fodder Beet Intake (kg DM/day)					
Controls	0.00	0.00	0.00	0.00	0.00
Lehmann System	0.68	1.11	1.58	1.27	0.76
Total Dry Matter Intake (kg DM/day)					
Controls	2.01	1.97	2.58	2.45	2.09
Lehmann System	1.82	2.10	2.70	2.38	1.94
Average Daily Live Wt. Gain (kg/day)					
Controls	0.65	0.63	0.64	0.59a	0.68a
Lehmann System	0.59	0.58	0.63	0.48b	0.53b
FCR (kg feed DM/kg live wt. gain)					
Controls	3.34	3.12	4.05	4.15a	3.12a
Lehmann System	3.51	3.63	4.29	4.94b	3.66b

1. Sim, Browning and Walsh (1953)
2. Braude and Mitchell (1949)
3. Dunkin and Cooper (1949)
4. Dunkin and Cooper (1949)
5. Rerat and Henry (1964)

* statistical analyses not performed

Means with different superscripts are significantly different ($P < 0.05$)

Table 1.11 : Addition of Sweet Potato to Basal Diets : Effects on Feed Intakes, Liveweight Gains and Feed Conversion Ratios.

	6	7	8
Weight range	23-77	14-60	
Level of Meal Fed (kg DM/day)			
Controls	1.68	2.07	2.57
Lehmann System	0.75	0.46	0.98
Average Sweet Potato Intake (kg DM/day)			
Controls	0.00	0.00	0.00
Lehmann System	0.84	1.15	1.26
Total Dry Matter Intake (kg DM/day			
Controls	1.68	2.07	2.57
Lehmann System	1.59	1.61	2.24
Average Daily Live wt Gain (kg/day)			
Controls	0.56a	0.57a	0.60a
Lehmann System	0.49b	0.33b	0.43b
Feed Conversion Ratio (kg feed DM/kg live wt. gain)			
Controls	3.06a	3.66*	4.07*
Lehmann System	3.38b	4.92*	5.12*

6. Devendra (1963
7. Malynicz (1971
8. Pond and Maner 1974)

not stated

* statistical analyses not performed

Means with different superscripts are significantly different ($P < 0.05$)

In experiments 1 - 4 and 6 the control pigs (meal only) were fed according to restricted feeding regimes, but in three of these studies, their daily dry matter intakes were still higher than pigs fed a limited meal allowance together with *ad libitum* root crop. When control pigs were allowed *ad libitum* access to meal in experiments 5, 7 and 8 they consumed approximately 8 - 29 per cent more dry matter / day than pigs fed by the Lehmann method. These results suggest that the root crops may have been limiting feed intakes. However, as the experimental diets were not balanced for nutrients, the reason why this occurred cannot accurately be defined. Although the low nutrient concentration and bulky nature of root crops is often thought to limit their intake by growing pigs, other factors such as nutrient imbalance can also exert an influence. For example, the protein content of the meal supplement used in experiment 4 (Dunkin and Cooper, 1949), was lower than that used by these workers in experiment 3, (100g fishmeal /kg cf 200 g/kg) and this resulted in significantly reduced daily intakes of fodder beet, possibly because of protein or amino acid deficiencies.

In all the experiments reported, daily liveweight gains of pigs fed by the Lehmann method, were lower than for the controls, partly because of reduced feed intakes and partly because of a less efficient feed conversion. The deterioration in feed conversion ratios indicated that the diets containing the root crops were of poorer nutritional value relative to the all-meal diets, either because of lower levels of nutrients or because of a reduced efficiency with which these could be utilized.

Although attempts were made in all experiments to increase the crude protein content of the meal fed in combination with the root crops, (taking into consideration the low levels of protein in these materials), experimental diets were not accurately balanced and therefore differences in feed conversion ratios could possibly be attributable to differences in dietary protein supply.

Protein deficiencies were probably responsible for the significant deterioration in growth performance recorded by Rerat and Henry (1964) when fodder beet was fed by the Lehmann system, as daily crude protein intakes by the fodder beet fed pigs were approximately 35 per cent less than intakes by the compound fed controls (206 cf 319 g/day). Information provided in other reports is rather limited and therefore the extent of any protein deficiencies when root crops were included in the diet is difficult to determine. Reductions in digestible energy supply when root crops were included in the diets may also have adversly affected feed conversion ratios and daily liveweight gains. Again, with the limited information provided in these reports, it is not possible to determine the extent to which energy supply affected growth performance. Further experiments, with root crops included in completely balanced diets, would therefore be useful in assessing the ability of pigs to utilize these types of materials efficiently.

These experiments were conducted primarily to assess, in economic terms, the potential of replacing a proportion of compound diet with fodder beet or sweet potato. This approach is of fundamental importance, as it is possible that poorer growth performances may be acceptable, if price differentials between root crops and compound diets are sufficiently pronounced. Braude and Mitchell (1949), Sim *et al.* (1953) and Calder (1955) reported improved returns over feed costs when fodder beet was fed by the Lehmann method, whereas Devendra (1963) and Malynicz (1971) found returns were very similar when all meal, or a limited amount of meal plus sweet potato *ad libitum* were fed to growing pigs. These economic analyses obviously bear no relevance to present situations but show that root crops could possibly result in greater economic returns, even without improved levels of pig performance.

1.4.1.2. *Substitution of root crops into basal diets*

Although the studies considered above provide valuable information about the practicalities of feeding root crops with low levels of compound feed, it is difficult in any of them to isolate the effect of the root crops, as this is often confounded with other factors. If root crops are substituted for other ingredients in a basal diet, any changes in pig performance can be attributed directly to the inclusion of that root crop (or to the basal diet that has been removed) and therefore its relative value can be more easily assessed. Unfortunately the number of experiments reported in the literature using this method to evaluate fodder beet and sweet potato is very limited, but the data available, for feed intakes and growth performance responses, is presented in table 1.12.

Experiments 1 - 3 were conducted primarily to assess fodder beet and sweet potato as suppliers of dietary energy and therefore additional protein was used to balance the experimental diets, to ensure that this nutrient did not influence the growth responses obtained. Liveweight gains and feed conversion ratios were similar when sweet potato was substituted for cereals in experiments 2 and 3, suggesting that these materials supplied approximately equal amounts of digestible energy, which could be utilized with the same degree of efficiency by the growing pig. Previous reports (Morimoto and Yoshida, 1954; Gallant *et al.*, 1982; Dreher *et al.*, 1984) suggest that sweet potato and cereal grain starch is digested predominantly in the small intestine, with similar levels of efficiency (Just *et al.*, 1983), and therefore the production and utilization of energy resulting from these digestion processes would be expected to be similar. In contrast, Livingstone, Baird, Atkinson and Jones (1978) reported a marked deterioration in carcass weight gain and efficiency of feed conversion, when fodder beet was substituted for barley at 400 g/kg DM of the total diet. These deteriorations were attributed partly to lower coefficients of energy (0.79 cf 0.83) and nitrogen (0.78 cf 0.86) digestibility in the fodder beet compared to all meal diet.

Increasing levels of fibre, or the bulky nature of the fodder beet, may have been responsible for these reductions in efficiency of digestion, by increasing the proportion of the diet digested microbially in the large intestine. Other workers have also reported deterioration in daily liveweight gains and feed conversion ratios when fodder beet or sugar beet have been substituted for cereals in growing pig diets (Harnisch, 1959; Danilenko, Bogdanov and Maksakov, 1963; Glaps, Bury, Szewczyk and Ziolkowski, 1985). However, in all these experiments, protein and amino acid levels were not balanced across treatments, which may also have exerted an influence on the results obtained.

Although substituting root crops into balanced diets provides useful scientific information about the ability of pigs to utilize these materials, this approach would probably not be used under most practical situations, which may explain why only a very limited number of experiments have been conducted in this manner.

1.4.1.3. *Protein supplementation of root crop diets*

As the levels of protein in fodder beet and sweet potato are very low, additional protein supplementation of diets containing these materials is necessary, if acceptable levels of pig performance are to be obtained.

Several experiments have been reported on the use of different protein sources (peanuts, soyabean meal, meat meal) as supplements for sweet potato diets (Springhall, 1969; Watt, 1973; Malynicz, 1971, 1974). However, as only one level of supplementation was used in all these studies, the results provide information only on the relative value of the different protein supplements used and do not enable estimates of optimum levels of protein supplementation to be made.

Table 1.12 : Substitution of Fodder Beet and Sweet Potato into Basal Diets : Effect on Feed Intakes, Liveweight Gains and Feed Conversion Ratios.

	Fresh Fodder Beet	Dried Sweet Potato	
	1 *	2	3
Basis of Substitution	DM	DM	DM
Max. Inclusion Level (g/kg)	444	500	730
Weight Range (kg)	50+	58+	16-90
Feed Intake kg DM/day			
Controls	-	2.85	1.75
Max. Root Crop Incl.	-	2.91	1.61
Average Liveweight Gains (kg/day)			
Controls	0.48$	0.71	0.53
Max. Root Crop Incl.	0.39$	0.67	0.50
Feed Conversion Rate (kg feed DM/kg livewt. gain)			
Controls	3.96	4.02	3.28
Max. Root Crop Incl.	5.03	4.35	3.22

1. Livingstone *et al.* (1978)
2. Koo and Kim (1974)
3. Lee and Yang (1979

$ carcass weight gains
* statistics not given
not stated

Experiments have been conducted to determine optimum levels of protein supplementation, when fodder beet and sweet potato have been included in growing pig diets, (Dunkin and Cooper, 1949; Calder, 1960; Rerat and Henry, 1964 and 1965) but as the proportions of concentrate and root crops in the diets were not always similar, these values differed markedly between studies. For example, Calder (1960) recommended that 1.14 kg/day of a meal supplement containing 210 g crude protein / kg, as opposed to 175 g/kg, be fed in combination with *ad libitum* sweet potato, whereas Rerat and Henry (1964) reported improved pig performance when the level of meal supplement (460g crude protein /kg) fed in combination with a limited amount of barley and *ad libitum* fodder beet, was increased from 0.225 to 0.425 kg/day. Obviously the recommendations made by these workers are very specific and may not be applicable in other situations. Further work, to clarify optimum protein supplementation levels, would therefore be beneficial if maximum levels of pig performance are to be achieved from these materials.

In most practical situations, the cost of supplementary protein will influence its usage when diets containing high levels of root crops are fed, and reduced levels of pig performance may be acceptable, with lower supplementation rates, if returns over feed cost can still be maintained.

1.4.2. Effects of fodder beet and sweet potato on carcass characteristics

The effect of dietary fodder beet and sweet potato on carcass characteristics has not been widely reported, but the available data from performance studies which took some account of carcass parameters is presented in table 1.13.

The results of the studies presented in table 1.13 suggest that inclusion of fodder beet and sweet potato in growing pig diets does not affect carcass fat content to any extent. However, as daily feed intakes and dietary energy and protein levels were not always equal across experimental treatments, the data can only be interpreted with caution. In experiments 1, 2 and 3 (where daily dry matter intakes were equal across treatment groups) similar levels of fat in the pig carcasses indicated that the root crops provided similar levels of digestible energy to the cereals which they had replaced. Digestible energy contents of sweet potato and cereals are similar when expressed on a dry matter basis, and therefore the results of Lee and Yang (1979) and Lee and Lee (1979) were as expected. The results of Korniewicz (1980) are rather more surprising, however, as fodder beet has a significantly lower digestible energy content than cereals and therefore its substitution for cereals in growing pig diets might have been expected to reduce carcass fat content.

A number of reports (Braude and Mitchell, 1949; Mitchell, 1952; Dunkin, 1953; Calder, 1955) suggested that fodder beet improves the firmness and quality of carcass fat by reducing unsaturated fatty acid levels. However, in all cases this was probably a response to decreasing levels of other dietary ingredients (notably maize).

Protein deposition, as measured by *Longissimus dorsi* area, was found to deteriorate significantly, when sweet potato was included in growing pig diets (Lee and Lee, 1979). As protein levels were maintained across experimental treatments in this study the reduction in *Longissimus dorsi* area was attributed to a reduced efficiency of dietary protein utilization, which was thought to have occurred as a result of high levels of trypsin inhibitors present in the sweet potato tubers. Lee and Yang (1979) reported similar protein yields from the carcasses of control pigs and pigs fed diets containing sweet potato and although trypsin inhibitor activity levels were not measured in this experiment, it is possible that they would have been significantly lower than reported by

Table 13 The Effect of Dietary Fodder Beet and Sweet Potato on Carcass Characteristics

	Root Crop in Diet (g/kg DM)	Killing Out Proportion	Carcass Length (cm)	Mean Back Fat (mm)	Loin Eye Area (cm^2)	Reference
Controls	0.0	0.7577	82.13	38.70	-	1
Sweet Potato	730.0	0.7311	81.25	36.50	-	
Controls	0.0	0.6324	82.56	28.30	30.44a	2
Sweet Potato	380.0	0.6404	80.05	29.60	24.72b	
Controls	0.0	0.8150	-	25.20	-	3 *
Fodder Beet	500.0	0.8550	-	24.10	-	
Controls	0.0	0.7240a	-	26.50	-	4
Fodder Beet	360.0	0.7040b	-	24.70	-	
Controls	0.0	0.7700a	-			5
Fodder Beet	450.0	0.7300b	-			

- not stated * statistics not given

1. Lee and Yang (1979
2. Lee and Lee (1979)
3. Korniewicz (1980)
4. Rerat and Henry (1965a
5. Meicklejohn (1952)

Means with different superscripts are significantly different ($P < 0.05$)

measured in the studies of Rerat and Henry (1965a) and Korniewicz (1980) these workers reported that protein deposition was not adversly affected when fodder beet was included in the diet.

Whilst the inclusion of fresh or dried sweet potato in growing pig diets does not appear to affect killing out proportion, reports suggest that fodder beet results in a significant deterioration in this parameter. The reduction in killing out proportion reported by Rerat and Henry (1965a) and Meicklejohn (1952) was attributed to increases in the weight of the gastrointestinal tract. Rerat and Henry (1965a) weighed the different sections of the gastrointestinal tract and found that the total increase in weight was due primarily to increases in stomach and large intestinal weights. Kesting and Bolduan (1986) reported similar results when feeding sugar beet at high rates to growing pigs and suggested that the increase in large intestinal weight was due to an increased proportion of digestion occurring in this organ, when the root crop was fed.

1.4.3. Effects of processing on root crop utilization

Various methods of processing are used to preserve or improve the nutritional value of feed ingredients. However, their use can only be justified if pig performance and economic returns are improved sufficiently, to cover the additional costs involved.

Apart from cleaning and chopping or slicing of fodder beet roots, reports suggest that this material is rarely processed prior to inclusion in growing pig diets. Sweet potato is also extensively fed as the fresh un-processed root, however, a number of experiments have been conducted to investigate the effect of cooking or drying of sweet potato, on its utilization by the growing pig.

1.4.3.1. *Drying*

Reduced daily feed DM intakes have been reported when fresh fodder beet and sweet potato were fed at high dietary inclusion rates (Rerat and Henry, 1964; Devendra, 1963; Malynicz, 1971; Pond and Maner, 1974), whereas dried sugar beet and sweet potato have been included in pig diets at levels up to 500 g/kg and 730 g/kg respectively without any reduction in feed DM intake or growth performance (Lee and Yang, 1979; Korniewicz, 1980). It is possible that the low nutrient concentration and associated bulk of the fresh root crops were causing the observed reductions in feed intake, and therefore drying, to remove a high proportion of the intra-cellular water, may be advantageous, particularly when these materials are fed at high dietary inclusion rates or under *ad libitum* feeding regimes.

Experiments directly comparing the utilization of fresh and dried root crops in nutritionally balanced diets are very limited and therefore further work is required before accurate conclusions about the advantages or disadvantages of feeding each type of material can be drawn.

1.4.3.2. *Cooking*

Fodder beet roots are not cooked prior to feeding, as the conversion of nitrates to nitrites which occurs during this process can lead to the poisoning and death of growing pigs if the nitrites are consumed in sufficiently large quantities (Forsyth, 1968).

In some studies, (Watt, 1973; Pond and Maner, 1974) cooking was reported to improve the nutritional value of sweet potato roots, whereas in others (Calder, 1960; Oyenuga and Fetuga, 1975) no benefical effect was seen. Watt (1973) reported a 40 per cent increase in daily liveweight gain when cooked sweet potato was substituted for raw sweet potato in growing pig diets, whereas Pond and Maner (1974) only recorded a 10 per cent increase. These improved liveweight gains were attributed primarily to increases in daily feed intake, which were thought to have occurred because of an improvement in palatability of the sweet potato following cooking. Although cooking does not improve the digestibility of dry matter and energy in sweet potato roots, (Pond and Maner, 1974; Oyenuga and Fetuga, 1975) it has been shown to reduce trypsin inhibitor activity in some cultivars (Dickey and Collins, 1984), which could result in improved utilization of both sweet potato protein and protein from other dietary sources.

1.4.3.3. *Ensilage*

A limited number of experiments have also been conducted to investigate the effect of ensiling fodder beet and sweet potato on growing pig performance. Mikolajczak (1987) reported improved liveweight gains (0.658 cf 0.625 kg/day) and feed conversion ratios (3.90 cf 4.40) when ensiled as opposed to clamped fodder beet was included in growing pig diets. However, these improvements may have been attributable to the additional rapeseed oilmeal, which was used in the ensiling process. Providing frost damage or over-heating in fodder beet clamps can be avoided, nutrient losses are minimal and therefore this method of storage is probably quite satisfactory.

Castillo, Aglibut, Javier, Gerpacio, Garcia, Puyaoan and Ramin (1965) investigated the effect of replacing maize (250 g/kg of the diet) with sweet potato silage and reported improved liveweight gains (0.48 cf 0.41 kg/day) when the root crop was fed. Although protein levels were balanced across experimental treatments in this study, protein quality was better in the diets of the sweet potato fed pigs (fishmeal / soyabean meal) than in the all meal diet (copra meal) which may have caused the different responses seen.

Ensiling of sweet potato roots has also been shown to reduce trypsin inhibitor activity (Lin *et al.*, 1988) and therefore this process may be useful in improving the nutritional value of certain cultivars with high trypsin inhibitor contents.

1.5. SUMMARY

Although literature concerning the nutritive value of fodder beet and sweet potato is not abundant, it is clear that there are several possible limitations to the use of these materials in the diets of growing pigs. These might be summarized as :-

1. Variability of composition - the variability of composition of fodder beet and sweet potato presents a problem for effective diet formulation and precludes the use of average values, if undersupply or oversupply of essential nutrients is to be avoided.

2. Low nutrient concentration - the high water content in fodder beet and sweet potato results in low nutrient concentrations, which may restrict feed DM intakes and reduce growth performance, if these materials are fed at high dietary inclusion rates.

3. Nutrient balance - the energy to protein ratio in fodder beet and sweet potato is very high and therefore additional protein supplementation will be necessary, when these root crops are fed, if satisfactory growth rates and carcass quality are to be obtained.

The experiments presented in the current study are an attempt to generate information about the nutritive value of fodder beet and sweet potato and assess the potential of these materials as alternatives to conventional ingredients, commonly used in pig diets.

Chapter 8

CONCLUDING DISCUSSION

8.1. NUTRIENT COMPOSITIONS OF FODDER BEET AND SWEET POTATO

The principle objectives of the experimental programme were to establish the nutritive values of fodder beet and sweet potato as feeds for growing pigs. The nutritive value of any feed can be expressed in a number of ways, from proximate analysis at the most basic level, to animal responses to dietary inclusion of that feed at the other extreme. Although response-type experiments were most widely used in this study, initial experiments were designed to evaluate the nutrient composition of fodder beet and sweet potato.

As carbohydrate is the main component of both materials, they would be used primarily for their energy-yielding potential in the diets of growing pigs. Initial experiments were therefore designed to characterize the energy contents of both root crops.

Although gross energy determinations are relatively simple and provide information on the total energy-yielding potential of a feed, they are of limited value as only part of the gross energy is available to the animal for maintenance and productive purposes. A number of systems have been devised for expressing the energy value of a feed in terms of that energy which is utilized by the animal. The most widely used system in the United Kingdom at the present time (in assessing feedstuffs for pigs) is the apparent digestible energy (ADE) system. In this system energy losses in the faeces, resulting from any particular input of food, are subtracted from the gross energy of that food to give the ADE content. Thus ADE, by taking losses associated with the indigestible portion of the food, accounts for the major proportion of variable losses of ingested gross energy. The ADE system of energy evaluation is considered sufficiently accurate to allow prediction of animal responses to any given intake of ADE (providing other nutrients are not limiting) and is widely used throughout the United Kingdom in diet formulation. This method of energy evaluation was used in metabolism trials 1A and 1B to determine the ADE contents of both fodder beet and sweet potato.

Although ADE values are widely used throughout the United Kingdom in diet formulation, the results from growth trial 1 suggest that their use for all types of materials may not be appropriate. In this experiment, four diets, containing varying proportions of fodder beet, but identical levels of ADE, protein and essential amino acids were fed to growing pigs. Feed intakes and therefore nutrient intakes were equal across treatments, but significant deteriorations in growth performance, with increasing proportions of fodder beet in the diet were observed. The digestibility of fodder beet and other components in the test diets were very similar, and therefore the deterioration in performance, of the order of 8 per cent in DLWG for example at the highest rate of inclusion of fodder beet, must have been attributable to other factors. Fodder beet contains relatively high levels of fermentable carbohydrate (Jarrige and Fauconneau, 1973; Livingstone, 1985; Livingstone and Fowler, 1987) which is digested predominantly through the action of microbial fermentation in the caecum and large intestine (Livingstone, 1985; Livingstone and Fowler, 1987). Microbial digestion in the caecum and large intestine is associated with energy losses in the form of combustible gases and heat (generated during the fermentation process). Clearly these losses are not accounted for in ADE measurements, which suggests that this system of energy evaluation over- estimates, to an extent, the energy available to the animal from materials such as fodder beet. Very few experiments have been conducted to calculate the magnitude of energy losses arising from microbial fermentation in the caecum and large intestine. However, using the limited data available, from pigs and other species, (Hungate, 1966; Blaxter, 1967; Webster, Osuji, White and Ingram, 1975) the ARC (1981) estimated that approximately 0.14 - 0.17 of the ADE arising from fermentation in the large intestine was lost as heat and methane gas.

Whereas digestion of complex carbohydrates in the small intestine generates monosaccharides, the end products of microbial digestion in the caecum and large intestine are the steam volatile fatty acids (VFAs). VFAs are utilized by the pig as energy-yielding substrates. However, this utilization is relatively inefficient in comparison to the metabolism of monosaccharides resulting from carbohydrate digestion in the small intestine. Although the efficiency of utilization of VFAs in metabolic processes has been extensively studied in ruminants (Blaxter, 1971; Hovell, Greenhalgh and Wainman, 1976; Orskov, Grubb, Smith, Webster and Corrigall, 1979) considerably less work has been performed using non-ruminant animals (Just, Fernandez and Jorgensen, 1983; Gadeken, Breves and Oslage, 1989). Using the limited amount of data available the ARC (1981) suggested that the energy value of absorbed volatile fatty acids in the metabolism of the pig was between 0.50 and 0.85 that of absorbed glucose, and proposed a value of 0.80 which was thought best to fit current theories.

Combining the relative metabolic inefficiency of utilization of volatile fatty acids with energy losses arising from heat of fermentation and methane production, the ARC (1981) suggested that fermented carbohydrate energy had approximately 0.67 of the value of energy digested in the small intestine. Muller and Kirchgessner (1982) and Livingstone and Fowler (1987) proposed values of 0.65 and 0.55 respectively for the relative efficiency of utilization of energy from fermentation compared to that derived from direct hydrolysis in the small intestine and therefore the figure of 0.67 presented by the ARC (1981) may have been a slight overestimate.

Livingstone (1985) and Livingstone and Fowler (1987) proposed a modification of the ADE system for materials such as fodder beet, with their system taking into account the proportion of digestion occurring through microbial action in the caecum and large intestine. This system whereby 'corrected' ADE values are calculated, requires ileal digestibility experiments, so that digestion occurring separately in the small and large intestines can be quantified. Although the concept of ileal digestibility is widely accepted in the evaluation of protein sources, its use in evaluating energy-yielding ingredients has rarely been applied. The equation developed by Livingstone and Fowler (1987) for the correction of ADE values, where a proportion of the energy is derived from fermentation, is presented below.

$$DE_c = GE \quad DE_i + K \quad DE_o - DE_i\ )$$

where

DE_c = corrected digestible energy value
GE = gross energy
DE_i = apparent ileal digestibility of energy as a decimal fraction
K = estimate of the efficiency of use of fermented energy (0.55)
DE_o = apparent whole gut digestibility of energy

A corrected digestible energy value for fodder beet of 11.4 MJ/kg DM was determined by these workers, which was approximately 14 per cent lower than their uncorrected value (13.2 MJ /kg DM) determined in a conventional digestion trial. Although intakes of apparent digestible energy were similar across treatments in growth trial 1 when the ADE value determined for fodder beet in metabolism trial 1 B was used, substitution of this value for the corrected DE value determined by Livingstone and Fowler (1987), resulted in significantly lower intakes of energy (corrected for fermentation losses and the relative metabolic inefficiency of utilization of VFAs) as fodder beet supplied increasing proportions of the diet (table 8.1). It is likely that these reductions in corrected DE intakes were partially responsible for the deterioration in pig performance as fodder beet supplied increasing proportions of the diet. Therefore, the use of a corrected DE value for fodder beet in diet formulation, would appear to be more appropriate than the ADE value used.

Increased levels of microbial fermentation have been associated with gastrointestinal and particularly large intestinal hypertrophy (Van Es, 1983; Dreher *et al.*, 1984). Hypertrophy of the large intestine, was recorded by Rerat and Henry (1965a) and in growth trial 2 when fodder beet was fed, and by Kesting and Bolduan (1986) when sugar beet was fed. These results clearly support the view that a significant proportion of the digestion of materials such as fodder beet, occurs through the action of microbial fermentation posterior to the terminal ileum. Gastrointestinal weights and lengths were measured in growth trial 3 to investigate whether sweet potato affected the gross physiology of the gastrointestinal tract. No response to increasing rates of sweet potato consumption was recorded, which suggests that microbial fermentation was not very important in the digestion of this material. Microbial fermentation of sweet potato would be expected to be limited, as this root crop contains only low levels of fibre, and sweet potato starch (the principle storage carbohydrate) is reported to be digested predominantly in the small intestine (Morimoto and Yoshida, 1954; Szylit *et al.*, 1978; Gallant *et al.*, 1982; Dreher *et al.*, 1984). As such, the ADE value determined for sweet potato in metabolism trial 1A, is likely to be an accurate assessment of the utilizable energy content of this material.

Table 8.1 : ADE and Corrected DE Intakes in Growth Trial 1, as Fodder Beet Supplied Increasing Proportions of the Diet.

Treatment Rate of Fodder Beet in Diet (g DM /kg DM)	ADE Intake	Corrected DE Intake
	-- (MJ /	day) --
151.0	21.19	20.64
224.0	21.17	20.38
315.0	21.15	20.03
413.0	21.10	19.65
Significance (P)	0.994	<0.001
SED	0.325	0.273

Although corrected digestible energy values offer a more accurate assessment of the nutritional value of materials such as fodder beet, their use is likely to remain limited due to the lengthy and expensive procedures required for their determination. The prohibitive cost and length of simple digestion experiments led to the development of equations which were used to predict the digestible energy content of a feed from its chemical composition. Numerous equations have been developed over the years and their relative merits have recently been discussed (Wiseman and Cole, 1985). The development of a prediction equation encompassing the relative energetic inefficiency of microbial fermentation, would be useful in allowing a rapid and more accurate assessment of the energy value of materials such as fodder beet.

It is relevant to note at this stage that average values were used for the digestible energy contents of the raw materials (except fodder beet and sweet potato) used in the formulation of all experimental diets. Although not ideal, use of average values is obviously a necessity in study programmes of this length. However, it is appreciated that marked variation in the nutrient content of one (or more) raw material could have influenced the results obtained. In an attempt to minimize the effect of any variation in raw material composition, treatment diets in any one experiment were formulated to contain, wherever possible, the same raw materials.

Although fodder beet and sweet potato would be used principally as sources of energy-yielding ingredients in pig diets, the low levels of crude protein in these materials necessitated a consideration of the levels of protein supplementation required for optimum biological (and economic) performance to be achieved.

Growth trial 2, although conducted primarily to provide information on the maximum voluntary intake of fodder beet by growing pigs, clearly demonstrated the deterioration in performance which occurs when diets increasingly deficient in protein and essential amino acids are fed. In this experiment daily intakes of crude protein decreased from 293 g/day when compound diet alone was fed, to 140 g/day when fodder beet was present at 680 g/kg and the compound only 320 g/kg of the total diet on a dry matter basis. Expressed in g/kg of the diet consumed, the control pigs were receiving diets containing 168.5 g crude protein /kg, whereas the pigs consuming the highest level of fodder beet were receiving diets containing only 91.5 g crude protein /kg. At this rate of fodder beet consumption an additional 245.5 g crude protein /kg would be required in the compound diet, to ensure a similar dietary protein concentration to the control diet. This theoretical level of protein supplementation (414 g crude protein /kg) was similar to that supplied by supplement B in growth trial 3 (385 g crude protein /kg), when sweet potato and coconut were supplying approximately 620 g/kg of the total diet. Comparison of these values is meaningless as fodder beet, sweet potato and coconut contain different levels of crude protein. However, these results clearly indicate the necessity for high rates of protein supplementation when diets containing high rates of root crops are fed.

It is well established that pigs respond primarily to the levels of essential amino acids within a feed, rather than the absolute protein content of that feed, providing nitrogen for the synthesis of non-essential amino acids is not limiting (Cole, 1979; ARC, 1981; Sparkes, 1982). An ideal protein for growing pigs, containing an optimal balance of essential amino acids, has been proposed (ARC, 1981). This theoretical ideal protein was used to assess the deficiencies / imbalances in amino acid supply when the different protein supplements were fed in combination with sweet potato in growth trial 3. Although lysine and methionine / cystine appeared to be in the greatest deficit when sweet potato was fed with supplement B in growth trial 3, pigs did not appear to respond to synthetic lysine supplementation of this diet in growth trial 4. The optimal balance of essential amino acids required for maximum growth performance is constantly being reviewed. Recent work (Fuller *et al.*, 1989; Wang and Fuller, 1989) has suggested that growing pigs require higher dietary levels of all essential amino acids (relative to lysine) than originally proposed by the ARC (1981). If the results from these recent studies are assumed to be correct, threonine was in greater deficit than lysine in the sweet potato / protein supplement diet fed in growth trials 3 and 4, and therefore synthetic lysine supplementation would obviously have had no beneficial effect.

The optimal dietary amino acid balances proposed by Fuller *et al.* (1989) and Wang and Fuller (1989) are compared to those originally proposed by the ARC (1981) and other workers (Rerat and Lougnon, 1968; Cole, 1979) in table 8.2.

Considerable variation clearly exists between the estimates of the different workers and therefore further work would be beneficial to clarify the optimal balance of essential amino acids for maximum growth.

8.2. UTILIZATION OF FODDER BEET AND SWEET POTATO

At the start of this experimental programme it was thought that the high levels of intracellular water in root crops would be the factor most likely to influence the ability of growing pigs to utilize efficiently these types of materials. Inclusion of root crops in pig diets results in reductions in dietary energy concentration, so that increased consumption of fresh material has to occur if the animal is to obtain the same level of digestible energy intake. Although pigs are able to adjust feed intakes in response to changing dietary energy concentrations (Cole *et al.*, 1967; Sparkes, 1982; Savidge *et al.*, 1984; Taverner *et al.*, 1984; Campbell and Taverner, 1986) compensation at low dietary energy concentrations is incomplete (Cole *et al.*, 1968; Cole *et al.*, 1972; Franck *et al.*, 1983).

Table 8.2 : Recommended Balance of Essential Amino Acids Relative to Lysine.

	1	2	3	4	5[*]	6[+]
Lysine	100	100	100	100	100	100
Methionine + Cystine	50	74	48	63	53	61
Threonine	60	69	59	72	69	64
Tryptophan	15	23	16	18	18	20
Isoleucine	55	80	44	60	63	-
Leucine	100	102	-	110	115	
Histidine	-	31	-	-	-	
Phenylalanine + Tyrosine	96	57	-	120	124	
Valine	70	68	-	75	78	

1. ARC (1981)
2. Rerat and Lougnon 1968
3. Cole (1979)
4. Wang and Fuller (1989)
5. Fuller *et al.* (1989)
6. Wang and Fuller (1990)

\- not determined
* proposed ideal balance for accretion of body protein
\+ proposed ideal balance for digestible amino acids

The inability of pigs to compensate completely at low dietary energy concentrations has been attributed to a physical limitation and satiety signals from the gastrointestinal tract (Cole *et al.*, 1972; Houpt, 1984; Henry, 1985; Rayner and Gregory, 1989). There is considerable variation in the literature concerning the point at which such a physical limitation occurs. However, in a recent review, Cole and Chadd (1989) suggested that 11.0 MJ/kg (on an as fed basis) might be the approximate point at which physical limitations begin to occur. The results from growth trial 1 clearly show that this figure is inappropriate when reductions in dietary energy concentration occur through the inclusion of root crops in the diet. Although feed intakes were restricted in this experiment, which limits to an extent the conclusions which can be drawn, pigs were able to consume approximately equal amounts of dry matter / day (and therefore digestible energy / day) when fed diets containing from 100 to 400 g fodder beet /kg (on a dry matter basis). At the highest rate of fodder beet inclusion, and when fresh material was fed, the dietary energy concentration (on a fresh weight basis) was only 5.3 MJ/kg, substantially below the value suggested by Cole and Chadd (1989) at which point physical limitations might be expected to occur. In previous experiments designed to investigate the effect of decreasing dietary energy concentrations, fibrous materials, including oatfeed, (Cole *et al.*, 1967; Cole *et al.*, 1968; Chadd, 1990), maize cobs (Franck *et al.*, 1983), sawdust (Owen and Ridgeman, 1967 and 1968), and straw meal (den Hartog, Verstegen, Huisman and van Kempen, 1985) have been most widely used to reduce the energy content of the diet. Clearly if pigs are able to compensate more completely with low dietary energy concentrations when root crops, as opposed to fibrous materials, are the cause of the dietary energy dilution, these materials must exert different effects on the satiety mechanism (s) within the gastrointestinal tract. Stimulation of stretch receptors in the stomach and other areas of the gastrointestinal tract, in response to intakes of feed, is considered to be part of the complex process controlling levels of feed consumption (Houpt, 1984; Rayner and Gregory, 1989). It is perhaps reasonable to assume that the longer a feed retains its structural integrity within the gastrointestinal tract, the greater effect it will have on pre-absorbtive feed intake control mechanisms such as stretch receptors. Cereal fibre sources, such as oatfeed and straw meal, contain lignified cell walls, which are resistant to microbial degradation, so that these materials retain much of their structural integrity during passage through the gastrointestinal tract (Bell, 1960; Chesson, 1990). In contrast vegetable fibre is composed mainly of unlignified primary cell walls, which are more readily fermented by intestinal microbes, so that materials such as fodder beet lose their structural integrity and water holding capacity relatively rapidly during passage through the gastrointestinal tract. If the water holding capacity of fodder beet is relatively quickly reduced during digestion, this in effect removes the nutrient diluent, which may explain why pigs are able to consume relatively high levels of this and other bulky root crops. Although the water content of fodder beet may be quickly reduced following ingestion, the results from growth trial 1 suggest that the intracellular water content of this material may still exert a limited influence on levels of feed intake, as pigs fed fresh fodder beet consumed slightly lower levels of the root crop than pigs fed the dried material. Nevertheless the ability of growing pigs to consume large quantities of fresh fodder beet was again confirmed in growth trial 2. In this experiment pigs were fed decreasing amounts of a compound diet in combination with *ad libitum* fodder beet. As the level of compound diet fed was reduced intake of fodder beet significantly increased. When fodder beet supplied nearly 700 g/kg of the total dietary dry matter, average daily dry matter intakes were only 12 per cent less than those of the compound fed controls. Obviously as fodder beet supplied increasing amounts of the total diet, nutrient deficiencies (particularly of protein and essential amino acids) became increasingly severe. The adverse effects of amino acid deficiencies / imbalances on voluntary feed intakes has been widely reported (Robinson *et al.*,1974; Robinson, 1975; Montgomery *et al.*, 1978; Sparkes, 1982) and therefore had these deficiencies been corrected through additional protein or amino acid supplementation, voluntary feed intakes of the fodder beet fed pigs may have approached those of the controls.

Growth trials 3 and 4 were designed primarily to study protein and amino acid supplementation of sweet potato diets, rather than the influence of this root crop on voluntary feed intakes. However, as the dry matter content of sweet potato is significantly higher than that of fodder beet, growing pigs would probably be able to consume adequate quantities of this material to meet their daily energy requirements.

The results from growth trial 2 confirmed earlier reports which indicated that older / heavier pigs were able to utilize diets containing high rates of root crops more efficiently than younger animals (Fagan, 1954; Rees and Westamacott, 1956; Rerat and Henry, 1964 and 1965). Increased consumption of fodder beet in growth trial 2 was associated with increased stomach and large intestinal weights. Increased stomach weights suggest an adaptation to the high levels of bulky feed, whereas hypertrophy of the large intestine has been attributed to increased levels of microbial fermentation (Van Es, 1983; Dreher *et al.*, 1984). Changes in gastrointestinal physiology suggest that pigs have to adapt to diets containing high rates of fodder beet, and as this adaptation is likely to occur over a period of time, utilization of these diets will clearly be less efficient in the younger animal.

The experiments reported in this study indicate that growing pigs are able to utilize fodder beet and sweet potato relatively efficiently, providing these materials are supplied as components of a balanced diet. The value of any feed ingredient, however, depends not only on its nutrient content but on its cost in relation to other available feeds. Fodder beet and sweet potato would therefore only be used in the diets of growing pigs, if their inclusion (or substitution for another raw material) resulted in an advantage, in cost- benefit terms.