THE DIGESTION AND UTILISATION OF FOOD FIBRE BY GROWING PIGS

Helen Rose Stebbens

PhD
University of Edinburgh
1988

DECLARATION

This Thesis has been composed by myself and has not been accepted in any previous application for a degree. The work of which this is a record, has been done by myself and all sources of information have been acknowledged by means of references.

HELEN R. STEBBENS

DEDICATION

To Mum and Dad
without whose love and support
this could not have been
achieved.

"There exists perhaps in all
creation no animal which has less
justice and more injustice shown
him than the pig."

Sir Frances Bond Head (1793-1875)

ABSTRACT

DIGESTION AND UTILISATION OF FOOD FIBRE BY GROWING PIGS

A series of investigations were undertaken to provide information for compounders to consider when including fibrous foods in diets for growing pigs. The work involved measurements of nutrient digestibilities, growth trials and calorimetric studies.

The digestibility of the neutral detergent fibre (NDF) fraction of a food was dependent on a number of factors including the source of fibre, the adaptation period and liveweight of the pig, and the protein and lipid contents of the diet.

The level of addition of food fibre was not important in determining the digestibility of the NDF component of a fibre source, whereas an inverse relationship was found between the digestibility of nitrogen and energy, and the level of added food fibre. It was concluded that increasing the level of addition of food fibre is more important in determining the depressive effect on the digestibility of non-fibre components than its own.

Rapid growth was achieved when young, weaned and growing pigs were given diets containing wheatfeed and sugar-beet pulp. A substantial part of the energy supplied was in the form of VFA produced by the fermentation of non-starch polysaccharides in the wheatfeed and sugar-beet pulp.

A growth trial with diets containing sugar-beet pulp and maize revealed that fermented energy from beet pulp was used with an efficiency of 0.72 that of the energy of maize. The apparently digested energy arising from the fermentation of non-starch polysaccharides, therefore, does not correspond directly in terms of potential use to the animal with that obtained by the enzymic digestion of maize starch. A net energy value for sugar-beet pulp was also calculated.

This work has shown that wheatfeed and sugar-beet pulp may be useful as dietary ingredients for growing pigs. However, growth rates may be slightly depressed due to a lower efficiency of utilisation of apparently digested energy from the fibrous fraction of the diet. This could lead to on farm problems associated with a decreased throughput eg overstocking. However, the use of a corrected digestible energy value and ileal digestibilities of amino acids for a fibrous food, when formulating rations, could lead to an improvement in the prediction in performance.

As well as the nutritional aspects of feeding fibrous foods, there are also a number of non-nutritional factors which will influence the use of fibrous materials and these are discussed in the light of their practical implications for the feeding of fibrous foods to pigs.

ACKNOWLEDGEMENTS

Firstly, I wish to acknowledge the receipt of a Co-operative Award between Science and Engineering presented by the Ministry of Agriculture, Fisheries and Food (MAFF) in conjunction with Dalgety Agriculture Limited. I thank these two bodies for the financial backing which enabled this research project to be carried out. I am also grateful to MAFF for giving me the opportunity to attend, and present some of my work, at a number of conferences and meetings throughout the course of my research which enabled me to broaden my knowledge. I am also particularly indebted to Dalgety Agriculture Limited and The Edinburgh School of Agriculture for the support which allowed me to travel to the Institute of Animal Physiology and Nutrition in Jablonna, Poland to attend an international seminar on digestive physiology in the pig.

The donation of unmolassed sugar-beet pulp made by British Sugar Plc was most gratefully received.

Throughout the course of my research I have been consistently encouraged and guided by my supervisor, Dr Colin A. Morgan, and I would like to thank him for all his help, enthusiasm and constructive criticism offered over the past three years.

My thanks also to Professor Colin T. Whittemore for assuring me that 'to cry is to think' and for the part he played in the progression of this project.

Close contact was maintained with the nutrition department of Dalgety Agriculture Limited over the three year period and I would particularly like to thank Dr Brian Cooke, Dr Brian Hardy, Dr Brian Vernon and Mr Mick Hazzeldine for their advice and most useful discussion.

My special thanks go to Dr Brian Hardy and Dr Brian Vernon for co-ordinating my time spent with the Company at their Deans Grove trials unit, which made this such a successful and enjoyable component of my research. Whilst working at Deans Grove, the help of the staff was invaluable. I am particularly indebted to Mr Gordon Spenceley and Mr Paul Atkins of the Deans Grove Pig Unit, for assistance with my trials.

I should like to thank Miss Pat Phillips of the Scottish Agricultural Statistics Service for her advice and help with the analysis of data.

For all of the arrangements regarding pigs I must thank Mr Sandy Taylor for his help during my first year at Edinburgh, and Miss Jackie Wharton and all of the staff at the Easter Howgate Pig Unit whose enthusiasm and cheerfulness was of great benefit in the latter stages of my research. Many thanks also to Mr Ross McGinn for the many hours of technical assistance with the respiration chambers.

I would also like to acknowledge the help offered by the staff of the Central Analytical Laboratory, East of Scotland College of Agriculture, in the analysis of samples and would like to thank Mr Jack McGowan and the staff of the Advisory Nutrition Laboratory for accommodating me and my analytical requirements in their laboratory.

Many, many thanks to Miss Fiona Chrystal for transforming my original manuscript from 'a sow's ear into a silk purse' with her very accurate and efficient typing of this thesis.

On a personal level I would like to acknowledge the support offered by my fellow postgraduates; those who I have seen complete their theses, Phil Bentley and Dave O'Donnell, for providing incentive and motivation, and my contemporaries, especially Ilias Kyriazakis for moral support and understanding.

And to Marie Quinn, who suffered every page of this thesis with me, many, many thanks, from one friend to another.

Lastly,
(which should have been firstly),
heart felt thanks to 9½
(who could have been 10)
For the dream and inspiration,
wherever he may be.

CONTENTS

Page

LIST OF TABLES

Page

Page

LIST OF FIGURES

INTRODUCTION

Reasons for the renewed interest in the feeding of fibrous materials to pigs

The recent renewed interest in the use of fibrous feedstuffs has been precipitated by a number of economic and welfare issues. Traditionally, pigs have been fed diets based predominantly on cereals and high-value protein supplements, but as the price of these commodities increases, producers and feed compounders are looking towards the use of alternative, cheaper ingredients e.g. by-products, which tend to be fibrous in nature. Major food shortages in some areas of the world have also brought about a reluctance to continue channelling cereals and protein concentrates into animal food, in direct competition with feeding the human population. Thus, there is an increasing need to find alternative feedstuffs for pigs, and special attention should be paid to materials which are in some way unsuitable for human consumption.

Economic incentives have led to the intensification of pig production and the development of systems which severely restrict movement and social activity. Highly digestible, finely ground diets tend to be fed in order to maximise pig performance. However, the feeding of such diets has been linked to high rates of morbidity and mortality resulting from gastrointestinal abnormalities e.g. ulceration of the *pars oesophagea*, and colitis. Farmers are under increasing pressure to be less dependent on antibiotics and other drugs for the alleviation and control of these conditions. It maybe necessary, therefore, to manipulate the gut environment by nutritional means. This can be achieved by the addition of fibrous materials to the diet.

A wide variety of feedstuffs is currently available for feeding to pigs including dried sugar-beet pulp, distillery and milling by-products, fodder beet and brassicas. At present, it is difficult to express practical responses of pigs to fibrous feedstuffs due to the fact that dietary fibre exerts indirect effects on other nutrients as well as direct effects as a source of nutrients in its own right. A much more detailed knowledge of the chemical and physical composition of sources of dietary fibre is required along with physiological studies on their mode of action, and their nutritive value at different stages in the life of the pig.

Current definitions of fibre and its determination

Many authors have attempted to define dietary fibre, but each one is lacking in some respect due to the variety and complexity of the chemical components of fibre, their physical composition, and their metabolic effects. The definitions also largely depend on the viewpoint of the definer. However, the widely accepted definition is;

> 'the sum of lignin and the polysaccharides that are not digested by the endogenous secretions of the digestive tract'
>
> (Trowell, Southgate, Wolever, Leeds, Gassull and Jenkins, 1976)

This conceptual definition manages to combine both chemical and physiological aspects of dietary fibre, but it does not apply directly to an entity which can be easily measured. Therefore, for practical purposes, it is important to have a definition which describes attributes of dietary fibre which can be determined by physical and chemical methods. Southgate (1982) described dietary fibre as;

> 'non-starch polysaccharides and lignin'

for this practical purpose, although measurement of non-starch polysaccharides is not without difficulty. Dietary fibre defined as non-starch polysaccharides and lignin will include a number of undigestible polysaccharides in addition to the major cell-wall constituents. Most of the storage gums and mucilages e.g. guar gum, a galactomannan, and algal polysaccharides e.g. alginate, which cannot be considered fibrous in a physical sense, are included in this definition.

The choice of method for dietary fibre analysis depends on the extent of information on dietary fibre composition that is required. A wide range of methods is available but comparisons between them show major differences due to varying efficiencies of extraction of the components of dietary fibre.

Methods for dietary fibre determination fall into three categories 1) Gravimetric methods 2) Colorimetric methods 3) Gas-liquid chromatographic methods.

GRAVIMETRIC METHODS

Gravimetric methods measure an insoluble residue after chemical or enzymic solubilisation of non-fibre constituents. Crude fibre (Weende method) and the detergent methods (Van Soest, 1963; Van Soest and Wine, 1967) are probably the most commonly used methods of this type.

Crude Fibre (e.g. Fertilisers and Feedingstuffs Regulations, 1976)

This method was developed in the 1850's for the determination of undigestible material in feeds and forages. Due to the lack of simple alternative methods it has come into use for human food. The sample is treated sequentially with petroleum ether, hot dilute sulphuric acid, boiling water and sodium hydroxide. The insoluble residue, isolated by filtration, contains mainly cellulose and lignin but the recovery is rarely complete (Van Soest and McQueen, 1973). The relationship between dietary fibre and crude fibre in various materials is highly variable and no standard conversion factor may be used. Despite the shortfalls, this method is still the official method of measuring dietary fibre in animal feedstuffs in many countries.

Acid detergent fibre (ADF) (Van Soest, 1963)

The losses of fibre components in the crude fibre assay are largely due to the alkali treatment. Walker and Hepburn (1955) therefore suggested the use of the acid extraction step only, but this gave a considerable protein residue. Van Soest (1963) solved this problem by including a detergent (cetyltrimethyl ammonium bromide) in 2M sulphuric acid. Digestion in the acid detergent solution is followed by filtration, and the residue is dried and weighed. Ideally it determines cellulose and lignin, but residues of pectin and hemicelluloses have been reported.

Neutral detergent fibre (NDF) (Van Soest and Wine, 1967)

In the neutral detergent fibre (NDF) method, the sample is boiled with a neutral, buffered solution of sodium dodecyl sulphate and EDTA. This milder treatment also retains hemicellulose in the residue, whereas pectins are efficiently extracted with EDTA. The neutral detergent system solubilises protein efficiently and fat to a limited extent, whereas in starchy materials starch residues cause filtration problems and erroneously high fibre values. This has led to several modifications using amylase to improve starch solubilisation.

These detergent methods can be used together for the analysis of dietary fibre; the difference between NDF and ADF is hemicellulose, and treatment of the ADF residue with 0.72 sulphuric acid, to solubilise cellulose, leaves a Klason lignin residue.

Enzymic assay of insoluble and soluble dietary fibre (Asp, Johannson, Hallmer and Siljestrom, 1983)

A rapid gravimetric method of enzymic hydrolysis of the sample has been described by Asp *et al.* (1983). The initial gelatinisation by boiling is followed by incubation with pepsin and then pancreatin. Insoluble dietary fibre is separated by filtration and the components are then analysed in as much detail as required.

COLORIMETRIC METHODS

In strong acid solutions, carbohydrates undergo condensation reactions with a large number of substances to give coloured products that can be measured spectrophotometrically. The method of Southgate (1969) is based on the fractionation into soluble and insoluble cellulosic polysaccharides, cellulose and lignin, followed by the acid hydrolysis and the colorimetric measurement of the component sugars. Although relatively simple, these methods need a carefully standardised technique concerning mixing of reagents, heating time, washing of glassware etc., in order to give reproducible results (Southgate, 1973).

GAS-LIQUID CHROMATOGRAPHIC (GLC) METHODS

A method using gas-liquid chromatography for dietary fibre determination has recently been developed by Englyst, Wiggins and Cummings (1982). It is a modified version of the procedure of Southgate (1969) which involves the hydrolysis of dietary fibre polysaccharides to their monomeric constituents and derivatization to volatile compounds (alditol acetate derivatives), which are measured by GLC.

Each of the methods described above has its own advantages and drawbacks. Gravimetric methods are easy to handle and do not require complex equipment.

Therefore, they lend themselves for use in routine analysis for legislation and labelling. The determination of total dietary fibre as the sum of the components determined by GLC (neutral sugars), colorimetry (uronic acids) and gravimetry (lignin) requires more complicated procedures at a much higher cost, and does not improve accuracy or precision in a total fibre determination (Asp and Johannson, 1984). Although the detergent methods have some shortfalls, their main advantages are simplicity and rapidity. The starch retention problem can be solved by the use of an α-amylase, leaving their main disadvantage as the loss of soluble components which are not determined and cannot easily be recovered from the filtrate. The detergent methods continue to have value in practical pig nutrition, however, due to the good inverse correlation between values obtained and the digestible energy (DE) of the diet (Morgan, Whittemore and Cockburn, 1984). For these reasons, acid detergent and neutral detergent fibre were used in this work which studies the digestion and utilisation of food fibre by growing pigs.

Objectives

If a proportion of the cereals in pigs diets is to be replaced by some relatively cheap and readily available fibrous feedstuff, an evaluation of the usefulness of potential materials requires information on:

- the digestibility of various sources of fibre in pigs of different ages
- methods of minimising the depressing effect of fibre on the digestibility of other nutrients
- the effect of level of feeding and possible ways of improving the digestibility of fibre
- the efficiency of utilisation of the products of fibre fermentation
- an evaluation of readily available fibrous feedstuffs as useful dietary ingredients for growing pigs

The work reported herein aims to provide information on these topics. This should enable the incorporation of fibrous feedstuffs into growing pig diets to be made on a more scientific basis. Section One will deal with some of the factors which are likely to effect nutrient digestibilities: bodyweight, level of fibre, fat and protein in the diet. Section Two will evaluate the utilisation of energy from a fibrous food source, and examine the usefulness and suitability of fibrous foods as dietary ingredients for both young, weaned and growing pigs.

SECTION ONE

AN EXAMINATION OF SOME OF THE FACTORS AFFECTING FIBRE DIGESTIBILITY

CHAPTER ONE

MICROBIAL AND ANIMAL FACTORS AFFECTING THE DIGESTIBILITY OF FIBRE

CHAPTER ONE

MICROBIAL AND ANIMAL FACTORS AFFECTING THE DIGESTIBILITY OF FIBRE

1.0 INTRODUCTION

The effects of dietary fibre on digestibility and the digestive processes have been examined by many workers. The results show that there is an inverse relationship between the digestibility of nutrients and energy, and the level of fibre in the diet. The magnitude of the decrease, however, is variable and is thought to be related to a number of factors including the source of fibre, transit time, the physical treatment of the feed, adaptation, feeding level and age/liveweight.

Differences in the extent of digestion of different feedstuffs between pigs of different age/liveweight might be expected due to anatomical differences of the intestinal tract (Nielsen, 1962; Fernandez and Jorgensen, 1986), and the development of the digestive function of the pig (Cranwell, 1968; Manners, 1976). It is therefore desirable to identify the possible differences in the digestive capacity, between pigs of different liveweight, with respect to dietary fibre and its influence on the digestibility of other nutrients.

This chapter aims to investigate the microbial and animal factors which are likely to influence the digestibility of fibre. Different sources of fibre were fed and measurements of digestibility made at different liveweights to attempt to illustrate the adaptation of the pig and its gastrointestinal microflora to the ingestion of diets containing fibrous materials.

The literature reviewed below reports the findings of work which has investigated the different aspects of adaptation and age/liveweight on the digestibility of fibre and other nutrients in pig diets.

Probably the most important factor determining the digestibility of any nutrient, and its effects on the digestive and absorptive processes, is the source of the nutrient and it is unlikely that fibre will be any different in this respect. The source of fibre is likely to override factors such as the period of adaptation and age of the pig since dietary fibre includes a complex variety of chemical structures with a wide range of physical properties. This gives rise to diverse physiological properties and nutritional effects.

The effect of source of fibre on nutrient digestibilities

Many types of dietary fibre have been shown to influence the digestion, absorption and metabolism of all nutrient types. Cranwell (1968) concluded that the proportion of fibre in the diet has little effect on its coefficient of digestion even when it forms 0.3 of the diet, but crude fibre has a significant effect on the digestibility of other nutrients. The apparent digestibilities of organic matter, nitrogen-free extract and crude protein decrease as crude fibre increases, and the more digestible the fibre, the less the decrease (Nordfelt, 1946). Stanogias and Pearce (1985a) concluded that the extent of fibre digestibility is predominantly dependent on the source of fibre and to a lesser extent on the amount of fibre in the diet.

The large scale physical and macromolecular structures of dietary fibre are major factors governing its nutritional properties. These structures are important in the less digestible fibres where an insoluble matrix can persist in the digestive tract. When this is the case, the chemical composition of the fibre may be irrelevant as far as the quality of the fibre is concerned. If dietary fibre is extensively fermented and highly degradable its intrinsic factors (e.g. crystallinity and hydration capacity), which influence its fermentation rate, become important. Lignification may become the dominant factor limiting the extent of degradation. The fermentation rate of fibre is affected by the hydratability and exchange properties, probably through the attraction and attachment of the microflora (Stotsky, 1980; Marshall, 1980; Van Soest, McBurney and Russell, 1984).

The depressing effect of fibre from different sources on digestibility varies. However, the results from different experiments are difficult to compare since the experimental designs and techniques used differ greatly.

In general, nitrogen and energy digestibilities appear depressed and the absorption of some minerals (phosphorus and zinc) has been decreased by the addition of fibrous materials to the diet, although the mechanisms involved remain unclear.

Fibre digestion in the pig is carried out entirely by the gastrointestinal microflora since fibre is resistant to the host's digestive enzymes. A short summary follows of the development of microbial fermentation in the pig together with a review of work which has investigated the effects of the ingestion of fibre on the gastrointestinal microflora.

Microbial fermentation in the gastrointestinal tract of the pig

Microbial fermentation in the gastrointestinal tract, which plays a significant part in the digestion of carbohydrates in the pig, has been reviewed by Cranwell (1968).

The microflora in the gastrointestinal tract can be of great benefit to the pig through the potential synthesis and supply of micronutrients and also, because of the ability of some bacteria to digest complex dietary compounds, the release of simpler compounds which become available to the host.

At birth, the gastrointestinal tract of the baby pig is sterile but rapidly becomes contaminated with microorganisms through contact with its dam and surroundings. Many of these microorganisms are unable to colonise the gut and simply pass through the system. However, the ingestion of milk provides a suitable substrate for some organisms and they rapidly become established in the stomach and small intestines (Fuller, 1962; Barrow, 1978). After weaning, healthy, growing pigs have a stable gastric flora of predominantly lactobacilli and streptococci.

In mature pigs, the hind gut (caecum and colon) contains large numbers of microorganisms and the flow of digesta is slow enough to permit microbial multiplication and extensive metabolism.

Fermentation occurs throughout all segments of the gastrointestinal tract and commences within the first week of life (Friend, Cunningham and Nicholson, 1963). The substrates fermented and the end products of fermentation are variable, the most important factors being the age of the pig, the type of diet fed, and the gut segment in which fermentation is occurring.

Since the degradation of fibre in the pig occurs by microbial action it will therefore rely on the establishment and maintenance of the gut flora. Hence, fibre digestibility in the pig might be expected to vary depending on the liveweight of the animal and the stage of development of the digestive tract (Smith, 1944; Cranwell, 1968; Manners, 1976).

It has been suggested that fibre may be digested in the stomach (Kidder and Manners, 1978; Sambrook, 1980). Some larger dietary particles appear to be retained in the stomach for periods of up to 60 hours (Clemens, Stevens and Southworth, 1975) and this could allow enough time for fermentation to occur. However, it seems unlikely that gastric digestion of fibre would have any marked nutritional significance for the pig, only as a preliminary processing prior to fermentation in the more distal portion of the gut.

In terms of the nutrition of the pig, the processes of digestion, fermentation and the production of VFA in the hind gut is probably the most significant contribution from the microflora but the amount of energy made available has not been clearly quantified. This topic will be discussed further in Chapter 3.

The effect of fibre on the gastrointestinal flora

Several workers have investigated the bacteriology of the digestive tract of pigs given fibrous diets. Liu, Fadden, Latymer, Low and Hill (1985) made use of pigs cannulated at the terminal ileum, caecum and mid-colon to study the effects of dietary fibre supplements on the bacterial flora of the hindgut. The diets fed were a standard control diet, and the control diet supplemented with wheat bran, pectin or lactulose. They observed that the terminal ileum and large intestine were heavily colonised, and that the bacterial flora at the cannulation sites when consuming the control diet was predominantly obligately anaerobic. The dietary fibre supplements had minimal effects on the faecal flora which was found to be in agreement with Hill (1981). Wheat bran, pectin and lactulose had little effect on the gross individual components of the bacterial flora but there was an overall increase in the total number of obligate anaerobes. The authors suggested that the short dietary period (2 weeks) and a high residue basal diet may in part explain the notable absence of changes in the gastrointestinal flora after feeding dietary fibre supplements. It is conceivable that the diet may be important in altering the metabolic capacity of the flora rather than producing qualitative differences in the resident genera or species.

Varel, Pond, Pekas and Yen (1982) studied the influence of high fibre diets on the bacterial populations in the gastrointestinal tracts of obese- and lean-genotype pigs. They concluded that the microflora in the porcine gastrointestinal tract is initially suppressed when exposed to a high-fibre diet and that at a later time the flora re-establishes itself, suggesting that some adaptation takes place. The adaptation of the cellulolytic population was seen to occur more rapidly in lean-genotype pigs than in obese genotypes. The number of cellulolytic bacteria in lean pigs increased 17 fold whereas a non-significant increase was observed in lean animals fed the low fibre diet. It was not established whether the increase in the cellulolytic population is indirectly responsible for the increase in the total counts. The cellulolytic bacteria cultured at no time represented more than 0.02 of the total viable counts. However, as a result of cross-feeding from the hydrolytic products of cellulose i.e. cellobiose and glucose, it was concluded that it is possible that the cellulolytic bacteria need to be present only in a catalytic concentration to greatly influence the total microbial count when a high-fibre diet is fed.

Varel, Jung and Pond (1988) made further studies on the effects on dietary fibre on the microbial populations of lean, obese and contemporary pigs. 21 genetically lean, obese or contemporary pigs were assigned to individual stalls and fed either a control diet (low fibre) or a diet containing 800 g alfalfa meal/kg. Faecal cellulolytic bacteria and total viable bacteria were enumerated at 0, 14, 35, 49 and 70 days. Faecal inocula were used to determine 48 hour *in vitro* digestibilities of alfalfa meal fractions on the same days. *In vitro* digestibility of alfalfa fibre fractions was not different between the genotypes. When the high fibre diet was fed, *in vitro* digestibility increased for all genotypes from day 0 to day 14 but not thereafter. The numbers of cellulolytic bacteria for all three genotypes were greater when pigs were fed the high fibre diet (23.0×10^8, 51.6×10^8, 37.2×10^8/g faecal DM;

obese, lean and contemporary pigs respectively) compared to the low-fibre diet (3.0 $\times 10^8$, 3.2 $\times 10^8$, 3.4 $\times 10^8$ respectively).

Chesson, Richardson and Robertson (1985) carried out bacteriological examinations of digesta taken from selected sites along the digestive tract of pigs fed a bran- or swede-based ration. Pectinolytic and cellulolytic anaerobes were detected in both the fore- and hind-gut of swede-fed animals. However, cellulolytic activity was absent from bran-fed animals and pectinolytic organisms were restricted to the hind gut.

Having reviewed the effects of fibre on the digestibility of nutrients (including the components of fibre itself) and the quantitative and qualitative responses of the gastrointestinal microflora to the ingestion of fibre, the possible adaptation of the pig to diets containing fibrous materials can be considered.

The effects of adaptation on fibre digestibility

The response in digestibility to shorter or longer periods of feeding fibrous feeds have been little studied. Cunningham, Friend and Nicholson (1962) conducted a series of metabolism trials with pigs weighing 65 kg. One group of pigs was given a control ration and another group the control with 0.4 purified cellulose (solka-floc). It was found that the pigs given the solka-floc supplemented diets for 15 weeks were not better adapted to digest it than those receiving it for one week. In contrast to this, Gargallo and Zimmerman (1981), concluded from repeated experiments with growing pigs fed three levels of purified cellulose that the observed digestibility increase was not only caused by the increased liveweight and age, but that progressive adaptation of pigs to cellulose had taken place.

The effects of liveweight and age on fibre digestibility

Changes in the digestive ability of the pig with age have been demonstrated by Nordfelt (1954), Cunningham, Friend and Nicholson (1962) and Roth and Kirshgessner (1984).

Nordfelt (1954) compared the ability of young pigs, weighing less than 92 kg, to digest feed with that of brood sows weighing 200 kg, using mixtures of oats and maize and also maize and sugar-beet pulp. Brood sows digested their feed better than young pigs, the difference being especially marked in feeds rich in fibre. All nutrients in all feeds were digested better by brood sows than by young pigs.

However, Axelsson and Eriksson (1950) concluded that digestibility was independent of liveweight, and Madsen (1963) was not able to show conclusively that there were differences in the digestive ability of pigs weighing 25, 45 and 75 kg. Kass, Van Soest, Pond, Lewis and McDowell (1980) found a higher digestibility of lucerne meal in pigs of 48 kg than in pigs of 89 kg liveweight.

Data from Cunningham *et al.* (1962) conducting trials in which purified cellulose was fed to 65 kg pigs, indicated that digestibility was influenced more by level of feeding of fibre and changes in liveweight rather than age.

Horszczaruk (1962), and Horszczaruk and Sljivovacki (1966, 1971) studied the rate of breakdown of cellulose in the large intestines of the pig by incubating commercial cellulose or ground lucerne meal in silk bags in either the caecum or colon of fistulated pigs and measuring the amount of crude fibre left in the bags after 2 or 4 days. The conclusions of this work were that the age of the pig was important, more fibre being broken down in the intestines of 160-170 kg pigs than in 120 kg pigs. In 40-50 kg animals practically no ground cellulose disappeared, and relatively little fibre from the lucerne. More crude fibre disappeared when the bags were in the caecum, than when they were in the colon, and ground cellulose disappeared to a greater extent than the lucerne fibre in the older pigs. Ground cellulose also disappeared more rapidly if the pig was on a high fibre diet, suggesting adaptation of the caecal flora.

The effects of fibre type and amount on the physical characteristics of the gastrointestinal tract

Nielsen (1962) reported the results of measurements of the length and weight of digestive organs of pigs of differing age and bodyweight, under the same or differing feeding regimes. The main conclusions were that the small intestine increases in length by approximately 0.2 m per day in the first 8-10 weeks, and by 20 kg liveweight, has reached 0.8 of its adult length. A gradual feeding level reduction of up to 0.3 resulted in a decreased total length of the large intestine and feeding diets with up to 200 g oat hull meal/kg did not affect the length or the weight of the digestive tract organs. Fernandez and Jørgensen (1986) suggested that recent experiments at the National Institute of Animal Science, Denmark have shown a very similar pattern of intestinal development.

Kass *et al.* (1980) however, reported an increase in the weight of the colon in pigs fed diets containing increasing amounts of lucerne meal. Stanogias and Pearce (1985b) studied the relative effects of feeding growing pigs with graded amounts of NDF from various sources on the empty wet weight of the segments of the pig gastrointestinal tract. They found that increased intakes of NDF were associated with significantly higher wet weights of all gastrointestinal segments. The lengths of the small and large intestines were unaffected by the ingestion of different amounts of NDF from various sources. However, the caecum responded to increased intakes of NDF by significant increases in length. The source of NDF in the diet was a factor which markedly influenced both the length and weight of the distal colon. The morphological nature of these increases in weight and length, and their biological significance was not determined.

Furthermore, Jørgensen, Just and Fernandez (1985) found a significant increase in the weight of the stomach as a result of the inclusion of barley-straw in the diet, and a decreased weight of the small intestine in response to increased nutrient density.

These results do not give a clear indication of the anatomical changes of the digestive tract in response to increasing dietary fibre. The lack of consistent evidence of the effects of fibre on anatomical changes could be due to different feeding practices and their implications for digestibility are therefore difficult to define.

The literature suggests a number of factors which affect the digestibility of fibre, including the source of fibre and the age of the pig. The gastrointestinal tract of the pig and the associated microflora, may both adapt to the ingestion of fibrous feedstuffs. This chapter will consider the adaptation of the pig and its microflora to the ingestion of fibre from different sources, one degradable and one less degradable, in terms of their digestibility of their fibrous fractions and other nutrients.

1.1 THE EFFECT OF BODYWEIGHT ON THE DIGESTIBILITY OF FIBRE FROM TWO SOURCES

1.1.0 INTRODUCTION AND AIMS

The aim of this experiment was to investigate the adaptation of growing pigs in their ability to digest fractions of food fibre from different sources over time.

Morgan, Whittemore and Cockburn (1984) measured the Digestible Energy (DE) value of dried unmolassed sugar-beet pulp for growing pigs to be 12.7/kg DM and the digestibility of the NDF fraction to be 0.75 after an adaptation period of only 14 days. The Metabolisable Energy (ME) value of sugar-beet pulp for ruminants is 11.6 MJ/kg DM (MAFF, 1986), the potential DE being 14.1 MJ/kg DM. It would appear, therefore, that sugar-beet pulp has only limited potential for illustrating adaptation in the growing pig, and was used in this trial as a source of readily digestible fibre.

In contrast to sugar-beet pulp, dried grass has been shown to have a lower and more variable DE (MJ/kg DM): 6.2 (Morgan, Cole and Lewis, 1975); 7.2 (Hensen, 1976) and 9.64 (Hakansson and Malmlöf, 1984). In the ruminant, good quality dried grass has a ME of 10.7 MJ/kg DM and a potential DE of 13 MJ/kg DM. Dried grass offers a greater potential for adaptation and was fed in this trial as a source of less degradable food fibre.

1.1.1 MATERIALS AND METHODS

Animals and Diets

Twelve Large White x Landrace entire male pigs of initial mean liveweight 35 kg (SE 2.5 kg) were used in this trial. A randomised design compared three dietary treatments. Four pigs were allocated at random to each of a control, sugar-beet pulp or dried grass supplemented diet.

The pigs in the control group received a low-fibre basal diet based on barley, wheat, fishmeal, skim-milk and soya-bean meal (see Table 1.1.0). The pigs on the other two treatments were given the same basal diet and in addition received either a sugar-beet pulp or dried grass supplement. The basal diet was fed on a restricted scale suggested by the Agricultural Research Council (ARC, 1967) and endorsed by the ARC (1981). This feeding scale is detailed in Table 1.1.1.

The sugar-beet pulp and dried grass supplements were fed on a scale which aimed to provide 0.1 kg of additional NDF at a liveweight of 60 kg. This was calculated to be equivalent to 0.26 kg of sugar-beet pulp and 0.22 kg of dried grass. The quantity of basal diet to be fed at 60 kg liveweight, according to the ARC scale, was 2.5 kg. The relative proportions of basal diet, and sugar-beet pulp (SBP) or dried grass (DG) in the ration, were calculated as shown below;

For Sugar-Beet Pulp:

2.5 kg Basal Diet + 0.26 kg SBP ≡ 0.906 Basal Diet + 0.094 SBP

For Dried-Grass:

2.5 kg Basal Diet + 0.22 kg DG ≡ 0.919 Basal Diet + 0.081 DG

These relationships were used to calculate the equivalent levels of fibrous supplements at other liveweights.

Trial procedures

The pigs were maintained in individual pens without bedding for a preliminary feeding period of 14 days. They were then placed into metabolism crates (Whittemore and Elsley, 1976) fitted with a feeding trough and a tray beneath for the collection of spillages. Total collections of faeces and urine were made into a plastic bucket and box, respectively, during the 7-day balance period. The faeces were collected twice daily and frozen in bulk. The urine was collected into distilled water acidified with sulphuric acid and the pH maintained between 2 and 3 by the addition of more acid. At the end of the balance period the faeces and urine were mixed thoroughly and sampled. Two faecal samples were taken; one was dried in a forced draught oven at 60°C for the determination of dry matter. This sample was subsequently ground to pass a 1 mm screen and used in the determination of gross energy, ADF and NDF. The other sample was frozen, as was the urine, until required for analysis. At the end of each balance the pigs were weighed, returned to their individual pens and the level of feeding adjusted accordingly. The weights were recorded at approximately weekly intervals and balances 2 and 3 carried out at liveweights of 65 kg and 95 kg, using the same procedures as for balance 1.

1.1.2 ANALYTICAL PROCEDURES

The gross energy of the basal diet, unmolassed sugar-beet pulp, dried-grass, dried faeces and freeze-dried urine were determined in an adiabatic bomb calorimeter. Total nitrogen was determined by the Kjehldahl method. Acid detergent fibre was determined by the method of Van Soest (1963) and neutral detergent fibre by that of Robertson and Van Soest (1977) including a treatment of the sample with a heat stable α-mylase (ex. *Bacillus subtilis*) as described by MAFF (1985) (See Appendix One). Calculations were made to estimate the digestibilities of ADF, NDF, energy and nitrogen for the whole diet. The digestibilities of the ADF, NDF and energy of the dried grass and sugar-beet pulp were calculated by difference. The amounts of nitrogen retained and excreted were also examined.

1.1.3 STATISTICAL ANALYSIS

Genstat V (Lawes Agricultural Trust, 1982) was used in the statistical analysis of the data using the technique of analysis of variance for a randomised design as recommended by the Scottish Agricultural Statistics Service (James Clerk Maxwell Building, West Mains Road, Edinburgh).

The analysis of variance identified the diet, and liveweight with orthogonal (LW), linear (LW_L) and quadratic effects (LW_Q). The significance of each mean square was tested by comparison of the mean squares of liveweight, LW_L and LW_Q and the diet * liveweight interaction with the error mean square. The statistical procedures used were as described by Snedecor and Cochran (1973).

Table 1.1.0 The ingredient composition of the low-fibre basal diet.

Ingredient	Basal Diet (g/kg)
Wheat	500
Barley	228
Hi-pro Soya	150
Fishmeal	50
Skim milk	50
Limestone	10
Di calcium phosphate	75
Vitamins & Minerals PT12C+	25
Salt	2
	1000

+Appendix 2

Table 1.1.1 Feeding scale (ARC, 1967; 1981)

Liveweight (kg)	Expected Daily Liveweight Gain (kg)	Daily Feed Intake (kg)
20	0.500	1.00
25	0.550	1.20
30	0.625	1.45
35	0.690	1.65
40	0.750	1.85
45	0.775	2.05
50	0.790	2.20
55	0.790	2.35
60	0.790	2.50
65	0.790	2.65
70	0.790	2.75
75	0.790	2.85
80	0.790	3.00
85	0.790	3.10
90	0.790	3.20

1.1.4 RESULTS

Some difficulties were experienced prior to, and during, the second balance period with the diets supplemented with dried-grass and sugar-beet pulp. Substantial quantities were refused by certain animals and some pigs were able to select against the fibrous supplement. The refusals were therefore analysed for NDF and Pearson's Square used to determine the proportions of basal diet and sugar-beet pulp/dried grass in the refusals. This information was then used to calculate the intake of basal diet and food supplement.

Since the pigs were refusing, the daily feed allowance was not increased following the second balance, but maintained at the level for a 66 kg pig to try and stimulate appetites.

The chemical compositions of the basal diet, dried grass and unmolassed sugar-beet pulp are given in Table 1.1.2.

Table 1.1.2 The chemical composition of the basal diet, dried-grass and sugar-beet pulp

	Basal diet	Dried Grass	Sugar-beet pulp
DM (g/kg)	913	930	926
GE (MJ/kg DM)	18.48	18.32	17.03
Crude Protein (g/kg DM)	231	178	91
Ash (g/kg DM)	56	103	70
ADF (g/kg DM)	44	269	233
NDF (g/kg DM)	114	495	448

NDF and ADF digestibility

The effect of diet on the digestibility of NDF and ADF is shown in Table 1.1.3.

Table 1.1.3 **The effect of diet on the digestibility of NDF and ADF in the basal, dried grass (DG) and sugar-beet pulp (SBP) supplemented diets**

(means of 12 values; means in the same row with the same subscript are not significantly different)

	DIET +Basal	+Dried Grass	Beet Pulp	SED	SIG
Digestibilities					
NDF of whole diet	0.549ab	0.469b	0.621a	0.0363	**
NDF of DG or SBP	-	0.293	0.843	0.1193	**
ADF of whole diet	0.407ab	0.356b	0.532a	0.0427	**
ADF of DG or SBP	-	0.288	0.788	0.1207	**

+ one missing value

Significant differences (P<0.01) were found between the NDF digestibility coefficients for the whole diets. The supplementation of the basal diet with dried grass depressed the digestibility of the NDF of the diet (although not significantly) illustrating that the NDF fraction of dried grass is less degradable than that of the mean value for barley, wheat and hi-pro soya, the main contributors to the NDF of the basal diet.

In contrast to this, the addition of sugar-beet pulp resulted in an increase in the digestibility of the NDF fraction of the whole diet, although the difference between the NDF digestibility coefficients for the basal diet and beet pulp supplemented diets were not found to be significant.

The digestibility of the NDF fractions of the dried grass and sugar-beet pulp, as calculated by difference, were found to be significantly different (P<0.01), the NDF of sugar-beet pulp being significantly more digestible than that of the dried grass.

The digestibility of the ADF of the whole diets (Table 1.1.3) was also significantly affected by the source of food fibre added. The supplementation of the basal diet with dried grass resulted in a depression of ADF digestibility, as was found for NDF. However, the magnitude of the depression was not significant. When sugar-beet pulp was fed with the basal diet the digestibility of the ADF component was increased above that measured for the basal diet alone. This indicates that the ADF of sugar-beet pulp is more readily degraded than that of the basal diet.

The digestibility of the ADF of sugar-beet pulp was significantly greater than that of the dried grass, which confirms that the ADF fraction of different materials is a non-uniform entity.

Table 1.1.4 gives the mean digestibility coefficients for ADF and NDF at liveweights of 37, 66 and 92 kg.

The liveweight of the pigs did not appear to be a significant factor affecting the digestibility of the NDF fraction of the diet. No significant linear trend could be identified but significant deviations from linearity were found. This was due to a significantly lower digestibility of the NDF of the whole diet at a liveweight of 66 kg.

Since significant differences between the two fibre sources have been identified it is more meaningful to examine the digestibility coefficients of each source separately. The digestibility coefficients for the NDF of dried grass and sugar-beet pulp at different liveweights are detailed in Table 1.1.5.

Although the analysis of variance did not reveal a significant diet * liveweight interaction, a significant difference was found between the NDF digestibility coefficients of dried grass at 37 and 92 kg liveweight. This significant improvement in digestion of NDF suggests that some degree of adaptation may be occurring over this weight range. The digestibility of the NDF fraction of sugar-beet pulp was not found to vary significantly over the weight range 37 to 92 kg.

Table 1.1.4 The effect of liveweight on the digestibility of ADF and NDF

(means of 12 values; means in the same row with the same subscript are not significantly different)

	LIVEWEIGHT (kg)			Level of Significance				
	37	66	+92	SED	LW	LW_L	LW_Q	t
Digestibilities								
NDF of whole diet	0.557	0.523	0.558	0.0165	NS	NS	*	2.58
NDF of BP/DG	0.502	0.532	0.670	0.0783	NS	NS	NS	-
ADF of whole diet	0.445_a	0.402_b	0.448_a	0.0152	*	NS	*	3.72
ADF of BP/DG	0.494	0.499	0.622	0.0589	NS	*	NS	2.35

+ two missing values

Table 1.1.5 The digestibility of the NDF fraction of dried grass and sugar-beet pulp at 37, 66 and 92 kg (as determined by difference)

(means of 4 values; means in the same column with the same subscript are not significantly different)

Liveweight (kg)	Dried Grass	Beet Pulp
37	0.173a	0.832
66	0.281ab	0.783
92	+0.426b	0.915
SED	0.1108	
Level of Significance	*	

+ one missing value

The digestibility of the ADF of the whole diets at 66 kg liveweight (Table 1.1.4) was significantly ($P<0.05$) lower than the values measured at 37 and 92 kg. Consequently, the relationship between ADF digestibility and liveweight was found to be non-linear, and the deviations from linearity were significant. This same pattern was also found for NFD digestibility and may be associated with the fact that some pigs were refusing significant amounts of their daily ration at this stage in the trial.

The proportion of the feed intake consisting of sugar-beet pulp for each of the balances 1, 2 and 3 were calculated to be 0.088, 0.079 and 0.085 respectively, and for dried grass the corresponding values were 0.081, 0.073 and 0.076. The variation in the proportions of basal diet and food fibre supplement will have implications for the measurement of ADF and NDF digestibility. For balance 2 there was an overall decrease in the proportion of food fibre supplement. The digestibility of the NDF of the sugar-beet pulp has been shown to be greater than that of the basal diet, giving rise to a significant increase in digestibility of the NDF of the whole diet on its addition to the basal diet. Dried-grass did not produce a significant effect. Over the period of balance 2, since a smaller proportion of beet pulp was ingested, then the NDF digestibility would be expected to be depressed and the same argument can be used to explain the reduction in ADF digestibility over the same balance period.

Although significant differences could not be found between the digestibility coefficients for the ADF of dried grass and sugar-beet pulp at different liveweights, a significant linear trend of increasing digestibility with increasing liveweight was identified, the slope being significantly different from zero, with no significant deviations from linearity.

Since the ADF fractions of these materials appear to be very different, it is more useful to consider them separately. The ADF digestibility coefficients for dried grass and sugar-beet pulp are given in Table 1.1.6.

Despite apparent increases in ADF digestibility with increasing liveweight, no significant differences could be identified, and no significant diet * liveweight interaction was recorded.

Table 1.1.6 **The digestibility of the ADF fraction of dried grass and sugar-beet pulp at 37, 66 and 92 kg (as determined by difference)**

(means of 4 values)

Liveweight (kg)	Dried Grass	Beet Pulp
37	0.243	0.746
66	0.263	0.735
92	+0.360	0.885
SED	0.0833	
Level of Significance	NS	

+ one missing value.

Nitrogen digestibility, nitrogen retention and nitrogen excretion

The effect of diet on nitrogen digestibility, nitrogen retention and nitrogen excretion is given in Table 1.1.7.

Nitrogen digestibility was found to be greatest in the pigs given the basal diet alone, and was depressed to a similar extent by the addition of both dried grass and sugar-beet pulp. However, the differences in digestibility coefficient were not found to be significantly different.

Nitrogen retention, expressed as g nitrogen retained/day, was lowest in the pigs fed the basal diet, highest in those given the sugar-beet pulp supplemented diet, an intermediate value being recorded for those pigs fed the dried grass supplement. None of the differences measured were found to be significant.

Table 1.1.7 The effect of diet on the digestibility of nitrogen, nitrogen retention and nitrogen excretion

(means of 12 values)

	DIET				
	Basal	Dried Grass	Beet Pulp	SED	SIG
N Digestibility	+0.900	+0.861	0.863	0.0177	NS
N retention (g/day)	#22.81	+25.56	31.31	3.064	NS
N retention (g/g N intake)	#0.37	+0.39	0.47	0.039	NS
Faecal N excretion (g/g N intake)	#0.10	+0.14	0.14	0.018	NS
Urinary N excretion (g/g N intake)	#0.48	+0.47	0.39	0.038	NS

+ one missing value; # two missing values.

Nitrogen retention, expressed as a proportion of nitrogen intake, varied with the diet fed, but significant differences were not found. The pigs given the basal diet plus the sugar-beet pulp retained the highest proportion of their nitrogen intake, whilst those given the basal diet alone retained the lowest proportion.

Faecal nitrogen, expressed as a proportion of the nitrogen intake, was higher in the pigs given the dried grass and sugar-beet pulp supplements, than those given the basal diet alone, but the difference was not significant.

Urinary nitrogen excretion, expressed as a proportion of the nitrogen intake, was lower in the pigs given the diets supplemented with dried grass and sugar-beet pulp. The pigs fed sugar-beet pulp excreted the smallest proportion of nitrogen in their urine, although this value was not found to be significantly different from those pigs on the other two diets.

The mean values for nitrogen digestibility, nitrogen retention and nitrogen excretion at liveweights of 37, 66 and 92 kg are given in Table 1.1.8.

Table 1.1.8 **The effect of liveweight on nitrogen digestibility, nitrogen retention and nitrogen excretion**

(means of 12 values; means in the same row with the same subscript are not significantly different)

	LIVEWEIGHT (kg)			Level of Significance				
	37	66	92	SED	LW	LW_L	LW_Q	t
N Digestibility	0.873	0.867	+0.883	0.0075	NS	NS	NS	-
N retention (g/day)	21.92	33.63	#24.14	2.229	**	NS	**	4.82
N retention (g/g N intake)	0.52_a	0.42_b	#0.30_c	0.025	**	***	NS	7.63
Faecal N excretion (g/g N intake)	0.13_a	0.13_b	#0.12_b	0.008	**	NS	NS	-
Urinary N excretion (g/g N intake)	0.35	0.45	#0.53	0.026	**	***	NS	-

+ one missing value; # two missing values.

No significant differences were found between nitrogen digestibility coefficients at different liveweights and no significant linear relationship could be identified between the digestibility of nitrogen and increasing liveweight.

Nitrogen retention (g/day) was seen to vary with liveweight. At a liveweight of 66 kg the pigs were found to retain significantly more nitrogen than at liveweights of 37 and 92 kg. Consequently the relationship between nitrogen retention and liveweight was found to be non-linear.

With increasing liveweight there was a significant reduction (P<0.01) in the nitrogen retained when expressed as a proportion of the nitrogen intake. The relationship was found to be linear. The slope of the line was found to be significantly different from zero. At a liveweight of 92 kg, a smaller proportion of the nitrogen intake was excreted in the faeces compared to that at liveweights of 37 or 66 kg but the difference was not found to be significant. The nitrogen excreted in the urine, expressed as a proportion of the nitrogen intake, increased significantly with increasing liveweight. The relationship was found to be linear and the slope was significantly different from zero. There were no significant deviations from linearity.

Energy digestibility and digestible energy values for dried grass and sugar-beet pulp

Table 1.1.9 shows the effect of diet on a) the digestibility of energy, b) the digestible energy values for dried grass and sugar-beet pulp and c) the effect of liveweight on the digestibility of energy.

The addition of dried grass to the basal diet significantly ($P<0.05$) depressed the energy digestibility of the basal diet. The addition of sugar-beet pulp also resulted in a lowering of energy digestibility but the difference was not significant.

The DE of the sugar-beet pulp was found to be almost twice that of dried grass, but due to the extremely wide variation, and the consequent large standard error of difference between the treatment means, the values were not found to be significantly different.

Since the DE values for the dried grass and sugar-beet pulp appeared to be so different it would be meaningless to consider them together when trying to establish whether there was any variation in DE with increasing liveweight. Table 1.1.10 shows the digestible energy values of dried grass and sugar-beet pulp measured at liveweights of 37, 66 and 92 kg.

No significant differences or linear trends could be found for either dried grass or beet pulp with increasing liveweight. This is probably due to the fact that the DE values were very variable between the pigs on the same dietary treatments. However, examination of the data shows quite large increases in DE, the DE for dried grass at 92 kg being 1.58 of the value measured at 37kg. The equivalent factor for beet pulp was 1.34.

Table 1.1.9 **The effects of diet and liveweight on energy digestibility, and the digestible energy values for dried grass and sugar-beet pulp.**

(means for 12 values; means in the same row with the same subscript are not significantly different)

	DIET				
	Basal	Dried Grass	Beet Pulp	SED	SIG
Energy digestibility	$+0.877_a$	$+0.831_b$	0.857_{ab}	0.0126	*
DE of dried grass or sugar-beet pulp (MJ/kg DM)	-	+5.49	10.66	2.686	NS

	LIVEWEIGHT (kg)							
	33	66	92	SED	LW	LW_L	LW_Q	t
Energy Digestibility	0.850	0.850	0.865	0.0045	*	**	*	3.31

+ one missing value

Table 1.1.10 **The digestible energy values (MJ/kg DM) of dried grass and sugar-beet pulp at 37, 66 and 92 kg (as determined by difference)**

(means of 4 values)

Liveweight (kg)	Dried Grass	Beet Pulp
37	4.52	9.41
66	4.82	9.91
92	7.14	12.65
SED	2.155	
Level of Significance	NS	

1.1.5 DISCUSSION

Several methods have been used by different workers for measuring the digestibility and energy value of feeds. The addition method used in this trial has the advantage that it provides a constant base line and can illustrate possible interactions between the test material and other components of the diet. The fact that different quantities of dried grass and sugar-beet pulp were fed should not invoke an error since it has been shown by Peers, Taylor and Whittemore (1977) amongst others, that the feeding of barley up to 3 x maintenance has no effect on apparent digestibility. However, to give a more accurate prediction of digestible energy, different levels of the test material should be fed to allow the digestible energy value to be estimated both by difference and by regression. This then tests the additivity of values over a range of feeding levels. The DE values measured in this trial were found to be highly variable and a more accurate measurement of DE may have been achieved using more than one level of dried grass and sugar beet pulp.

Quantitatively, the ADF and NDF contents (g/kg DM) of dried grass (269 and 495) and beet pulp (233 and 448) were not very different but, qualitatively, in terms of their own degradability and their effects on the digestibility of the other nutrients in the diet, there were very marked differences.

The source of fibre therefore appears to be an important factor determining the digestibility of its fibrous component. This is in agreement with the findings of Baird, McCampbell and Allison (1970) and Stanogias and Pearce (1985a). The NDF and ADF components of the sugar-beet pulp were found to be highly degradable whereas the digestibilities of the same fractions of dried grass were low and variable, thus indicating important differences between sugar-beet pulp and dried grass fibre.

It seems that the nutritional effects of food fibre are not accounted for particularly well by measuring the NDF and ADF fractions, and that the nutritional properties of fibre are likely to be determined by associations between the different components of the plant cell wall at the macromolecular level.

Van Soest (1985) reviewed the sources of variation in fibre. Many factors were shown to influence the composition and quality of plant fibre. The fundamental proportions of pectin, hemicellulose and lignin in the plant cell wall are determined by the plant species, distinct differences existing between monocotyledonous and dicotyledenous plants, represented largely by grasses and legumes respectively. The broad chemical compositions of dried grass and sugar-beet pulp are given in Table 1.1.11.

Table 1.1.11 The composition of dried grass and sugar-beet pulp (g/kg)

Fibre component	Dried Grass1	Sugar-beet pulp2
Hemicellulose	220	260-320
Cellulose	240	220-240
Uronic acids	70	220-230
Lignin	60	10-20

1. Gaillard (1962)
2. Michel, Thibault and Barry (1988).

Sugar-beet pulp is comparatively high in pectin and low in lignin, while the pectin in dried grass is probably too low to be of any nutritional consequence. Lignin is usually considered the primary factor causing a decline in digestibility of plant cell walls with increasing maturity. It has been shown to reduce the digestibility of plant cell wall carbohydrates, mainly hemicellulose and cellulose, with which it is bonded (Van Soest, 1985). However, it appears to have little effect on the digestibility of pectin which it is not associated with. Gaillard (1962) and Bailey (1973) have shown pectin and the non-cell wall polysaccharides to have very high digestibilities and in some cases they appear to be completely digestible.

In his review, Van Soest (1985) discussed how lignin protects approximately 2.4 to 3.0 times its own weight of plant cell wall material from ultimate degradation. On this basis alone, less dried grass would be expected to be digested when compared to the relatively unlignified cell walls of sugar-beet pulp.

The methods of measuring fibre in this trial i.e. by the detergent methods, will lead to a serious underestimation of the fibre content of sugar-beet pulp since pectin, which is a rapidly fermentable component of plant fibre (Van Soest, 1985), is efficiently solubilised by the chelating agent EDTA in the neutral detergent solution (Asp and Johannson, 1984). Pectin has important physicochemical effects and sources of fibre such as pectin rank above insoluble fibres in their effect on rate of passage in the upper gastrointestinal tract, but have less effect upon the colon and caecum (Van Soest, 1985).

Van Soest (1985) also suggested that the extent of lignification is probably the primary factor determining the potential extent of digestion, but it is less well correlated with the rate of digestion. Grasses appear to have lignin acids esterified to hemicellulose of the arabinoxylan type (Hartley, 1972), and it has been shown by Lau and Van Soest (1981) and Hartley (1983) that alkali-cleavable lignin probably accounts for the indigestibility of the cell wall of grasses.

Dried grass and sugar-beet pulp contain cellulose in approximately the same proportion. Cellulose tends to be fairly uniform chemically (as ß-glucan), but nutritionally it appears to be very variable. One of the principle reasons offered for this in forages such as grass is that the ratio of lignin:cellulose increases, rendering it less digestible. Coupled with inter-species differences in physical properties this factor leads to nutritional non-uniformity. For these reasons differences would be expected to exist between the fibre of dried grass and sugar-beet pulp, the cellulose component of sugar-beet pulp being inherently more digestible than that of dried grass.

The intrinsic structural and compositional properties of dried grass and beet pulp are likely to provide an explanation, at least in part, for trends observed in the digestibility of NDF and ADF with increasing liveweight. The fact that beet pulp NDF was highly digested at all liveweights, including 37 kg when the pigs had only received the diets for 14 days, suggests that this fraction is readily degradable and that only a minor part of the NDF is unavailable for digestion. The microflora required to bring about this degradation might be regarded as relatively simple. There was a tendency for the digestibility of the sugar-beet pulp NDF to increase (by approximately 0.09 units) over the weight range 37-92 kg. However, the very variable mean values obtained resulted in this increase not being considered significant. Therefore, in the case of beet pulp, it would appear that there is some improvement in NDF digestibility with increasing liveweight, suggesting a limited amount of adaptation to this already well digested source of NDF. It is also apparent that NDF digestion in the pig is highly variable between pigs given the same diet at the same liveweight.

In contrast to beet pulp, the digestibility of the NDF of dried grass, showed a significant improvement over the liveweight range 37-92 kg; the digestibility of NDF at 92 kg was 2.5 times that measured at 37 kg. Bonding within the grass plant cell wall, mainly between lignin and cellulose, will render the NDF less available for digestion. It is conceivable that a more complex microflora may be required to degrade successfully the ligno-cellulosic complexes. Such a population may well require a period of time to develop and stabilise, and digestibility will therefore improve over time and hence improve with liveweight. It was suggested by Varel *et al.* (1982) that cellulolytic bacteria need only be present in a catalytic concentration to influence greatly the total number of microorganisms present suggesting that a large population of microbes will develop in response to the feeding of high fibre diets, which will conceivably take a period of time to become established.

ADF digestibility was also found to be variable and although the mean digestibility coefficients for dried grass and sugar-beet pulp appeared to increase with increasing liveweight the variation was too great to identify any trends. The extent of the improvement in the mean ADF digestibility of sugar-beet pulp when compared to the improvement in NDF digestibility over 37-92 kg was 0.139 units as compared to 0.09 for the NDF. The equivalent values for dried grass were 0.253 and 0.117.

Since the degradability of the ADF fraction (lignin and cellulose) was found to increase more with liveweight than NDF it would appear that it is the digestibility of the cellulose fraction which is increasing over time and it could be the hemicellulose fraction which is limiting the overall cell wall digestibility. Bailey (1973) showed that hemicellulose contains a variety of sugars and linkages, and it is also associated with lignin. All linkages between lignin and carbohydrate have been demonstrated to occur between lignin and arabinoxylan. Lignification of plant cell walls renders the hemicellulose insoluble and partially indigestible whereas the soluble unlignified fraction of hemicellulose is completely digestible. A certain proportion of the cellulose in both dried grass, and a limited amount in sugar-beet pulp, is also likely to be unavailable for digestion by virtue of its association with lignin.

The results obtained illustrate that a degree of adaptation has occurred over the liveweight range 37 to 92 kg, measured in terms of fibre digestibility. This suggests that the microflora responsible for the breakdown of fibre has responded to this increased supply of fermentable carbohydrate. Data from the literature suggests two alternative forms of microbial adaptation to the ingestion of fibrous materials; increased proliferation and hence increased microbial numbers, or an alteration in the rate of metabolic activity of the flora. The former of these two suggestions will have implications for the measurement of digestibility of other nutrients in the diet, in particular nitrogen and energy.

Increased microbial metabolism in response to the supply of extra fermentable carbohydrate is likely to lead to increased microbial proliferation and an increased output of bacterial material in the faeces. Microbial metabolism is dependent not only on a supply of fermentable carbohydrate but also on a supply of nitrogen. The incorporation of nitrogen/amino acids entering the hind gut into the microbial protein is likely to increase the faecal nitrogen output and may also reduce the urinary nitrogen excretion by depressing the flow of nitrogen out of the hind gut into the bloodstream. Consequently the energy passing out of the pig in the faeces is also likely to be increased and will have the effect of depressing apparent energy digestibility. These effects are likely to be dependent on the fermentability of the fibre and hence its digestibility. For this reason the effects of dried grass and sugar-beet pulp on microbial output and therefore energy and nitrogen digestibility would be expected to differ.

An alternative suggestion to qualitative and quantitative changes in the resident genera or species made by Lui *et al.* (1985) was that the metabolic capacity of the microflora is altered in response to the presence of fibrous materials. It might be envisaged that this form of adaptation could occur for more rapidly than the establishment of a more complex microflora.

Nitrogen digestibility was depressed to a similar extent by the addition of dried grass and sugar-beet pulp to the basal diet, but no significant differences were measured between the digestibility coefficients of nitrogen for the whole diets. The addition of dried grass to the basal diet significantly depressed the energy digestibility of the whole diet, whereas sugar-beet pulp did not cause such a marked depression. In the light of the NDF and ADF digestibility coefficients obtained for these materials it would be reasonable to suppose that sugar-beet pulp would support a greater microbial metabolism than dried grass, and might therefore be expected to cause a greater reduction in nitrogen and energy digestibility than dried grass.

Whiting and Bezeau (1957) reported that the type and amount of dietary fibre considerably affected the metabolic nitrogen excretion in pigs whether expressed as a proportion of the DM intake or faecal DM output. Mason and Palmer (1973) concluded that it was not the amount but the extent of fermentation of dry matter which resulted in the production of more bacterial cells and as a result more bacterial residues appear in the faeces increasing faecal nitrogen. Therefore, according to Mason and Palmer (1973) fibre sources that are extensively degraded in the large intestine of the pig will decrease the apparent digestibility of nitrogen to a larger extent than fibre sources less susceptible to microbial attack provided that they are fed at similar levels. However, Stanogias and Pearce (1985a) found that while the reduction in the apparent digestibility of nitrogen caused by the inclusion of soya-bean hulls, lupin bulls and wheat bran in the diet of growing pigs confirmed this view, the reduction brought about by the inclusion in the diet of the less-digestible lucerne stems, as compared with the above mentioned sources of fibre suggests that factors other than the digestibility of fibre. Such factors, which may include the nitrogen content of the fibre source and perhaps volume, are also important. The results obtained for this trial appear to be very similar to those obtained by Stanogias and Pearce (1985a).

However, the situation is certainly more complex than this since processes are occurring which produce opposing effects. The relative chemical composition and energy contents of these two sources of fibre will be important in explaining some of the effects seen.

The crude protein contents of the dried grass and sugar-beet pulp were 178 and 91 g/kg DM respectively, and the crude protein content of a mixed rumen population of bacteria has been measured to be 375 g/kg (Mason and Palmer, 1971). As mentioned above, the sugar-beet pulp will support a greater microbial metabolism than dried grass by virtue to the higher degradability of its fibrous components. Relative to dried grass, sugar-beet pulp will give a higher output of microbial matter and a lower output of undigested residues of the plant cell wall which will contain very little nitrogen. However, dried grass will not produce such a great amount of microbial nitrogen, but a higher proportion of undigested grass with a higher nitrogen content will be excreted in the faeces. The relative increase in bacterial nitrogen output relative to that of undigested feedstuff will determine the effect on the overall nitrogen digestibility. In this trial the increased microbial output and low output of nitrogen from sugar-beet pulp appears to have produced the same effect as the dried grass, envisaged to be due to a lower microbial output of nitrogen but a higher output of nitrogen from the grass.

The gross energy contents of the dried grass and sugar-beet pulp were similar at 18.3 and 17.0 MJ/kg DM respectively. Dried grass significantly reduced the energy digestibility of the whole diet and since, relative to beet pulp, its fibrous fractions were less digestible it would appear that the relative balance between increased microbial output of energy and undigested grass produced a greater energy loss than from beet pulp. This indicates the operation of mechanisms which alter the digestibility of nutrients in the diet other than microbial output.

Alternative mechanisms for the depressive effects of increased NDF and ADF intakes on nitrogen and energy digestibility are; 1. a faster rate of passage of digesta through the gastrointestinal tract (Gargallo and Zimmerman, 1981); 2. an increased excretion of metabolic nitrogen (Whiting and Bezeau, 1957); 3. the low availability of nitrogen and other nutrients in the fibre (Forbes and Hamilton, 1952; Pals and Ewan, 1978); 4. the increased excretion of nitrogen and other nutrients which have become bound or physically entrapped in the body of the fibrous digesta (Bailey, Mills and Hove, 1974; Eastwood and Kay, 1979).

Nitrogen retention, expressed as g/day and as g/g nitrogen intake, was higher in the pigs given the dried grass and sugar-beet pulp supplements in addition to the basal diet. Stanogias and Pearce (1985a) found that there was a tendency towards increased nitrogen retention with increased levels of NDF intake, particularly with diets containing soya-bean hulls, wheat bran, maize hulls and lucerne stems. They also suggested that in addition to the increased nitrogen intake, more energy was available for the synthesis of new tissue when NDF was added, since increased nitrogen retention can only be achieved if the intake of energy is adequate too (Fuller and Crofts, 1977). Pals and Ewan (1978) also reported increased nitrogen retention when wheat bran was added to a basal ration for pigs.

The pigs given the sugar-beet pulp were shown to retain the most nitrogen in terms of g/day and as a proportion of nitrogen intake. This confirms the hypothesis of Stanogias and Pearce (1985a), since the DE value of sugar-beet pulp was found to be higher than that of dried grass, hence more energy will be available from the sugar-beet pulp for the synthesis of new tissue.

Dried grass and sugar-beet pulp increased the output of faecal nitrogen, expressed as a proportion of the nitrogen intake, to a similar extent. Conversely, urinary excretion was depressed more so by sugar-beet pulp than dried grass. In the case of beet pulp the decrease in urinary nitrogen excretion exceeded the increase in faecal nitrogen output, and consequently nitrogen retention was increased. The results obtained for the dried grass are less clear; the decrease in urinary nitrogen excretion did not exceed the increase in faecal nitrogen output, yet the pigs given these diets showed a small increase in nitrogen retention over those given the basal diet alone. The effects described above have been found for a number of fibre sources by several workers and will be further discussed in Chapter 2.

Since there appear to be marked differences in the effects of the fibre of dried grass and sugar-beet pulp on the digestibility of other nutrients in the diet it is probably more meaningful to examine the effects of these two fibre sources on nitrogen excretion and retention individually. Tables 1.1.12, 1.1.13 and 1.1.14 show the mean values for faecal nitrogen excretion, urinary nitrogen excretion and nitrogen retention respectively with increasing liveweight.

The results detailed in Table 1.1.12 show that faecal nitrogen remained approximately constant over the three balance periods which is consistent with the measurements made of apparent nitrogen digestibility. The slight, but non-significant increase in nitrogen output suggests that the microflora could become established over a number of weeks (37- 66 kg) and that the metabolism of the microflora becomes adapted to the breakdown of plant cell material. Microbial numbers may stabilise and decrease, hence reducing the faecal output of nitrogen, best illustrated by the trend observed for the pigs given the diet supplemented with dried grass. Varel *et al.* (1988) found that *in vitro* digestibilities of alfalfa meal increased over the first 14 days of a trial but not thereafter suggesting an adaptation period, which may be due to increased numbers or an increased microbial activity.

Table 1.1.12 Faecal nitrogen excretion (g/g N intake) by the pigs on each diet at 37 66 and 92 kg liveweight

(mean values for 4 pigs)

			Diet
Liveweight (kg)	Basal	Dried Grass	Beet pulp
37	0.102	0.141	0.138
66	0.106	0.150	0.144
92	0.092	0.127	0.131
SED			0.0130
SIG			NS

Table 1.1.13 Urinary nitrogen excretion (g/g N intake) by the pigs on each diet at 37, 66 and 92 kg liveweight

(mean values for 4 pigs; values in the same column with the same letter are not significant)

			Diet
Liveweight (kg)	Basal	Dried Grass	Beet pulp
37	0.368_a	0.354_a	0.330_a
66	0.530_b	0.464_a	0.370_a
92	0.537_b	0.591_b	0.466_b
SED			0.0458
SIG			**

Urinary nitrogen output (Table 1.1.13) showed a distinct increase over the liveweight range 37-92 kg for all groups of pigs, but the effect was most marked in the pigs given the dried grass supplemented diet. The trend was strongly observed in the pigs given the basal diet suggesting that this may largely be an age effect rather than an adaptative response to fibre, but higher microbial activity could account for increased urinary excretion with increasing liveweight. As well as the anabolic process of nitrogen incorporation into microbial protein, the bacteria can also catabolise amino acids to release ammonia. In the absence of sufficient fermentable carbohydrate, microbial metabolism will be limited and the ammonia produced by the action of the bacterial urease may be absorbed into the blood and excreted into the urine. This might be expected to occur with less digestible fibre, i.e. dried grass in this trial, since the energy supply to the microbes will be limited. High concentrations of ammonia circulating in the blood could prove to be toxic and lead to less efficient nitrogen metabolism and reduction in nitrogen retention as was shown by the results.

Much of the decline in nitrogen retention with increasing liveweight will be accounted for by the decrease in nitrogen retention shown by the control pigs given the basal diet. However, despite a decline in all groups of pigs, at 92 kg liveweight the pigs on the dried grass and sugar-beet pulp supplemented diets retained more nitrogen.

Table 1.1.14 Nitrogen retention (g/g N intake) by the pigs on each diet at 37, 66 and 92 kg liveweight

(mean values for 4 pigs; values in the same column with the same letter are not significant)

			Diet
Liveweight (kg)	Basal	Dried Grass	Beet pulp
37	0.528_a	0.505_a	0.530_a
66	0.363_b	0.392_{ab}	0.493_{ab}
92	0.213_c	0.282_b	0.400_b
SED			0.0431
SIG			**

The DE values obtained for the beet pulp at 33 and 66 kg liveweight were lower than the value of Morgan *et al.* (1984), but the value obtained at 92 kg (12.65 MJ/kg DM) was in line with the DE obtained by these workers (12.7 MJ/kg DM). The DE of dried grass was very close to that measured by Morgan *et al.* (1975) (6.2 MJ/kg DM). However, dried grass is a very variable and in the absence of information on the species used, stage of maturity at cutting and temperature of drying, comparisons are difficult to make.

To summarise. This experiment has investigated the adaptation of growing pigs in their ability to digest the ADF and NDF fractions of unmolassed sugar-beet pulp and dried grass over time. The extent of fibre digestion appears to be highly variable between pigs and very much dependent on the source of ADF and NDF, which is in agreement with the recent work of Stanogias and Pearce (1985a). There is some improvement in fibre digestibility with increasing liveweight over the range examined in this trial (37-92 kg), but this is also dependent on the source of fibre. The digestibility of the ADF and NDF of sugar-beet pulp was generally high, and the improvement over time was proportionally less than that of the less degradable ADF and NDF fractions of dried grass. The composition/structure of the dried grass cell wall appears more complex than that of the sugar-beet pulp, thus a microflora capable of degrading it may require some time to become established, resulting in increased fibre digestibility with increasing liveweight. It maybe that the ingestion of food fibre also alters the metabolic capacity of the microflora rather than producing qualitative differences in the species present in the gastrointestinal tract.

There was an inverse relationship between the digestibility of nitrogen and energy, and the level of NDF and ADF in the diet. The magnitude of the decrease was also dependent on the source of fibre in the case of energy and it is likely to be mediated by a number of factors including a faster transit time of digesta through the gut, an increased excretion of microbial and metabolic nitrogen, the low availability of nitrogen and other nutrients in the fibre, and the increased excretion of nitrogen and other nutrients which have become bound or physically entrapped in the body of the fibrous digesta.

The results also indicate an alteration in the route of nitrogen excretion. The pigs on the dried grass and sugar-beet pulp supplemented diets excreted a higher proportion of nitrogen in their faeces (g/gN intake), whilst a lower proportion was excreted in their urine. The pigs on these diets also retained a higher proportion of their nitrogen intake, probably as a consequence of the relative changes in nitrogen excretion. However, this trial was not designed to reveal the biological significance of this increased nitrogen retention. It could be that part or all of this increase in nitrogen retention could be due to increased protein deposition in the gut wall, the increase in size occurring in response to increased bulk or gut fill, or increased protein deposition in the carcase. This point will be investigated further in Chapters 3 and 4.

CHAPTER TWO

DIETARY FACTORS AFFECTING THE DIGESTIBILITY OF FIBRE

CHAPTER TWO

DIETARY FACTORS AFFECTING THE DIGESTIBILITY OF FIBRE

2.0 INTRODUCTION

Chapter One discussed how the pig and its microflora may adapt with increasing liveweight to the ingestion of diets containing fibrous materials. The digestibility of fibre is also dependent on a number of dietary factors due to the complexity of its physical and chemical properties (Cummings, 1978). Such factors will include the source of fibre (Stanogias and Pearce, 1985a) and its level of inclusion (Farrell and Johnson, 1972; Gargallo and Zimmerman, 1980, 1981) and the other components of the diet e.g. fat type and level (Kennelly and Aherne, 1980) and protein level (Nyman and Asp, 1985).

The addition of a fibrous feed to a diet has the effect of diluting the digestible energy concentration so that compensatory amounts of high energy materials, such as oil or fat, will need to be added in order to maintain energy levels. The use of fats in animal foods has increased in recent years since they are extremely concentrated sources of dietary energy. A considerable amount of work has been centred around the determination of DE values for fats, not least because they may be influenced by a large number of factors. Numerous interactions between fats of differing chemical structure, and possible interactions between fats and the non-fat component of the diet have been illustrated. These two types of interaction involving fats may be of importance during the determination of their dietary energy content.

Wiseman (1986) reviewed interactions involving fats. It was established that the addition of a fat containing a high proportion of unsaturated fatty acids to one containing predominantly saturated acids, will enhance the absorption and subsequent energy value of the latter. Similar observations were made with complete fats where the determined dietary value of a mixture of saturated fat (e.g. tallow) and a relatively unsaturated one (e.g. soya-bean oil) has been higher than would have been predicted. Studies of interactions between added fats and the non-fat components of a basal diet have indicated that the addition of fat can enhance the utilisation of the non-fat components. This effect has been attributed to the added fat reducing the overall rate of passage through the gut thus allowing a greater period of time for the processes of digestion and absorption (Pearson and Panzer, 1949). It has also been suggested that the level of protein in the basal diet may influence the availability of added fat. Young, Garrett and Griffiths (1963) demonstrated an improvement in the absorbability of both lard and tallow when the crude protein content of the diet was increased from 240 to 280 and 300 g/kg.

Fibre digestion in the ruminant has been shown to be depressed by the addition of lipid to the diet (Brooks, Garner, Gehrke, Muhrer and Pfander, 1954; Ward, Tefft, Sirny, Edwards and Tillman, 1957; Nottle & Rook, 1963; Steele & Moore, 1968; Kowalcyk, Ørskov, Robinson and Stewart, 1977). It maybe that fermentation in the hind gut of the pig is similarly affected. Clapperton & Steele (1973) found that the addition of fat to ruminant diets resulted in a reduction in apparent digestibility of fibre and that this change in fibre digestion was influenced by the fatty-acid composition of the added fat. Short-chain fatty-acids caused a greater depression than long-chain fatty-acids, and unsaturated oils caused a larger reduction than saturated fats. Free fatty-acids were found to cause a much greater depression in fibre digestibility than their corresponding triglycerides (MacCloed and Buchanan-Smith, 1972). Nottle & Rook (1963) working with ruminants, showed that cod liver oil caused a pronounced fall in the molar proportion of acetic acid in the rumen fluid and a complimentary increase in propionic acid, whereas tallow tended to give the reverse changes. With the addition of tallow a slight decrease in the digestibility of crude fibre and fat free dry matter was observed.

Microbial activity in the hind gut of the pig is dependent not only on a supply of readily fermentable carbohydrate, but also on a supply of nitrogen. It is conceivable that the amounts of nitrogen available could limit microbial metabolism and hence fibre digestibility at high levels of intake.

This chapter presents and discusses the findings of two trials designed to examine the effects of;

1. Level of fibre in the diet on the digestibility of fibre and lipid.

2. Degree of saturation of added fatty-acids on the digestibility of fibre.

3. Level of crude protein in the diet on the digestibility of fibre

4. Level of fibre in the diet on the digestibility of nitrogen, nitrogen retention and nitrogen excretion.

2.1 THE EFFECT OF LEVEL OF FIBRE AND SATURATION OF LIPID ON THE DIGESTIBILITY OF FIBRE AND LIPID

2.1.0 INTRODUCTION

In Chapter 1, the source of food fibre added to a basal diet was found to be one of the most important factors governing its digestibility, and some of the reasons for this were reviewed and discussed in Sections 1.0 and 1.1.5. However, the level of feeding of a fibrous food could also affect the rate of passage and fermentation (and hence digestibility), and the efficiency of utilisation of dietary energy. In the ruminant, energy is lost through rumination and gastrointestinal work (Webster, 1978) so that the heat increment is associated with the level of fibre in the diet. It is possible that similar losses could occur in non-ruminants where fermentative digestion contributes significantly to the digestible energy of the diet. Fermentation of materials in the hind gut results in the production of acetate and hydrogen gas. This gas is used in methanogenesis and the hydrogenation of unsaturated fats – wasteful processes as far as the animal is concerned. Insoluble, undigested fibre increases the rate of passage of digesta in all animals and this leads to a greater loss of energy in the faeces. An increase in the rate of passage also leads to a greater turnover of microbial metabolism and an increased output of faecal nitrogen as microbial protein (Mason, 1979; Van Soest, 1981).

Cummings (1978) discussed the nutritional implications of dietary fibre and showed that when diets were supplemented with wheat bran or whole wheat products, the excretion of faecal fat, nitrogen, energy and minerals all rose. Fibre intake on a control diet was 17 g/day and this was increased to 45 g/day by the addition of wheat bran or whole wheat products. A small change in fatty-acid intake occurred but the faecal fatty-acid output increased significantly from 1.7 to

2.7 g/day. This increase in faecal fat, although not considered significant in terms of overall digestibility and absorption of fat, poses the following questions:

1. Does it represent an alteration in the digestive and absorptive processes for fat in the gut?

2. Is a proportion of fat associated with the fibre in such a way as to be unavailable for digestion?

3. Does this represent an increase in endogenous lipid excretion?

Information presented in the literature which may be helpful in explaining this effect, at least in part, is reviewed below along with the results of work which may help to answer the question;

4. How does the addition of fat and its degree of saturation affect the digestibility of fibre?

If fat is to be added to diets containing higher proportions of fibrous materials, in order to maintain the digestible energy content, it is important that any interactions between fat and fibre that could alter the digestive processes are recorded so that the accuracy of diet formulation is maximised.

The alteration of the digestive and absorptive processes in the gut by dietary fibre

There are two possible ways in which dietary fibre could alter the digestibility of fat and other nutrients in the diet, through its effects on digesta transit time and the processes of digestion and absorption.

Firstly considering the effects of dietary fibre on transit time. Table 2.1.0 reviews the effects of dietary fibre on overall transit time and the rate of passage through the various gastrointestinal segments of pigs.

Table 2.1.0 **The effects of dietary fibre on overall transit time and in the various gastrointestinal segments of pigs**

Source and Level in diet (g/kg)		Diet Type	Initial LW (kg)	Segment	Measurement	Effect and time (h)	Reference
Guar Gum	60, 20 10	Semi-purified	30	Stomach	Gastric emptying	↑	Rainbird *et al.* (1984)
Carboxymethyl-cellulose Bran		Semi-purified	45	Stomach	Gastric emptying	↑	Rainbird and Low (1983)
Guar Gum		Semi-purified		Stomach Duodenum	Gastric motility & duodenal motility	=	Sissons *et al.* (1984)
Crude Fibre	52 92	Cereal	40	Duodenum	Retention time	6.3 ↑7.1	den Hartog *et al.* (1985)
Crude Fibre	52 92	Cereal	40	Large intestine	Retention time	24 20	den Hartog *et al.* (1985)
Crude Fibre	89 129	Cereal	45	Overall	Retention time	24.3 22.4	Cole *et al.* (1967)
Lucerne leaf	50 100 150 200	Semi-purified	44	Overall	Transit time	43.7 ↓41.6 ↓29.7 ↓28.4	Kuan *et al.* (1983)
Coarse bran Fine bran Lucerne meal Solka Floc	312 472 308 150	Semi-purified	70	Overall	Retention time	51.6 ↓49.7 ↓36.0 ↑71.0	Ehle *et al.* (1982)
None None Bran	- - 170	Cereal Milk substitute Milk substitute	50	Overall	Retention time	40 ↑120 ↑66	Fioramonti & Bueno (1980)
None Bran None Bran	- 100 or 200 g/d - 100 g/d	Cereal Milk substitute	30	Overall	Retention time	49 ↑52 107 ↓79	Canguilhem and Labie (1977)
None Bran	- 100 g/d	Milk substitute	90	Overall	Retention time	98.6 ↓64.3	Bardon & Fioramonti (1983)

↑, increased; , decreased; =, unchanged

Certain types of soluble dietary fibre (e.g. pectin, guar gum, sodium carboxymethyl cellulose) increase the viscosity of solutions in which they are dissolved through the adsorption of water and the formation of a gel. Rainbird, Low and Sambrook (1984) and Rainbird and Low (1983) showed that whilst gums did not affect the rate of gastric emptying of dry matter, they delayed the rate of gastric emptying of digesta. It is evident that these materials are capable of reducing the rate of water passage into the duodenum, probably in part due to their large water-holding capacity. However, Sissons, Rainbird and Thurston (1984) showed that gastric motility appeared to be unaffected by the addition of guar gum to the diet.

Dietary fibre may have an effect on motor activity in the small and large intestines. Sissons *et al.* (1984) concluded that duodenal activity, when assessed in terms of the duration of spike activity, may be reduced by the presence of guar gum in the diet. Further evidence to support this was produced by den Hartog, Boon, Huisman, van Leeuwen and van Weerden (1985). The effect of crude fibre in the diet on rate of passage using Cr-EDTA as a marker was investigated using diets with 52 g crude fibre/kg and 92 kg crude fibre/kg. The rate of passage of the marker for the diet with 92 g CF/kg was decreased in the small intestine and increased in the large intestine as compared to the diet of lower fibre content. Cole, Duckworth and Holmes (1967) reported that small differences in the fibre content of the diet did not seem to effect the rate of passage of digesta greatly when cereal-based diets were fed. This was also found to be the case by Canguilhem and Labie (1977). However, the results are very different for the supplementation of semi-purified diets with fibrous foods. Fioramonti and Bueno (1980) and Bardon and Fioramonti (1983) examined the nature of the effects of bran on digestive transit time in pigs fed cereal or milk-based diets. Bardon and Fioramonti (1980) found that the mean retention time of a polyvinylchloride marker was reduced from 98.6 hours on a milk diet to 64.3 hours on a bran supplemented milk diet. They concluded that the decrease in transit time associated with bran supplementation is mediated by direct mechanical factors rather than fermentation products including volatile fatty acids.

A decreased transit time through the whole gut, or through certain segments of the tract, will reduce the time available for the processes of digestion and absorption to occur. This could result in a reduction in the digestibility of all major nutrient types. Dietary fibre has, however, other characteristics which may also act in the gut to reduce the digestion and absorption of nutrients.

Within the small intestine it has been shown that the rate of glucose absorption is reduced by a number of types of dietary fibre. The largest effects have been seen with those sources which increase the viscosity of the meal and gut contents (Jenkins, Wolever, Leeds, Gassull, Haisman, Dilawari, Goff, Metz and Alberti, 1978). Similar effects have been reported with guar gum in pigs (Leeds, Kang, Low and Sambrook, 1980). Rainbird, Low and Zebrowska (1984) found these effects to be partly due to reduced absorption from isolated loops of the jejunum. Guar gum significantly reduced the net absorption of glucose from 0.742 to 0.414 from a glucose solution, and 0.717 to 0.350 from a maltose solution perfused into this section of the gut. The net absorption of water from the glucose solution was also reduced by the addition of guar gum from 0.427 to 0.083. The mechanism by which this occurs is not yet fully understood but it is thought to be associated with reduced diffusion from the intestinal lumen to the epithelial cells or inhibition of the absorptive process. Sambrook, Rainbird and Low (1982) found that the appearance of glucose and NH_2-nitrogen in blood plasma was delayed and that peak concentrations were lower following meals containing guar gum. This indicates that this source of dietary fibre has an effect on both carbohydrate and protein digestion and absorption. The absorption of amino acids is also delayed by the presence of guar gum (Low, 1985). Other evidence from Rerat, Vaissade and Vaugelade (1979) suggests that dietary fibre may influence the rate of nutrient absorption.

Murray, Fuller and Pirie (1977) investigated the effect of cellulose, methyl cellulose and pectin on the digestibility of protein in pigs (50-100 kg) cannulated at the terminal ileum. Cellulose (0.10) and gel-forming polysaccharides (0.06) replaced starch in a control diet composed of starch, barley and soya-bean meal. The addition of the gel-forming polysaccharides produced a decrease in the apparent digestibility of nitrogen to the terminal ileum compared to the control diet. The largest decrease, from 0.76 to 0.48 was recorded when methyl cellulose was added. Cellulose did not have any effect. The apparent digestibility of protein-bound lysine was also reduced by methyl cellulose and the rate of passage of digesta to the terminal ileum was increased. It was suggested that bulk had no effect on protein digestion but that it was the hydrolysis of protein rather than the absorption of the products which was impaired when gel-forming polysaccharides were given.

Combined studies of ileal and faecal digestibilities have been carried out by many workers. Just, Jørgensen and Fernandez (1983) carried out trials using a series of semi-purified diets including fibre from oats, barley and carboxymethyl cellulose with pigs weighing 60-90 kg. The major effects were that the addition of fibre markedly depressed ileal apparent energy digestibilities, but effects on other components were negligible. Faecal apparent digestibilities of nitrogen, lysine and energy fell sharply while the values for Stoldt fat declined to a lesser extent and those for crude fibre remained approximately constant. The proportions of nutrients disappearing, during their passage through the large intestine, increased for those involving gross energy but fell for all other components. There was a possible net synthesis of fat and lysine, presumably as a result of microbial metabolism.

Zoiopoulos, Topps and English (1983b) measured the digestibility of a number of dietary components in the terminal ileum of growing pigs fed on a barley-based diet supplemented with soya-bean meal, malt culms, dark grains or weatings. It was found that the higher the crude fibre content of the diet, the lower was the apparent digestibility of each component. Kass *et al.* (1980) investigated the digestion of diets containing 0, 200, 400 and 600 g alfalfa meal/kg in pigs after slaughter at 48 and 89 kg. The digestibility of dry matter, nitrogen and cell wall components in the small intestine, caecum, colon and faeces decreased as the level of alfalfa in the diet increased.

In general, the digestibility of nitrogen is depressed by the addition of fibrous materials. Increasing the fibre content of the diet has been shown to reduce both the ileal and faecal digestibility of nitrogen and organic matter (Zoiopoulos *et al.*, 1983; Just *et al.* 1983; Dierick, Vervaeke, Decuypere and Henderickx, 1983). Similar effects have been reported for rye straw (Zebrowska, 1982), whole and dehulled barley (Just, Sauer, Bech-Andersen, Jørgensen and Eggum, 1980), ground barley straw (Just, 1982) and wheat and oat bran (Just, 1982). These results are characterised by an increasing proportion of the energy digested in the large intestine as the dietary fibre is increased, with corresponding reductions in nitrogen and fat absorption.

The association of fat with fibre

The second suggestion made in Section 2.1.0., which might help explain an increase in faecal fat output when diets high in dietary fibre are fed, was that a proportion of fat becomes associated with fibre in such a way as to render it unavailable for digestion.

Lipids are largely non-polar compounds which are insoluble or sparingly soluble in water. Unless added as special compounds to a diet, lipids tend to associate with the solid phase of digesta, which will include fibrous components (Harfoot, 1978). Any factor which affects the wetability of the fibre surface is likely to reduce hydratability, and hence fibre fermentation rates and digestibility (Van Soest, 1985). Not only will fibre digestibility be impaired if such an association occurs between fat/fibre, but the fatty-acids may also be rendered unavailable for digestion.

An important physical characteristic of vegetable fibre is its capacity for organic acid adsorption, which was reviewed by Eastwood (1973). Bile-acids have been found adsorbed to fibre in the faeces. This adsorption has been shown to be greater in normal rats than in germ-free animals which implicates the involvement of the gastrointestinal microflora. Similarly, the adsorption of bile-acid metabolites to faecal fibre was greater in infected animals on a fibre-containing diet than in similar animals given a semi-synthetic diet. This indicates that the bacterial metabolites of bile-acids are more strongly adsorbed than the primary bile-acids. Bloomfield (1963) has shown that an increased fibre content in the diet increases faecal bile-acid output. These materials will be hydrolysed and extracted by the AHF method of analysis, and it is conceivable therefore that the apparent digestibility of AHF could be reduced. Cereal fibre is also capable of adsorbing bile-acids, although in his review Eastwood (1973) was unable to detail the effect of feeding cereal fibres on the faecal bile-acid output over a sufficient period of time which could show an effect on bile-acid loss.

In the upper small intestine conjugated bile acids play an important role in micellar formation with lipids, and as a result of this there is very little or no adsorption onto fibre. However, in the colon, free bile-acids are strongly adsorbed (Eastwood and Hamilton, 1968). Thus, the bacterial transformation of bile-acids changes the physical state of the bile-acids in the intestinal contents by forming derivatives which are strongly adsorbed on to the residues. Bacteria hydrolyse water-soluble, conjugated organic acids and the less water-soluble fraction produced, e.g. bilirubin, thyroxine and bile-acids will be either precipitated, adsorbed onto fibre through hydrophobic bonding or adsorbed onto bacteria, e.g. deoxycholic acid is adsorbed onto vegetable fibre, while lithocholic acid is adsorbed onto bacteria (Midtvedt and Norman, 1972).

The effect of dietary fibre on organic acid adsorption has been widely studied in the rat. The addition of various polysaccharides, sodiumcarboxymethylcellulose and bran, to the diet have been shown to increase the amount of intestinal bile salts (Eastwood and Boyd, 1967) and they are apparently distributed between the water and solid phase. A diet which contains a significant amount of polysaccharide could therefore result in an increase in the size of the bile-acid pool.

There seems to be evidence to suggest that both dietary lipid, and endogenous lipid in the form of bile-acids, could become associated with dietary fibre. In the case of dietary lipid this could result in a decreased availability of the lipid for digestion, and for bile-salts the prevention of their reabsorption. Both of these associations will give the same effect; a reduced apparent digestibility of lipid. Fibre digestibility is also likely to be depressed.

The effect of dietary fibre on digestive secretions and endogenous losses

Gastric, biliary and pancreatic secretions all appear to be affected by the presence of dietary fibre. Zebrowska, Low and Zebrowska, (1983), Partridge, Low and Sambrook (1982) and Sambrook (1981) showed marked differences in the volume and composition of pancreatic and biliary juices secreted by pigs fed on semi-purified or cereal-based diets. Crude fibre intakes were similar on both diets but the NDF intake of those pigs given the cereal-based diet was 180 g/day as compared to 50 g/day for those on the semi-synthetic diets. This emphasises the large contribution of non-cellulosic components of dietary fibre from cereals.

Zebrowska (1985), feeding pigs diets based on wheat, wheat bran, wheat flour and cellulose found that the average volume of pancreatic juice and the contents of K^+, Na^+, Cl^- and HCO_3^- were greater with the wheat or wheat bran than with wheatflour or cellulose. The average daily secretion values for HCO_3^- were 2.5 times greater for the diets containing wheat or wheat bran. The total buffering capacity of the juice was therefore markedly greater with these diets. This suggests that there was a much greater secretion of gastric acid which produced more secretin, the major stimulant for electrolyte and water secretion in monogastrics. The type of diet did not appear to affect the total activity of pancreatic proteases, peptidases or amylase, in accordance with the findings of Partridge *et al.* (1982) and Zebrowska *et al.* (1983). Since the diets were similar in starch and crude protein content, and differed only in the content and type of crude fibre, the latter seems to be responsible for the changes in volume and composition of the pancreatic secretion.

A further secretory response was found by Low and Rainbird (1984) in the jejunum of growing pigs. The addition of guar gum to glucose solutions, which were perfused through isolated loops of the jejunum, increased nitrogen secretion. The nature of this material has not been fully elucidated, but it has been shown to contain protein and deoxyribose nucleic acid (DNA). DNA is likely to be a constituent of mucosal cells, the exfoliation of which increased following the addition of guar gum to the diets of rats (Johnson, Gee and Mahoney, 1984). Intestinal protein synthesis was also increased in rats consuming a diet containing 99 g dietary fibre/kg from a cereal based ration rather than a semi-synthetic diet containing 40 g cellulose/kg (Southon, Livesey, Gee and Johnson, 1985). Sauer, Stothers and Parker (1977) and Taverner, Hume and Farrell (1981) observed the same effect on the flow of nitrogen and amino acids passing through the ileum of pigs given protein free diets supplemented with cellulose. Whiting and Bezeau (1957) showed that the supplementation of diets with cellulose increased faecal nitrogen output to a greater extent than oat hulls, but methylcellulose had little effect.

The effects of added fat and its degree of saturation on the digestion of fibre

The possible associations between dietary fibre and dietary and/or endogenous lipid, and the implications for the digestibility of fat and fibre were discussed earlier in this review. Lipid, hydrophobically bound to the surface of the fibre, could reduce the wetability of the fibre surface. As a consequence of this, hydratability, and hence fibre fermentation rate and digestibility could also be reduced (Van Soest, 1985). However, if as suggested above, there is also a reduction in the absorption of the products of digestion, partially undigested fat and free fatty-acids may enter the hind gut and interfere with microbial activity, hence indicating a further mechanism for the depression of fibre digestibility by the addition of fat.

A number of authors have investigated the effects of fatty acids on microbial activity using cultures of microorganisms and adding small quantities of the fatty acid. From the results obtained it would appear that unsaturated fatty acids are more antibacterially active than saturated ones and that cis-acids are more potent than trans-acids (Nieman, 1954; Galbraith, Miller, Paton and Thompson, 1971; Henderson, 1973).

In screening tests performed by Galbraith *et al.* (1971) it was shown that Gram positive bacteria, which includes many cellulolytic species, are inhibited by long-chain fatty-acids. No inhibition was demonstrated with Gram negative bacteria. Lauric acid was found to be the most active saturated acid but the activity was less than that of the C18 unsaturated acids.

The literature reviewed above suggests ways in which dietary fibre can 1) alter the processes of digestion and absorption in the gut, 2) become associated with the fibrous components of the diet, 3) affect the endogenous losses. It also outlines the mechanism by which fat may alter the digestion of fibre.

These points are summarised below;

The increased intake of fibre could lead to a depression in lipid digestibility due to the effects of both a reduction in retention time and in the absorption of the breakdown products of lipid, and the possible association of fibre with fat of dietary and/or endogenous origin. As a result of an increased supply of fermentable carbohydrate to the microbes in the hind gut, there could be an increased output of microbial matter which has implications for the measurements of the apparent digestibility of lipid, nitrogen and energy. An increased flow of partially digested and/or unabsorbed and free fatty-acids into the hind gut could interfere with microbial fermentation to produce a depression in the digestibility of fibre. An association between fat and fibre could depress the digestibility of both fat and fibre.

In this trial wheat bran provided a source of dietary fibre. Maize oil was used as a source of unsaturated fatty-acids, and tallow to supply predominantly saturated fatty-acids.

2.1.1 MATERIALS AND METHODS

Animals and Diets

Twelve Large White x Landrace entire male pigs of initial mean liveweight 62 kg were used in a series of digestibility, and nitrogen and energy balance trials.

A low fibre basal diet, composed mainly of wheat, barley, hi-pro soya, fishmeal and skim milk (Table 2.1.1) was given at a rate of 1.5 kg/day with the addition of either maize oil or tallow (80 g/day). In addition to this, wheat bran supplements of 80, 160 or 320 g/day were fed to give neutral detergent fibre (NDF) intakes of approximately 40, 80 or 160 g/day from the wheat bran. As a control, the basal diet was fed with the lowest and highest wheat bran supplements, no maize oil or tallow being added. The ration was fed as a meal, twice daily, to which drinking water was added at an approximate feed:water ratio of 1:2.

Table 2.1.1 Ingredient composition of the basal diet

Ingredient	g/kg
Barley	228
Wheat	500
Skim Milk	50
Fishmeal	50
Hi-pro soya	150
Dicalcium phosphate	7.5
Limestone	10
Vitamins and Minerals (PT12C)+	2.5
Salt	2

+, see Appendix 2 for the composition

Trial Procedure

The preliminary feeding period, collections of faeces and urine, and the sampling techniques were as described for Experiment 1.1 (Chapter 1, Section 1.1.1).

The experiment was carried out over three balance periods. For the first period, two pigs were allocated to each combination of fat source and wheat bran level and coded MNDF40, TNDF40, MNDF80, TNDF80, MNDF160 and TNDF160 as described in Table 2.1.2. Following the completion of the 14-day adaptation period the first balance was carried out. For the second period, pigs were maintained on the same level of wheat bran but those pigs which had been given maize oil were fed tallow and *vice versa*. Following the completion of a further 14-day adaptation period the second balance was carried out. For the third period, eight pigs were retained on the trial for the control balance. Four pigs received the basal diet with an 80 g supplement of wheat bran/day (NDF40), the other 4 pigs the basal diet plus 320 g wheat bran/day (NDF160). After 7 days the third balance was carried out.

Table 2.1.2 Summary of the dietary treatments

Treatment	Lipid Source (g/day)		Wheat Bran (g/day)
MNDF40	Maize oil	80	80
TNDF40	Tallow	80	80
MNDF80	Maize oil	80	160
TNDF80	Tallow	80	160
MNDF160	Maize oil	80	320
TNDF160	Tallow	80	320
NDF40	–		80
NDF160	–		320

2.1.2 ANALYTICAL PROCEDURES

The analytical procedures were as described in Chapter One (Section 1.1.2). The acid-hydrolysed fat (AHF) was determined by the method of Wiebul (1919).

Calculations were made to estimate the digestibilities of ADF, AHF, NDF, nitrogen and energy for the whole diet. The digestibilities of the ADF, NDF and energy of the wheat bran were calculated by difference. The amounts of nitrogen retained and excreted were also calculated.

2.1.3 STATISTICAL ANALYSIS

Genstat IV (Lawes Agricultural Trust, 1982) was used in the statistical analysis of the results following the recommended procedures of the Scottish Agricultural Statistics Service. The data were analysed using the technique of analysis of variance. This analysis identified the source of fat and the level of NDF with orthogonal (NDF), linear (NDF_L) and quadratic (NDF_Q) effects. The significance of each main effect was tested by the comparison of the mean squares of NDF, NDF_L, NDF_Q and the NDF x fat interaction with the error mean square. The statistical procedures used were described by Snedecor and Cochran (1973).

2.1.4 RESULTS

The chemical composition of the basal diet and wheat bran, maize oil and tallow are given in Tables 2.1.3 and 2.1.4 respectively.

Table 2.1.3 Chemical composition of the basal diet and wheat bran

	Basal diet	Wheat Bran
GE (MJ/kg DM)	18.2	18.3
Crude Protein (g/kg DM)	230	160
Ash (g/kg DM)	55.0	69.9
NDF (g/kg DM)	110	540
ADF (g/kg DM)	43	149
AHF (g/kg DM)	25.8	51.1
DM (g/kg)	913	933

Table 2.1.4 Chemical composition of maize oil and tallow

	Maize Oil	Tallow
	(g/kg)	
Gross Energy (MJ/kg)	39.5	37.8
C16:0	101	232
C18:0	17	185
C18:1	267	377
C18:2	537	27
C18:3	14	7
C20+	22	7
Others	4	98
Elutables	962	933
Unsaponifiable	20	—
Free Fatty-Acids	11.4	19.7

Digestibility of NDF and ADF

Tables 2.1.5 and 2.1.6 show the effect of the level of wheat bran added to the diet on the digestibility of the NDF and ADF fractions of the control and fat-supplemented diets respectively. The digestibility coefficients are given for the whole diets, and also for the wheat bran alone, as calculated by difference.

Table 2.1.5 Effect of level of added wheat bran on the digestibility of the NDF and ADF of the control diets (NDF40 and NDF160).

(mean values for 4 pigs)

	Level of Wheat Bran (g/day) 80	320	SED	SIG.
Digestibilities				
NDF of whole diet	0.526	0.522	0.0202	NS
NDF of Wheat Bran	0.490	0.509	0.0700	NS
ADF of whole diet	0.390	0.350	0.0320	NS
ADF of Wheat Bran	0.381	0.296	0.1299	NS

The increased intake of wheat bran did not significantly affect the digestibility of the NDF of the whole diet, or the wheat bran (as calculated by difference), in the control (Table 2.1.5) or fat-supplemented diets (Table 2.1.6). No significant linear relationship could be identified between the level of wheat bran in the diet and the digestibility of the NDF of the whole diets, or the wheat bran, thus confirming that the level of wheat bran added to the diet does not appear to be important in determining the digestibility of the NDF fraction.

The digestibility of the NDF of the wheat bran in the fat-supplemented diets (Table 2.1.6) did however increase by 0.114 units, which is equivalent to a 0.3 proportional rise. Although not statistically significant, this trend could be important.

Table 2.1.6 Effect of level of added wheat bran on the digestibility of the NDF and ADF of the fat-supplemented diets (MNDF40, TNDF40, MNDF40, MNDF80, TNDF80, MNDF160, TNDF160)

(†, mean values for 8 pigs; §, mean values for 4 pigs)

		Level of Wheat Bran (g/day)			SED	SIG.		
		80	160	320		NDF	NDF_L	NDF_Q
Digestibilities								
NDF of whole diet								
†Level of bran		0.502	0.493	0.512	0.0138	NS	NS	NS
§Fat * Bran	M	0.502	0.505	0.513	0.0298	NS		
	T	0.502	0.482	0.511				
NDF of Wheat Bran								
†Level of bran		0.376	0.415	0.490	0.0568	NS	NS	NS
§Fat * bran	M	0.377	0.477	0.492	0.0935	NS		
	T	0.375	0.382	0.489				
ADF of whole diet								
†Level of bran		0.330	0.415	0.490	0.0228	NS	NS	NS
§Fat * bran	M	0.312	0.333	0.318	0.0381	NS		
	T	0.347	0.300	0.319				
ADF of Wheat Bran								
†Level of bran		0.012	0.124	0.225	0.1043	NS	NS	NS
§Fat * bran	M	-0.093	0.184	0.223	0.1623	NS		
	T	0.117	0.064	0.226				

M, added maize oil; T, added tallow.

No significant fat * bran interaction could be identified from the analysis of variance indicating that increasing the level of added wheat bran produced the same effect on the digestibility of the NDF and ADF fractions whether the diet was supplemented with maize oil or tallow.

Generally, the NDF of the whole diet was digested to a greater extent than that of the wheat bran. This suggests that differences exist between the NDF of wheat bran and that of wheat, barley and soya, the major components of the basal diet contributing towards its NDF content.

The digestibility of the ADF of the whole diet and of the wheat bran, in both control and fat-supplemented diets, were found to be low (Tables 2.1.5 and 2.1.6). The increased intake of wheat bran tended to depress the digestibility of ADF of the whole diet and the wheat bran in the control diet, although no significant differences were found between the digestibilities of the ADF at the different levels of wheat bran addition (Table 2.1.5).

When the control diet was supplemented with fat, the digestibility of the ADF of the whole diets and wheat bran tended to increase with the level of added wheat bran, although again no significant differences could be found between the digestibility coefficients, and no significant linear trend could be identified (Table 2.1.6).

For both the control and fat-supplemented diets, the digestibility of the ADF of the wheat bran was lower than that measured for the whole diet, indicating differences in the ADF fraction of wheat bran, and wheat, barley and soya in the basal diet, as was found to be the case for NDF.

Table 2.1.7 below gives the mean digestibility coefficients for the NDF and ADF of the whole diets, and the wheat bran, in the presence of maize oil and tallow.

Table 2.1.7 Effect of fat source on the digestibilities of NDF and ADF of the fat-supplemented diets, and the wheat bran.

(mean values for 12 pigs)

	Fat Source		SED	SIG.
	Maize Oil	Tallow		
Digestibilities				
NDF of whole diet	0.506	0.498	0.0216	NS
NDF of Wheat Bran	0.439	0.416	0.0607	NS
ADF of whole diet	0.321	0.322	0.0249	NS
ADF of Wheat Bran	0.105	0.136	0.1021	NS

No significant differences in NDF or ADF digestibility could be found between the diets supplemented with maize oil or tallow. This suggests that the degree of saturation of fatty-acids is not an important factor determining the overall apparent digestibility of the NDF and ADF components of a diet.

Student t-tests were performed to compare the digestibility of the NDF and ADF fractions of wheat bran in the control diet, with those measured in the presence of maize oil and tallow. The results are given in Tables 2.1.8 and 2.1.9.

The mean digestibility coefficients obtained for the diets MNDF40, TNDF40 and MNDF160, TNDF160 were not significantly different from the control diets NDF40 and NDF160 respectively. Thus, the addition of fat in the form of either maize oil or tallow did not significantly depress the digestibility of the NDF fraction of the wheat bran, although the digestibilities for MNDF40 and TNDF40, were lower, as was found to be the case for ADF digestibility.

Table 2.1.8 **A comparison of the NDF digestibility of wheat bran in the pigs given the control and lipid supplemented diets**

Diet	NDF Digestibility
MNDF40	0.377
NDF40	0.490
t	0.61
Level of Significance	NS
TNDF40	0.376
NDF40	0.490
t	0.79
Level of Significance	NS
MNDF160	0.492
NDF160	0.509
t	0.25
Level of Significance	NS
TNDF160	0.489
NDF160	0.509
t	0.41
Level of Significance	NS

When t-tests were performed to examine differences between the digestibility of the ADF of wheat bran in the control diets, and in the presence of fat, a significant difference was found between the MNDF40 and NDF40 diets, but not in the diets to which higher levels of wheat bran were added. Tallow did not have a similar affect to the maize oil (see Table 2.1.9). This suggests that maize oil had a depressing effect on the digestibility of the ADF of wheat bran at a high fat:bran ratio.

Table 2.1.9 A comparison of the ADF digestibility of wheat bran in the pigs given the control and lipid supplemented diets

(t on 6 DF, 2.45; *, $P<0.05$)

Diet	ADF Digestibility
MNDF40	-0.093
NDF40	0.381
t	2.58
Level of Significance	*
TNDF40	0.117
NDF40	0.381
t	1.14
Level of Significance	NS
MNDF160	0.223
NDF160	0.296
t	0.85
Level of Significance	NS
TNDF160	0.226
NDF160	0.296
t	0.68
Level of Significance	NS

Digestibility of AHF

Table 2.1.10 summarises the effects of level of wheat bran and source of fat on the digestibility of the AHF of the whole diets, and of the maize oil and tallow, for the control and fat-supplemented diets.

In the control pigs, the digestibility of the AHF of the whole diet was unaffected by the level of added wheat bran. However, when the diets were supplemented with fat, increasing the level of added bran resulted in a depression of the AHF digestibility of the whole diet, but the difference in digestibility was not found to be significant.

No significant fat * bran interaction could be found which indicates that the digestibility of AHF was similarly affected by increasing wheat bran addition for both maize oil and tallow.

The AHF digestibility of the maize oil supplemented diet was significantly ($P<0.01$) higher than that of the diet to which tallow was added, since the digestibility coefficient of maize oil was found to be significantly ($P<0.01$) higher than that of tallow.

Nitrogen digestibility, nitrogen retention and nitrogen excretion

The effects of added wheat bran on the digestibility of nitrogen, nitrogen retention and nitrogen excretion for the pigs given the control diets are shown in Table 2.1.11.

Nitrogen digestibility was not significantly affected by increasing the level of added wheat bran from 80 to 320 g/day. However, nitrogen retention expressed both in terms of g/day and g/g N intake, both showed a significant increase ($P<0.01$) when the higher level of wheat bran was fed. Faecal nitrogen excretion, expressed as a proportion of the nitrogen intake, increased as more wheat bran was fed, but the difference was not found to be significant. The pigs given the diet supplemented with 320 g wheatbran/day excreted a significantly ($P<0.01$) lower proportion of nitrogen in their urine when expressed as a proportion of their nitrogen intake.

Table 2.1.10 **Effect of level of added wheat bran and source of fat on the digestibility of the AHF of the whole diets, maize oil and tallow, for the control and fat supplemented diets (NDF40, NDF160, NDF40, TNDF40, MNDF80, TNDF80, MNDF160, TNDF160)**

Digestibility		Level of Wheat Bran (g/day)			SED	SIG.		
		80	160	320		NDF	NDF_L	NDF_Q
Control;								
AHF Digestibility								
†Bran		0.595	–	0.603	0.0416	NS	–	–
Fat supplemented;								
For whole diets;								
AHF Digestibility								
§Bran		0.804	0.779	0.770	0.0137	NS	NS	NS
†Fat * bran	M	0.821	0.797	0.797	0.0193	NS		
	T	0.787	0.761	0.743				
For added fat;								
§Bran		0.905	0.884	0.876	0.0210	NS	NS	NS
†Fat * bran	M	0.930	0.912	0.920	0.0297	NS		
	T	0.880	0.857	0.831				

	Fat Source			
	Maize Oil	Tallow	SED	SIG.
For whole diets;				
††AHF	0.805	0.764	0.0111	**
For added fat;				
††AHF added fat	0.921	0.856	0.0171	**

†, mean values for 4 pigs; §, mean values for 8 pigs; ††, mean values for 12 pigs; ** P<0.01, t, 9 DF, 3.25. M, added maize oil; T, added tallow.

Table 2.1.11 Effect of level of added wheat bran on the digestibility of nitrogen, nitrogen retention and nitrogen excretion for the pigs given the control diets (NDF40 and NDF160).

(mean values for 4 pigs)

	Level of Wheat Bran (g/day)		SED	SIG.
	80	320		
N digestibility	0.912	0.895	0.0080	NS
N retention (g/day)	20.11	24.28	0.449	**
N retention (g/g N intake)	0.39	0.43	0.010	**
Faecal N excretion (g/g N intake)	0.089	0.105	0.0078	NS
Urinary N excretion (g/g N intake)	0.520	0.470	0.0117	**

**, $P<0.01$, t, on 6 DF = 2.45

Table 2.1.12 shows the effects of level of added wheat bran on the same variables for the pigs fed the diets supplemented with maize oil and tallow.

No significant differences could be found between the nitrogen digestibility coefficients measured at the 3 levels of wheat bran addition. However, a significant linear relationship of decreasing nitrogen digestibility with increasing wheat bran level was identified in the pigs given the fat supplemented diets.

The digestibility of nitrogen was regressed against the level of added wheat bran (Figure 2.1.0) and the regression equation (with the standard deviations in parentheses) obtained was;

$$\text{N digestibility} = \underset{(0.0077)}{0.904} - \underset{(0.03622)}{0.0936} \times \text{added wheat bran (kg)}$$

The slope of the line was significantly different from zero ($P<0.05$) and the value for $r = 0.48$.

Table 2.1.12 Effect of level of added wheat bran on the digestibility of nitrogen, nitrogen retention and nitrogen excretion for the pigs given the fat-supplemented diets (MNDF40, TNDF40, MNDF80, TNDF80, MNDF160 and TNDF160)

(†, mean values for 8 pigs; §, mean values for 4 pigs)

		Level of Wheat Bran (g/day)			SED	SIG.		
		80	160	320		NDF	NDF_L	NDF_Q
N Digestibility								
†Bran		0.900	0.884	0.876	0.0086	NS	*	NS
§Fat * Bran	M	0.901	0.881	0.876	0.0135	NS		
	T	0.898	0.888	0.875				
N retention (g/day)								
†Level of bran		20.18	23.30	22.76	1.676	NS	NS	NS
§Fat * bran	M	19.86	23.18	21.89	2.417	NS		
	T	20.50	23.43	23.64				
N retention (g/g N intake)								
†Bran		0.393	0.439	0.399	0.0302	NS	NS	NS
§Fat * bran	M	0.385	0.438	0.383	0.0453	NS		
	T	0.400	0.440	0.415				
Faecal N excretion (g/g N intake)								
†Bran		0.100	0.116	0.124	0.0087	NS	NS	NS
§Fat * bran	M	0.099	0.119	0.123	0.0135	NS		
	T	0.102	0.112	0.125				
Urinary N excretion (g/g N intake)								
†Bran		0.506	0.446	0.476	0.0314	NS	NS	NS
§Fat * bran	M	0.514	0.445	0.492	0.0519			
	T	0.499	0.447	0.461				

*, $P<0.05$, t on 9 DF = 2.26

Nitrogen retention, expressed as g/day and as g/g N intake, was not found to be significantly affected by the increasing addition of wheat bran. No significant linear relationship could be identified between the level of added wheat bran and nitrogen retention.

Faecal nitrogen excretion, expressed as a proportion of the nitrogen intake, was increased as more wheat bran was fed, but the effect was not found to be statistically significant, as was the case for the pigs given the control diets (NDF40 and NDF160). Urinary nitrogen excretion, expressed in the same way, was found to increase with increasing level of added wheat bran, but the trend was not found to be significant, unlike the situation in the control pigs. There was no significant NDF x Fat interaction for faecal or urinary nitrogen excretion.

The source of fat did not have a significant effect on nitrogen digestibility, nitrogen retention, faecal or urinary N excretion (Table 2.1.13). Similar values were obtained for both the diets supplemented with maize oil and those supplemented with tallow.

Energy digestibility and the DE value of wheat bran

Table 2.1.14 details the effects of added wheat bran and source of lipid on the digestibility of energy, and the DE value of wheat bran for the control and fat-supplemented diets (as calculated by difference).

Table 2.1.13 Effect of fat source on the digestibility of nitrogen, nitrogen retention and nitrogen excretion

(mean values for 12 pigs)

	Fat Source		SED	SIG.
	Maize Oil	Tallow		
N digestibility	0.886	0.887	0.0085	NS
N retention (g/day)	21.64	22.52	1.422	NS
N retention (g/g N intake)	0.40	0.42	0.028	NS
Faecal N excretion (g/g N intake)	0.114	0.113	0.0084	NS
Urinary N excretion (g/g N intake)	0.484	0.469	0.0337	NS

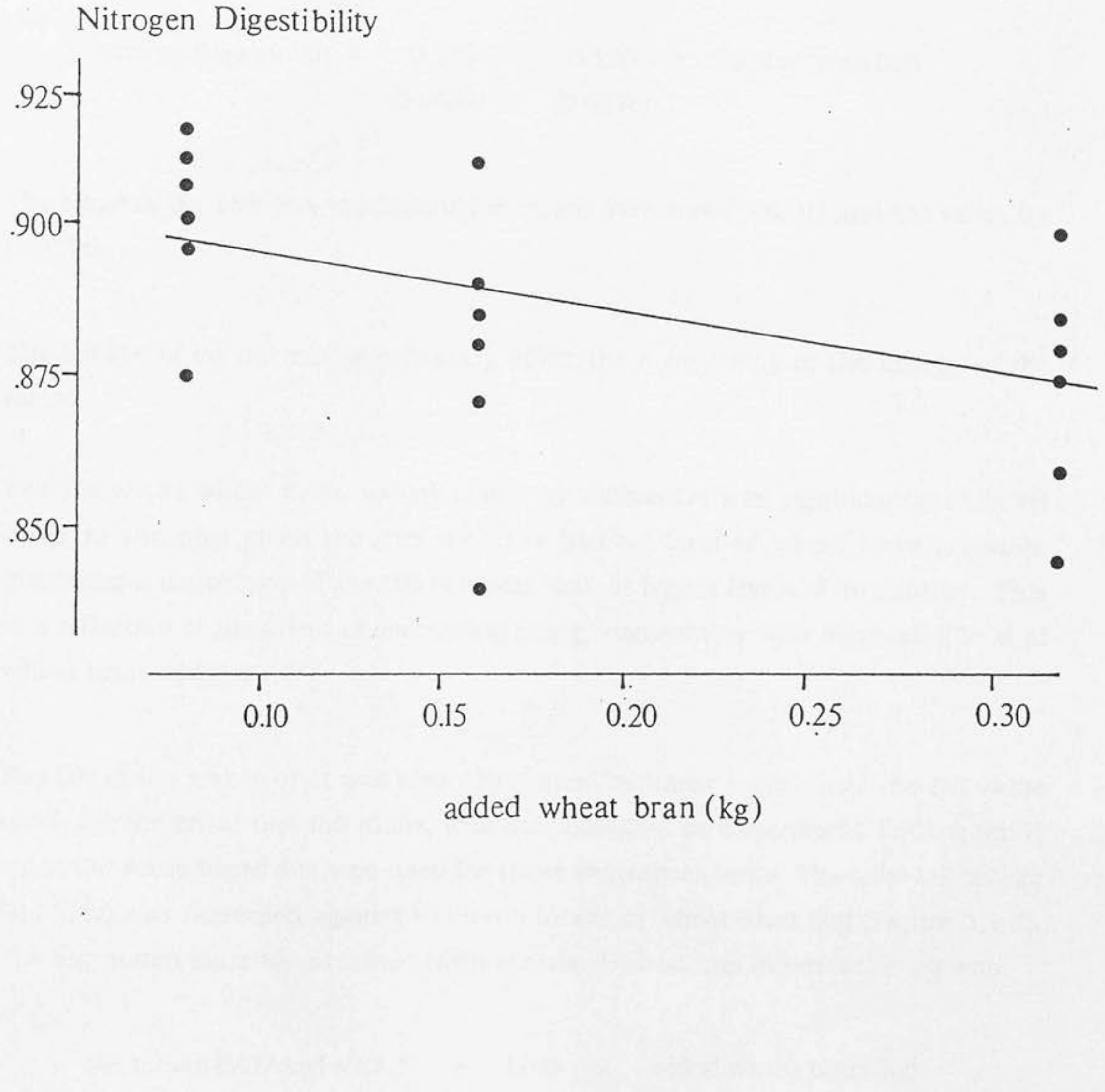


Figure 2.1.0 **Relationship between nitrogen digestibility and level of added wheat bran**

The digestibility of energy was significantly ($P<0.01$) depressed at the highest level of wheat bran addition for both the control and fat supplemented diets. The relationship between the level of added wheat bran and energy digestibility was found to be linear with no significant deviations from linearity. Energy digestibility was regressed against the level of wheat bran (Figure 2.1.1) and the regression equation obtained is shown below (with standard deviations in parentheses);

$$\text{Energy Digestibility} = \underset{(0.0058)}{0.875} - \underset{(0.0275)}{0.150} \times \text{added bran (kg)}$$

The slope of the line was significantly different from zero ($P<0.01$) and the value for $r = 0.75$.

The source of fat did not significantly affect the digestibility of the energy of the diets.

The DE of the wheat bran, as calculated by difference, was significantly ($P<0.01$) lower in the pigs given the diet with the highest level of wheat bran addition, indicating a depression of the DE of wheat bran at higher levels of its addition. This is a reflection of the affect of decreasing energy digestibility with increasing level of wheat bran addition.

The DE of the wheat bran was also determined by linear regression. The DE value used, for the basal diet fed alone, was that obtained in Experiment 1 (Chapter 1) since the same basal diet was used for these two experiments. The total DE intake (MJ/day) was regressed against the fresh intake of wheat bran (kg) (Figure 2.1.2). The regression equation obtained (with standard deviations in parentheses) was;

$$\text{DE intake (MJ/day)} = \underset{(0.13)}{21.7} + \underset{(0.69)}{10.9} \times \text{added wheat bran (kg)}$$

The slope of the line was significantly different from zero and the correlation coefficient, $r = 0.98$.

Table 2.1.14 Effect of level of added wheat bran and source of fat on the digestibility of energy of the whole diets,and the DE value of wheat bran for the control and fat supplemented diets (NDF40, NDF160, MNDF40, TNDF40, MNDF80, TNDF80, MNDF160, TNDF160)

Digestibility	Level of Wheat Bran (g/day)			SED	SIG.		
	80	160	320		NDF	NDF_L	NDF_Q
Control;							
For whole diets							
†Energy	0.871	–	0.833	0.0080	**	–	–
†DE (MJ/kg DM)	15.85		15.16	0.1469	NS		
For wheat bran;							
†DE (MJ/kg DM)	14.96		11.91	1.82	NS		
Fat supplemented;							
Energy							
§Bran	0.865	0.848	0.828	0.0054	**	**	–
†Fat * bran M	0.868	0.851	0.834	0.0099	NS		
T	0.863	0.846	0.823				

	Fat Source		SED	SIG.
	Maize Oil	Tallow		
Added fat;				
††Energy	0.851	0.844	0.0068	NS

†, mean values for 4 pigs; §, mean values for 8 pigs; ††, mean values for 12 pigs; ** P<0.01, t, on 6DF, 3.71.

The DE of the basal diet was therefore 14.5 MJ/kg (15.9 MJ/kg DM). The DE of the wheat bran was 10.9 MJ/kg (11.68 MJ/kg DM).

The value obtained for the wheat bran by linear regression was in good agreement with that measured by difference when 320 g wheat bran were fed with the basal diet. These two values are lower than that obtained by difference when only 80 g of wheat bran. This indicates the error involved in determining DE values by difference when only a relatively small sample of the test material is fed with the basal diet.

2.1.5 DISCUSSION

This experiment has investigated the effect of level of added wheat bran and source of fat, and their interactions, on nutrient digestibilities and nitrogen balance. In conclusion, the level of food fibre added as wheat bran did not appear to be an important factor determining the digestibility of the NDF and ADF components of the diet, or of the wheat bran. Secondly, the increasing addition of wheat bran did not depress the digestibility of the AHF fraction, but the addition of fat, in particular an unsaturated fat such as maize oil, caused a reduction in ADF digestibility at the highest fat:bran ratio. An inverse relationship was apparent between the level of wheat bran added and the digestibilities of nitrogen and energy. The addition of wheat bran also resulted in an alteration in the route of nitrogen excretion, which had implications for the amount of nitrogen retained. Lastly, the source of fat appeared to be important only in determining its own digestibility; the less saturated maize oil was more digestible than tallow, which contained a higher proportion of saturated fatty acids.

The interactions of fibre and fat, both with each other and with the other components of the diet, thus appear complex. Possible outcomes of these interactions were outlined in Section 2.1.0. It was suggested that an increased intake of fibre could depress lipid digestibility through its effects on gut motility and a reduction in the absorption of the products of lipid digestion. Undigested and partially digested lipid could therefore enter the hind gut and interfere with microbial metabolism, leading to a lowering of fibre digestibility. The association of lipid with the fibrous fraction of the digesta may also render the fatty-acids less available for digestion and absorption. Depending on the relative inhibitory effects of lipid and fibre, an increased microbial metabolism could result in a greater output of bacterial lipid. These effects are likely to be governed by the origin of dietary fibre since wide ranging chemical and physical properties are reported in the literature for different sources of fibre.

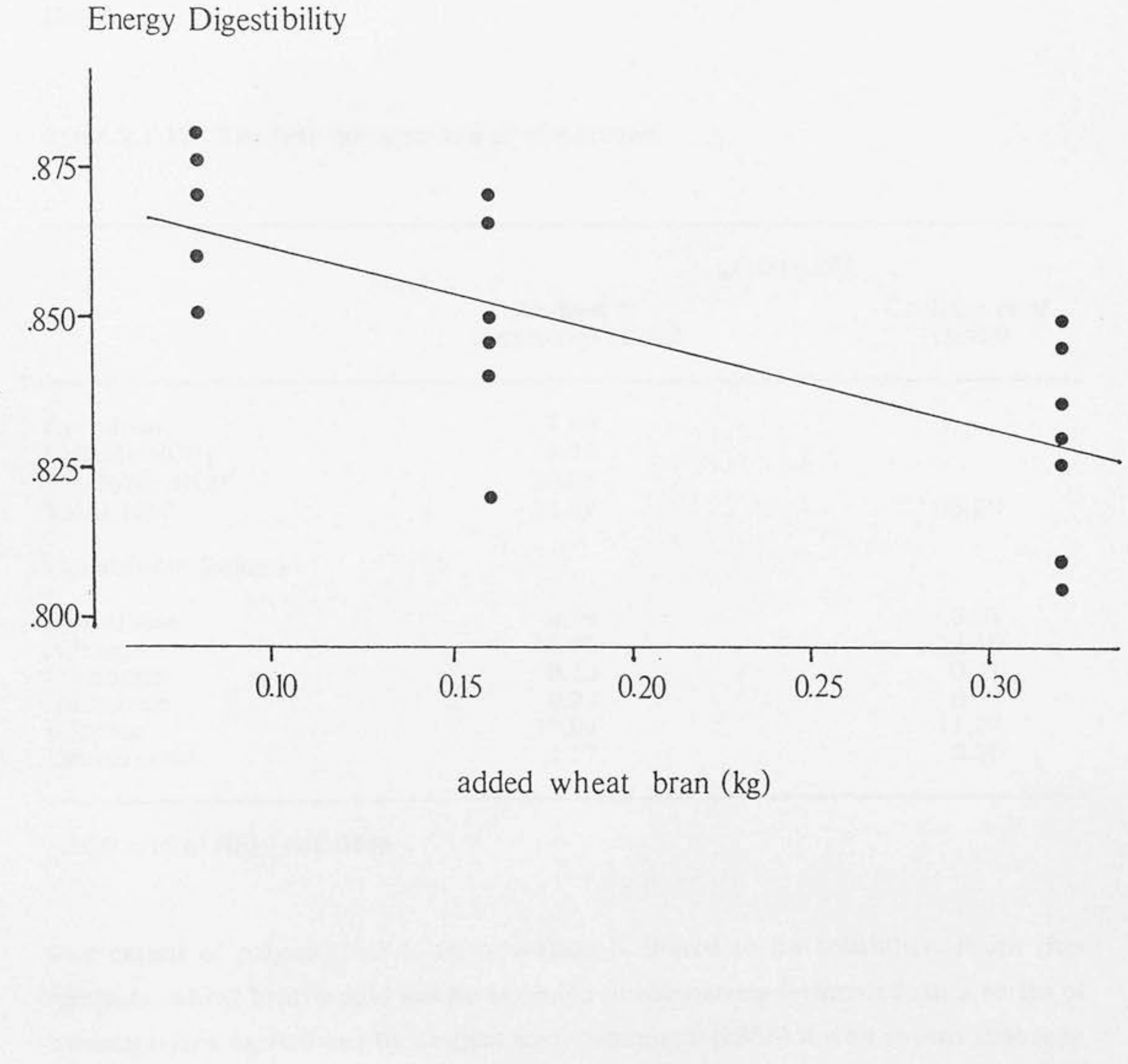


Figure 2.1.1 Relationship between energy digestibility and level of added wheat bran.

The chemical analysis of the wheat bran used in this trial revealed that it contained approximately 500 g NDF/kg DM. A low proportion of this (0.28) was found to be cellulose and lignin (ADF), and by difference 0.72 of the NDF fraction was hemicellulose. Englyst and Cummings (1985) measured the starch and non-starch polysaccharide (NSP) content of wheat bran, and their breakdown in the small intestine of man. It was found that wheat bran contained 41.67 g NSP/100 g DM of which only 0.08 was measured to be soluble. The analysis is detailed in Table 2.1.15 along with a similar analysis carried out by Graham, Hesselman and Aman (1986).

Table 2.1.15 The NSP components of wheat bran

	g/100 g DM	
	Englyst & Cummings (1985)	Graham *et al.* (1986)
Cellulose	7.98	
Soluble NCP[1]	3.22	
Insoluble NCP	30.37	
Total NSP	41.57	36.29
Constituent Sugars		
Arabinose	9.79	8.61
Xylose	18.76	12.10
Mannose	0.13	0.11
Galactose	0.71	0.97
Glucose	11.01	11.27
Uronic acid	1.17	2.36

[1] NCP = total NSP- cellulose

The extent of polysaccharide fermentation is linked to its solubility. From this analysis, wheat bran would not be expected to extensively fermented. In a series of investigations carried out by Englyst and Cummings (1985) it was shown that NSP is virtually completely recovered from the small intestine of man. Longland and Low (1987) examined the apparent digestibilities of the individual NSP in a diet containing wheat bran given to growing pigs. The digestibilities were generally poor and highly variable. The results are detailed in Table 2.1.16. The digestibilities obtained by Graham *et al.* (1986) are also shown.

The results of this trial indicate that quantitatively, the NDF fraction and the NSP fraction are similar. Treatment with neutral detergent solution solubilises the pectin and hence removes uronic acid moieties. Uronic acid represents only a small portion of the dietary fibre of wheat bran and its loss, therefore, did not lead to large errors in the estimation of the fibre content of wheat bran.

Hemicellulose, which formed a high proportion of the NDF fraction of the wheat bran fed, is not chemically or nutritionally uniform. It contains a variety of sugars (e.g. xylose, arabinose, glucose, mannose) and it is associated with lignin, linkages being formed between lignin and arabinoxylan. It is intertwined with lignin and laid down around cellulose fibres with a physical admixture through covalent bonding (Aspinall and Ferrier, 1957). The digestibility and rate of digestion of hemicellulose is generally considered to be greater than that of cellulose (Van Soest, 1985). Eastwood (1973) showed that hemicelluloses adsorb water well and this could result in an increased bulk and rate of passage. Low (1985) discussed the fact that dietary fibre will swell to a variable extent in water. The water-holding capacity is determined by the physicochemical structure of the molecule, but the pH and electrolyte concentration of the surrounding medium are also determining factors. During its passage through the gut, dietary fibre will therefore swell to varying degrees. Hemicellulose has been shown to swell in water but when contained in an insoluble matrix of less hydrophilic substances, which may be the case for wheat bran, the extent to which it swells may be limited.

Table 2.1.16 The apparent digestibilities of the NSP in a diet containing wheat bran

	Apparent Digestibility	
	Longland & Low (1987)	Graham *et al.* (1984)
Arabinose	0.124	0.257
Xylose	0.629	0.377
Galactose	0.191	0.178
Glucose	0.343	0.114
Uronic acids	0.485	0.136
Total NSP	0.506	0.156

The mean digestibilities of hemicellulose by the pigs on each dietary treatment in this trial are presented in Table 2.1.17. The results were not considered suitable for any form of statistical analysis since they were calculated using the difference between the NDF and ADF fractions. Hence the errors in measuring both of these fractions will be passed onto the hemicellulose component of the diet. Generally, digestibilities for hemicellulose were high. There seems to be very little effect of increasing wheat bran level on the digestibility of hemicellulose in the whole diet, but a clear trend was observed for the hemicellulose fraction of the wheat bran (as calculated by difference). As the level of wheat bran fed increased, the digestibility of the hemicellulose fraction decreased. Considering these results with those obtained for the digestibility of NDF and ADF, it can be seen that the digestibility of the ADF fraction increases at a greater rate than that of the NDF fraction, hence producing a decrease in the digestibility of hemicellulose with increasing level of wheat bran.

Table 2.1.17 The digestibility of hemicellulose by the pigs given the control and lipid supplemented diets

Diet	Whole Diet	Wheat bran
MNDF40	0.610	>1
MNDF80	0.596	0.937
MNDF160	0.608	0.837
TNDF40	0.590	>1
TNDF80	0.578	0.903
TNDF160	0.584	0.807
NDF40	0.604	>1
NDF160	0.606	0.835

Van Soest (1985) indicated that the large scale physical structure of dietary fibre is the main factor determining some of its nutritional properties, and that this factor is more evident in less digestible fibres when the insoluble fibrous matrix persists in the gut. Indigestible material decreases transit times so that highly fermented sources have little effect on transit times (Wrick *et al.*, 1983). Wheat bran was not shown to be highly digestible in these studies or in those of Longland and Low

(1987), and the presence of indigestible residues in the gut may have some effect on bulk and transit times.

Wheat bran has been used in several studies of gastrointestinal transit times and the results vary with the type of diet fed. Fioramonti and Bueno (1980) noted a vast reduction in transit time when wheat bran was added to a milk powder-based diet, but when it was added to cereal-based ration, no effect was seen (Canguilhem and Labie, 1977). This was also found to be the case by Latymer, Low and Woodley (1985) when supplements of bran were fed in combination with a barley/soya basal diet. Transit times were not significantly altered in any region of the gut, or overall, although there was some phase separation between solid and liquid. Low (1985) suggested that the lack of effect of supplementary dietary fibre in reducing transit times of cereal-based diets (which have a relatively high content of dietary fibre) may imply that there is a minimum transit time in growing pigs irrespective of the fibre content of the diet.

Potkins, Lawrence and Thomlinson (1985) studied digesta transit time to the rectum and terminal ileum, and gastric emptying with diets into which bran, oatfeed, guar gum or pectin had been substituted for barley. Barley, guar gum, and pectin significantly accelerated gastric emptying. No significant effects were found on transit time to the terminal ileum but bran reduced the transit time to the rectum. Sissons *et al.* (1984) and den Hartog *et al.* (1985) obtained results which suggested that motor activity may in fact be reduced in the duodenum by the presence of indigestible particles, resulting in an increased transit time to the terminal ileum.

The evidence suggests that wheat bran has very little effect on gastrointestinal transit time of digesta in pigs given unpurified diets, similar to those fed in this trial. It is likely that any effects of dietary fibre on the digestibility of maize oil or tallow will therefore be mediated by factors interfering with the hydrolysis of the oil/fat, or the absorption of their digestion products, rather than a reduced time for the processes of digestion and absorption to occur. Microbial output of lipid could also lead to a reduction in the apparent digestibility of lipid.

The mean digestibilities for maize oil and tallow (0.921 and 0.856) are lower than values reported in the literature. Morgan *et al.* (1984) found tallow to have a digestibility of 0.963 as compared to 0.856 in this trial. The mean DE of Tallow measured in this trial was 32.86 MJ/kg, and the corresponding value for maize oil was 36.38 MJ/kg. Data on maize oil is not readily available in the literature although values for soya oil, very similar to maize oil in its fatty-acid composition, can be found. Morgan *et al.* (1984) found the soya oil to have a DE of 40.8 MJ/kg, and a digestibility of 0.986. The mean digestibilities of maize oil and tallow are both reduced, by approximately 0.07 and 0.11 respectively, when wheat bran is added to the diet. It is also apparent that the digestibility coefficient of tallow, the less digestible of the two fats, is reduced to a greater extent than that of maize oil.

Murray, Fuller and Pirie (1977) concluded that bulk had no effect in the case of protein digestion, but that it was hydrolysis of protein rather than the absorption of the products of protein digestion which was impaired when gel-forming polysaccharides were given. Southgate (1973) concluded that the physicochemical effects from increased bulk reduced the diffusion of digestion products towards the absorptive mucosal surface. It may be that lipid hydrolysis and absorption are therefore impaired in the presence of dietary fibre. The fairly high proportion of hemicellulose in wheat bran is likely to be important in these processes since on swelling it forms a gel which could hinder the action of lipolytic enzymes and reduce the flow of fatty-acids towards the absorptive mucosa.

Reduced hydrolysis and absorption in the small intestine will result in an increased flow of lipid into the large intestine. Sambrook (1979) studied the flow of total lipid in the gastrointestinal tract of pigs using diets containing starch, sucrose and groundnut meal (SSG), starch, sucrose and casein (SSC) or wheat, barley and fishmeal (WBF), which contained different levels of dietary fibre. There was substantial secretion of lipid into the proximal small intestine and the major site of lipid absorption was the distal portion. In the large intestine, little or no further absorption of lipid occurred for SSG or SSC, but there was a significant synthesis or secretion of lipid for the WBF diet. Fibre digestion occurred in both the small and large intestine and apparent absorption of ADF in different regions was influenced by the diet fed.

The most important feature of the digestion of lipid in Sambrook's work was the net addition of considerable amounts of endogenous lipid to the gut contents. This lipid would probably have originated from the bile secretions, sloughed mucosal cells, secretions through the intestinal mucosa and also from the bacterial population of the large intestine. Bile plays a very important role in the digestion and absorption of dietary fat. Conjugated bile acids assist in the emulsification of fat, in particular the micellar dispersion of the products of fat digestion, facilitating their absorption.

Sambrook (1981) studied the flow and composition of bile entering the duodenum of pigs given the diets SSC or WBF. The variation between and within pigs was high, but the pigs on the WBF diet produced more bile and total lipid than those fed the semi-purified diet. It is therefore unlikely that the emulsification of fats will be impaired since these results suggest that there will be an excess amount of bile available for this process. However, dietary fat which may have become associated with the fibrous components of the diet may be unavailable for absorption, and will therefore pass into the hind gut, along with the bile. The conjugated acids found in the bile and in the upper duodenum are only weakly adsorbed onto dietary fibre, but under the influence of the bacteria in the large intestine unconjugated acids are produced which are strongly adsorbed. Eastwood and Hamilton (1968) found adsorption to be pH dependent being greatest at an acid pH. The VFA produced by the fermentation of fibre could well lower the pH in the hind gut and encourage organic adsorption. Cereal fibre is capable of binding bile acids and it is likely that some bile acids became associated with the wheat bran fed in this trial. This would increase faecal lipid output and hence reduce lipid digestibility. Low and Rainbird (1984) concluded that there appeared to be an increased exfoliation of the gut wall with high fibre diets and it is likely that this could also contribute to higher endogenous losses of lipid.

There are a number of different ways in which fat entering the large intestine could affect the microbial activity. Most of the metabolic exchanges which occur between bacterial cells and the environment must involve the surface of the microorganism, unless the cell is lysed and the contents released into the medium. Bacterial cells have a well developed membrane involving complex structural lipids and it is likely that a large proportion of lipid adheres to the microbial cells (Harfoot, 1978). Surface active compounds such as lipids are therefore likely to have some effect, especially the polar lipids e.g. unesterified fatty-acids (Czerkawski & Clapperton, 1984). Bacteria can hydrolyse water-soluble, conjugated organic acids and the less water-soluble fraction produced will be precipated, adsorbed to fibre through the formation of hydrophobic bonding or adsorbed by bacteria.

In a review by Nieman (1954) it was concluded that fatty-acids in very low concentrations may influence the growth of various microorganisms; the effect can be inhibition or growth promotion. The magnitude of the effect is dependent on the concentration and nature of the fatty acids and the bacterial species involved. Generally, it was found that only Gram positive organisms were susceptible to the actions of fatty acids although influences on Gram negative organisms were also observed. Growth inhibition was affected by both saturated and unsaturated fatty-acids. The anti-bacterial activity of unsaturated fatty acids increased with the number of double bonds, and the natural cis-forms were generally more active than their trans-isomers. The anti-bacterial activity of saturated fatty-acids was optimal at a chain length of around 12. Growth stimulating properties were exhibited mostly by unsaturated fatty-acids (C18) and the stimulatory activity of these acids decreased with increasing saturation. Galbraith *et al.* (1971) and Henderson (1973) confirmed some of these findings. A large proportion of the fatty-acids released by the hydrolysis of the maize oil and tallow fed in this trial will be mainly in the range C16 to C20 as shown by the chemical composition in Table 2.1.3. Their potency as anti-bacterial agents is therefore likely to be low, and their presence may even be stimulatory to microbial growth.

Many authors have studied the effects of lipid on fibre digestibility in the ruminant. Brooks *et al.* (1954) looked at the effect of added fat on the digestion of cellulose and protein by ovine microorganisms. The addition of corn oil reduced cellulose digestion and lowered protein digestion in sheep. The total number of bacteria present was not reduced. Lard added to the basal ration also decreased cellulose digestion. Clapperton and Steele (1983) also found that the addition of fat to the diet of ruminants resulted in a reduction in apparent digestibility of fibre in most cases. The change in fibre digestion was also influenced by the fatty-acid composition of added lipid, short-chain fatty-acids causing a greater depression than long-chain acids and unsaturated acids a larger reduction than saturated acids. Free fatty-acids also caused a much greater depression in fibre digestibility than their corresponding triglycerides. The mechanism of the depression was not clear but it was thought that it may be due to physical coating of the fibre particles.

The free carboxyl group greatly increased the depression in fibre digestibility which implies hydrolysis must first occur.

The trend described above was also observed in this current study. The values in Table 2.1.8 and 2.1.9 illustrate this point. Maize oil is likely to have caused a greater depression in ADF digestibility than tallow by virtue of the unsaturation of its component fatty-acids. Table 2.1.4 detailed the chemical composition of the fat sources fed in this trial. Approximately 0.82 of the fatty-acids of maize oil were unsaturated (present mainly as C18:1, C18:2 and C18:3), whereas the corresponding value for tallow was 0.41. The proportion of free fatty-acids in both fat sources was low, and the actions of this small proportion is therefore likely to be small. The chemical composition of the tallow used in this trial revealed that it was not a typical feed grade tallow (which would have contained an even higher proportion of saturated and free fatty-acids), but is more accurately described as white grease. The differences obtained between maize oil and tallow are therefore probably smaller than might be expected.

The effect seen in this trial of a greater digestibility of fibre at higher levels of its inclusion with the same level of added fat, has also been illustrated in ruminants (Andrews, 1966), and much of the work which suggests possible mechanisms for this has been performed using bacteria from sheep.

Harfoot, Crouchman, Noble and Moore (1974) looked at the competition between food particles and rumen bacteria in the uptake of long-chain fatty-acids and triglycerides. The uptake of FFA and triglycerides by the bacteria was largely due to physical adsorption. With increasing saturation of the FFA less adsorption occurred and in all instances the presence of food particles reduced greatly the extent to which FFA were adsorbed onto the bacteria. It is likely therefore, if the large intestinal bacterial population behaves similarly to that of the rumen, that as more fibre enters the gut, the lipid will tend to become associated with the food particles rather than the surface of the bacteria. The anti-microbial effect on fibre digestibility is likely therefore to be minimised at higher fibre:fat ratios.

Devendra and Lewis (1974) suggested a possible mechanism by which the physical coating of dietary lipid on the fibre component might lead to a decreased digestibility. Initially, the fibre surface is hydrophilic with the microorganisms in the aqueous medium actively breaking down the fibre so that the digestibility of the fibre is high. The addition of lipid causes a physical coating of the surface of the fibre and the surface is made hydrophobic. This reduces the angle of contact of the microorganisms on the fibre surface leading to a depression in fibre digestibility. The extent to which this occurs probably determines the magnitude of fibre digestibility and is dependent on the level of fibre in the diet. When the level of dietary fibre is high the lipid is spread over a wider surface area, so that physical coating is much less in comparison with diets of lower fibre content.

The discussion so far has considered fat/fibre interactions in the large intestine. However, if fibre digestion occurs anterior to the large intestine it may be similarly effected. Millard and Chesson (1984) discussed the modification of dietary fibre anterior to the terminal ileum. The small intestine of pigs is extensively and permanently colonised by microorganisms. Friend *et al.* (1963), Argenzio and Southworth (1975) and Clemens *et al.* (1975) identified VFA in the stomach and small intestines of slaughtered pigs, and VFA have also been found in digesta collected from the duodenum, mid-jejunum and terminal ileum (Sambrook, 1979). Lactic and acetic acids were present in the largest quantities, with smaller amounts of propionic and butyric acids. Lactic acid has only been detected in small amounts in the large intestine which suggests that contamination from the large intestine, as a result of disturbed flow by cannulation, is unlikely. However, the fermentation of any carbohydrate leads to the formation of VFA. Mason and Just (1976) showed that as the digestible carbohydrate intake increases there will be relatively more fermentation in the stomach and less in the large intestine. VFA therefore indicate the presence of microbes anterior to the terminal ileum, and fermentation anterior to the large intestine is therefore strongly implicated.

Losses of certain fibrous fractions in the small intestine have been reported by some authors. Keys and De Barthe (1974) reported losses of hemicellulose up to 0.47 before the terminal ileum from diets containing 300 g cell wall material/kg. An apparent digestibility of cellulose of 0.33 was also recorded anterior to the terminal ileum. Sambrook (1979) also reported a loss of ADF anterior to the duodenum and between the mid-jejunum and terminal ileum.

These results suggest that microbial fermentation of cell wall components can occur anterior to the terminal ileum. Millard and Chesson (1984) reported a substantial loss of pectic polysaccharides, phenolic material and (1->4) linked glucan (cellulose) from swedes. The entire tract was removed from unmodified animals and was sectioned. The digesta was subsequently examined for microbial activity. Pectinolytic and cellulotytic bacteria were present in substantial numbers in swede-fed pigs, but much reduced numbers of pectinolytic bacteria were isolated from bran-fed animals. The faster overall transit time found in the bran-fed pigs compared to those given swede, may have been an important factor mediating the establishment of a stable cellulolytic population in these animals.

In view of the work of Millard and Chesson (1984) it would appear that digestion anterior of the hind-gut of the non-starch polysaccharides of the wheat bran fed in this trial will be minimal. The assumption that the NDF and ADF fractions of wheat bran are digested almost entirely in the hind gut may therefore be considered correct, and any interfering effects of fat with the process of fibre digestibility are likely therefore to take effect in this region of the gastrointestinal tract.

The effects discussed so far have only been concerned with the interaction of dietary fibre and added lipid. However, the digestibilities of energy, nitrogen and the route of nitrogen excretion were also found to be effected by the addition of wheat bran to the diet.

Energy digestibility was depressed by the increasing level of wheat bran in a similar manner in both the control pigs and the pigs given the fat supplemented diets. This suggests that the mechanism by which energy digestibility is depressed was not significantly affected by the addition of maize oil or tallow. Many authors have reported a similar inverse relationship. Stanogias and Pearce (1985) examined the effects of soyabean hulls, lupin hulls, pea hulls, wheat bran, maize hulls and cobs, oat hulls and lucerne stems on the apparent digestibility of dietary components. They found that both the amount and type of dietary fibre significantly influenced the apparent digestibility of energy, but they were unable to draw any conclusions about the extent to which this was due to a direct decrease in the apparent digestibility of energy, or whether it was due to an increased excretion in the faeces of microbial and endogenous material. The level of fibre in the diet did not appear to influence the apparent digestibility of its own components, as was found in this experiment.

The apparent digestibility of nitrogen, although not significantly lowered by the addition of wheat bran in this trial, tended to decrease with increasing wheat bran level. The effects of fibre level of the digestibility of nitrogen will be investigated further in Experiment 2.2.

The results also illustrate an alteration in the route of nitrogen excretion. The control pigs given the higher level of wheat bran excreted a significantly lower amount of nitrogen in their urine (Table 2.1.10). The fermentation of fibre in the hind gut of the pig is effected by the proliferation of the bacteria which retain more nitrogen during their growth, and are passed out in the faeces. This is then recorded as a depression in nitrogen digestibility. The effect seen in this experiment, i.e. a decrease in urinary nitrogen excretion which exceeded the increase in faecal nitrogen excretion, therefore increasing nitrogen retention, was also observed by Malmlöf and Hakansson (1984). Morgan and Whittemore (1988) confirmed these observations but did not establish whether this nitrogen was retained as useful protein in the carcase or as increased gut wall protein. The results of the experiments in Chapters 3 and 4 explain in part their findings on this subject.

To summarise, the results of this present study show that the apparent digestibility of energy and AHF are inversely related to the proportion of dietary fibre in the diet, and to a lesser extent this also seems to be true for nitrogen. The results obtained however do not illustrate clearly the extent to which this is due to a decrease in apparent digestibility, or due to an increased faecal excretion of microbial and endogenous material. The level of fibre added to the diet, at the levels fed in this trial, did not appear to influence the apparent digestibility of its own components.

The depressant effect of unsaturated fatty-acids appears to be limited to certain components of the dietary fibre, suggesting the preferential association of unsaturated fatty-acids with specific chemical moieties. The digestibility of NDF, although not significantly depressed by the addition of either maize oil or tallow, tended to be slightly lower in the diets supplemented with maize oil when compared to those to which tallow was added.

If the digestibilities of energy and AHF were both depressed by the same mechanism i.e. that of an increased output of microbial material, then nitrogen digestibility would be expected to be similarly effected. A tentative conclusion to draw at this stage would be that the decrease in AHF digestibility measured in this experiment was probably brought about by an increase in output of endogenous lipid, and lipid which has in some way become associated with the fibre rendering it less available for the processes of digestion and absorption.

2.2 THE EFFECT OF LEVEL OF FIBRE AND PROTEIN IN THE DIET ON THE DIGESTIBILITY OF FIBRE AND NITROGEN

2.2.0 INTRODUCTION AND AIMS

In the ruminant, microorganisms within the gastrointestinal tract play an important role in the nitrogen nutrition of the host, but they do not appear to be so important in the protein metabolism of the monogastric. Many of the reactions involved in the metabolism of proteins may be affected by the microorganisms within the gut, and whether the effect they have on the nutrition of the host animal is measurable is therefore of special concern. If pigs are given diets which supply a source of fermentable carbohydrate, leading to increased microbial metabolism and proliferation within the gut, then there is likely to be some effects on the protein economy of the host animal. Figure 2.2.0 details a scheme of possible activities of microorganisms within the gastrointestinal tract which are likely to influence the course of digestion and absorption of proteins.

The literature reviewed below summarises the work which has shown how the gastrointestinal microflora may affect 1) the digestion of protein and its absorption in the small intestine 2) protein digestion and the absorption of nitrogen in the large intestine and 3) the interactions between protein and fibre digestion. The implications of these effects for the measurement of nitrogen digestibility, retention and excretion will be discussed.

Protein digestion and nitrogen absorption in the small intestine

In the small intestine, digestion and absorption of proteins occurs rapidly as a result of the actions of large quantities of endogenous enzymes and the large epithelial area. Microorganisms within the gut have to compete with the hosts enzymes for nitrogenous compounds in the diet. Urea diffuses from the tissues into the gut lumen and is a ready source of nitrogen for those bacteria with urease activity. The microorganisms themselves are also capable of breaking down nitrogenous compounds to produce ammonia, and if a fermentable energy source is available then nitrogen may become incorporated into bacterial cells, thus preventing its absorption.

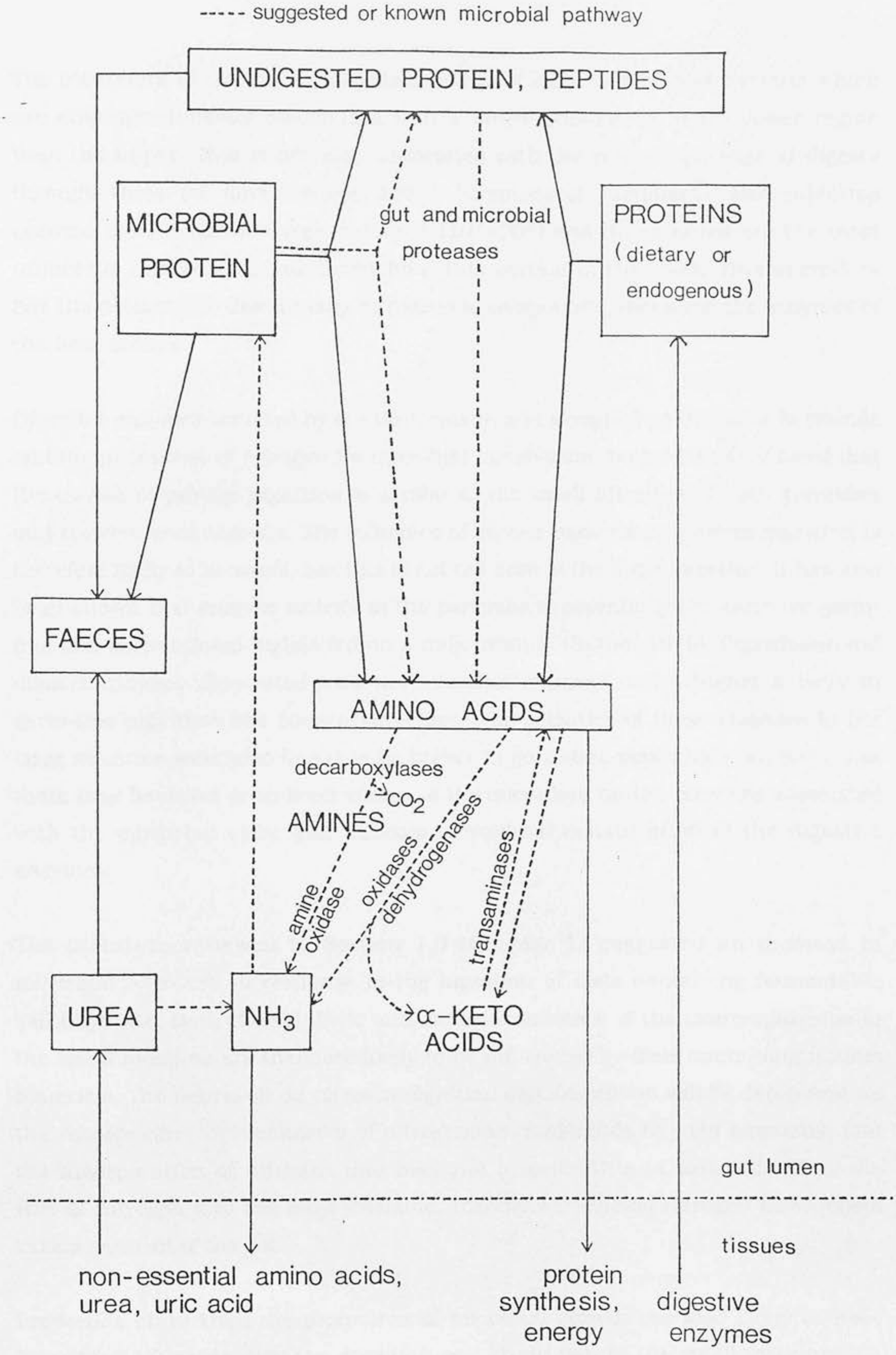


Figure 2.2.0 **An outline scheme of some possible activities of the microorganisms of the gut which might influence the course of digestion and utilisation of protein.**

The microflora of the small intestine consists of large numbers of bacteria which are disproportionately distributed with a larger population in the lower region than the upper. This is probably associated with the rates of passage of digesta through these sections (Savage, 1977). Streptococci, lactobacilli and coliforms become established in large numbers (10^7-10^9) and *Bacteroides* are the most numerous anaerobic genus throughout this portion of the tract. This microflora has the potential to digest many nitrogenous compounds, including the enzymes of the host animal.

Digestive enzymes secreted by the host, mucin and sloughed epithelial cells provide additional sources of nitrogen for microbial metabolism. Salter (1984) showed that the course of protein digestion is similar in the small intestine of both germ-free and conventional animals. The influence of enteric bacteria on protein digestion is therefore likely to be small, but this is not the case in the large intestine. It has also been shown that enzyme activity in the pancreas is essentially the same for germ-free and conventional piglets fed on a milk formula (Szabo, 1979). Peptidases and disaccharidases associated with the intestinal mucosa had a higher activity in germ-free pigs than the conventional pigs. The activities of these enzymes in the large intestine were also found to be higher in germ-free pigs which suggests that there may be direct or indirect effects of the microflora on the enzymes associated with the epithelial cells, and indicate a bacterial denaturation of the digestive enzymes.

The literature reviewed in Section 1.0 (Chapter 1) suggested an increase in microbial numbers in response to the ingestion of diets containing fermentable carbohydrate. Both the catabolic and anabolic activities of the microorganisms in the small intestine are therefore likely to be influenced by diets containing fibrous materials. The net result on nitrogen digestion and absorption will be dependent on the relative rates of breakdown of nitrogenous compounds to yield ammonia, and the incorporation of nitrogen into bacterial protein. This in turn will effect the flow of nitrogen into the large intestine, thereby influencing nitrogen metabolism in this segment of the gut.

Properties other than the promotion of microbial growth are also likely to have important effects on nitrogen digestion and absorption in the small intestine. An increased rate of passage of digesta, and hence a reduced period of time available for the digestive and absorptive processes to occur, has been implicated by several workers (see Section 2.1.0) as one of the factors responsible for a reduction in nutrient digestibilities, along with other physico-chemical properties. The ability of fibre to adsorb water, swell and reduce the diffusion of the products of digestion towards the absorptive mucosal surface could be important in reducing the absorption in this gastrointestinal segment.

Protein digestion and nitrogen absorption in the large intestine

Incompletely digested protein entering the hind gut may come under the influence of bacterial proteases to yield amino acids. The proteolytic enzymes of the pig probably play only a limited role in the digestion of nitrogenous compounds within the large intestine since Chung, Kim, Schadcher, Garrido, MacGregor and Sleisenger (1979) showed that only a small amount of trypsin enters the hind gut, and that there is no protease secretion by the caecal or colonic mucosa.

The microorganisms in the large intestine are highly concentrated, the density being greater than in any other portion of the gastrointestinal tract (Decuypere & Van der Hyde, 1972). In this region of the gut, the flow of digesta is sufficiently slow to allow microbial multiplication and metabolic activity to occur. The microflora is dominated by strict anaerobes both in the gut lumen and attached to the intestinal epithelium (Harris & Kinyon, 1974; Allison, Robinson, Bucklin and Booth, 1979).

The most numerous Gram-negative species have been identified as *Bacteroides ruminicola*, *Selenomonas ruminantum*, *Butyrivibrio fibrisolvens* and *Bacteroides uniformis*, and the Gram-positive species *Lactobacillus acidophilus*, *Peptostreptococcus productus* and *Eubacterium aerofaciens* (Robinson, 1981).

The bacteria of the large intestine are thought to be able to degrade most of the nitrogenous substances in the digestive tract whether they are of dietary or endogenous origin. It was shown by Zebrowska (1975), Rerat (1978), and Just, Jørgensen and Fernandez, (1981) that the proteolytic activity of some gastrointestinal bacteria may replace the pancreatic enzymes, although the microflora is solely responsible for the hydrolysis of urea to yield ammonia. Microorganisms within the large intestine inactivate most of the proteolytic enzymes reaching the hind gut and are involved in the nitrogen metabolism in digesta where it is retained within the large intestine for several hours (Genell, 1976). Michel (1966) reported that the caecal microflora was very active in the decarboxylation of amino acids. Aspartic and glutamic acids were most readily decarboxylated; arganine, histidine, alanine and tryptophan were also attacked while lysine, ornithine and methionine were rarely affected.

The end products of microbial activity, amines and ammonia appear of little or no nutritional value to the animal. Zebrowska (1973, 1975) illustrated the lack of nutritional importance of protein digestion and absorption in the large intestine of the pig. Intact casein or enzymatically hydrolysed casein infused into the terminal ileum of pigs fed on a nitrogen free diet was digested, but the absorbed material was rapidly and completely excreted in the urine (see Table 2.2.0).

Table 2.2.0 Nitrogen balance of pigs given untreated (A) or heat-treated casein (B) into the terminal ileum. In period 2 streptomycin, neomycin and sulphaquanidine were given with the feed (Zebrowska, Buraczewska and Zebrowska, 1978)

	A		B	
	1	2	1	2
N-intake (g/d)	36.56	37.43	37.30	38.17
Faecal N (g/d)	7.84	8.75	12.49	15.47
Urinary N (g/d)	22.29	21.40	18.02	18.58
N retained (g/d)	6.43	7.28	6.79	4.12
N retained (g/g N intake)	0.179	0.199	0.180	0.110
N digestibility	0.786	0.785	0.665	0.608

Casein in the diet produced a high level of amino acids in the portal blood, whilst urea concentrations were low. However, when casein was infused into the caecum, portal blood urea concentrations were very high with little or no increase in blood amino acids (Zebrowska and Burazewska, 1979). Just *et al.* (1981) in similar studies, infused soyabean meal, protein concentrate, skim milk powder, meat and bone meal and lysine-HCl into the caecum of pigs. The protein from the infused material was digested almost as well as if it had been fed orally indicating the high digestive capacity of the caecum and colon. However, the majority of the nitrogen from the digested protein was not utilized and was excreted in the urine.

This indicates that undigested protein entering the hind gut, as a result of the impairment of its digestion and absorption in the small intestine, which is then catabolised by microorganisms in the hind gut, will not be available for useful purposes in the pig and will be excreted in the urine. In this way, dietary fibre could produce negative effects on the nitrogen retention of the host animal.

The main nitrogenous compound absorbed from the large intestine is ammonia. It appears to move freely between the intestines and the body fluids but there is no marked uptake of amino acids in the large intestine. In the new born piglet the proximal colon has the ability to absorb methionine by active transport (James & Smith, 1976), but there does not appear to be evidence of active transport in older animals. The lack of active transport of amino acids in the hind gut does not exclude the possibility of amino acid absorption, since the mechanism may be that of simple diffusion. For net absorption to occur by diffusion the amino acid concentration in the caecum should be higher than that in the blood. In experiments with rats, it was shown that the amino acid concentration gradient between blood and the caecal contents did not indicate significant exchange between these two compartments excepting glutamic and aspartic acids which are more concentrated in the caecal contents (Demigne & Remesy, 1979).

Experiments on cannulated pigs showed that approximately 0.5 of the nitrogen entering the large intestine is absorbed in this part of the gut (Zebrowska & Buraczewski, 1977; Sauer *et al.*, 1977, 1980). The apparent absorption of nitrogen within the large intestine, assessed in terms of the difference between the nitrogen entering the hind gut and the faeces varies with the diet and accounts for 0.05 to 0.2 of the nitrogen intake. The disappearance of individual amino acids within the large intestine differs but in general, amino acids of low apparent ileal digestibility such as proline, glycine, threonine and tryptophan are extensively degraded in the large intestine, as illustrated in Table 2.2.1.

Interactions between nitrogen and fibre digestion

A vast literature exists on the effects of fibre on nitrogen metabolism, but it is very difficult to draw general conclusions due to the extremely wide range of conditions, pigs and diets used.

Table 2.2.1 **Proportion of amino acids digested in the large intestine of pigs given different diets (Zebrowska, 1982)**

	Barley	Rye	Wheat Bran	Rapeseed	Peanut meal
Essential amino acids					
Lysine	0.062	0.140	-0.028	0.163	0.053
Methionine	0.004	0.048	-0.043	0.011	0.018
Threonine	0.119	0.208	0.300	0.134	0.129
Tryptophan	0.142	0.224	0.220	0.126	0.145
Non-essential amino acids					
Proline	0.081	0.109	0.183	0.111	0.161
Glycine	0.172	0.329	0.291	0.172	0.150
Cystine	0.132	0.172	0.270	0.160	0.167

As was reported in Experiment 1.1 (Section 1.1.5, Chapter 1) the source of fibre appears to be important in determining its effects on nutrient digestibilities. For example, supplements of ground wood cellulose have been shown to depress nitrogen digestibility by Horszczaruk (1962), Kirchgessner, Roth-Maier and Roth (1975) and Partridge, Keal and Mitchell (1982). However, studies by Potkins, Lawrence and Thomlinson (1984), failed to show this effect when oatfeed digestibilities were significantly reduced. Unmolassed sugar-beet pulp and dried grass fed in Experiment 1.1 (Chapter 1) and wheat bran in Experiment 2.1, reported earlier in this chapter all produced a depression in nitrogen digestibility. Other forms of dietary fibre have also produced contrasting effects. Low and Keal (1981) found that guar gum did not significantly alter the digestibility or retention of nitrogen in growing pigs. Alkali-treated straw tended to reduce nitrogen digestibility in the trials performed by Farrell (1973) and Bergner, Simon and Bergner (1980).

Oat hulls (Kennelly and Aherne, 1980), barley hulls (Bell, Shires and Keith, 1983) and corn cobs (Frank, Aherne and Jensen, 1983) were all found to have very little effect on nitrogen digestibility, but the digestibilities of energy and dietary fibre were both depressed. Albers and Henkel (1979) and Mosenthin and Henkel (1983) investigated the effect of pectin, and it was found that nitrogen digestibility was reduced, although nitrogen balance was unaffected since urinary nitrogen excretion was depressed.

More recently, Huisman, den Hartog, Boer, van Weerden and Thielen (1985) investigated the effect of various carbohydrate sources on the ileal and faecal digestibilities of protein and amino acids in growing pigs. The inclusion of 0.05 pectin or cellulose did not significantly effect the ileal or faecal digestibility, whereas the inclusion of 0.05 straw meal produced a significantly decreased ileal digestibility of protein and nine amino acids (isoleucine, lysine, phenylalanine, threonine, valine, alanine, aspartic acid, glutamic acid and tyrosine). Faecal digestibility of protein and amino acids was not significantly affected by the inclusion of straw meal.

Bergner (1982) fed young pigs (30 kg) different amounts of partially hydrolysed straw meal as a supplement to a barley-skimmed milk ration. The apparent digestibility of the crude protein was lowered from 0.84 (without straw meal, 0.04 crude fibre) to 0.68 (270 g DM partially hydrolysed straw meal, 0.14 crude fibre in the diet). The apparent digestibility of lysine decreased the most with increasing fibre level. In a second experiment, after adaptation to the diets which contained different sources of protein or urea, young pigs received a single dose of ^{15}N-urea. The ^{15}N-excretion in the faeces was higher when the diet contained partially hydrolysed straw meal. The correlation between mg ^{15}N-excreted in the faeces and the blood concentration was found to be -0.89. These results indicate that urea was transported through the gut wall into the hind gut. The conventionally measured N-digestibility was depressed in proportion to the fibre content of the diet.

The implications of added fibre for the measurement of nitrogen digestibility, nitrogen retention and nitrogen excretion.

The literature reviewed has revealed that, as well as their catabolic activity, the microorganisms within the large intestine are capable of incorporating nitrogen into their protein. A net synthesis of some amino acids including methionine and lysine has been reported in the large intestine by many authors (Holmes, Bayley and Leadbeater, 1977; Mason, Just and Bech-Andersen, 1976; Sauer *et al.*, 1977; Zebrowska *et al.*, 1978; Just *et al.*, 1981) and the amount of carbohydrate entering the hind gut appears to determine the magnitude of microbial synthesis which occurs. The information shown in Table 2.2.1 for wheat bran also shows a net synthesis of lysine and methionine. Mason *et al.* (1976) showed that the replacement of maize starch by raw potato starch in growing pigs increased the proportion of bacterial protein voided in the faeces and decreased the apparent digestibility of nitrogen by 1 to 4 percentage units.

Zebrowska *et al.* (1981), who infused wheat starch into the caecum of pigs fed a diet of barley and meat and bone meal showed that the apparent digestibility of nitrogen was depressed by 3 to 4 percentage units. Large differences were found in the digestibility of the essential amino acids, threonine, lysine, valine, leucine and histidine which exceeded those measured for total nitrogen digestibility. When starch was given, nitrogen excretion in the urine decreased but no effect on overall nitrogen retention was seen. The infusion of maize starch or potato starch into the caecum had a small depressant effect on nitrogen digestibility and urinary nitrogen excretion but the nitrogen balance was unaffected (Just *et al.*, 1981; Misir & Sauer, 1980). From the results, it seems that starch entering the caecum modifies the route of nitrogen excretion by increasing the nitrogen excretion in the faeces and decreasing to a similar extent the nitrogen excretion in the urine. The increase in faecal nitrogen has been shown to be associated with an increasing proportion of bacterial protein (Mason & Palmers, 1973; Mason *et al.*, 1976). It was estimated that over 0.6 of the faecal nitrogen is of bacterial origin and this explains why the amino acid composition of faeces after feeding different diets, and of bacteria, are very similar.

The work reviewed above suggests that fibre often reduces the digestibility of nitrogen, i.e. it increases the nitrogen output in the faeces, but this may be countered by a reduced nitrogen output in the urine. This results in little overall effect on nitrogen balance (Low, 1985). Malmlöf and Hakansson (1984) found that urinary nitrogen excretion decreased and that the extent of this decrease exceeded the increase in faecal nitrogen excretion. As a consequence the nitrogen retained increased. Morgan and Whittemore (1988) examined the effect of the addition of different levels of fibre sources (straw, oatfeed and sugar-beet pulp) to a low-fibre basal diet on nitrogen excretion and retention. The findings of Malmlöf and Hakansson (1984) were confirmed i.e. that increasing fibre in the diet increased faecal nitrogen output, decreased urinary nitrogen output and increased nitrogen retention. Whether this increased nitrogen retention is in the carcase or merely in the gut wall is yet to be elucidated, but it is recognised that gut size increases when diets rich in dietary fibre are fed (Pond, 1984; Low, 1985; Stanogias and Pearce, 1985b).

The effects of dietary fibre on gut motility and transit time, digestive secretions and nutrient absorption, and the ways in which they could also contribute to reduction in nitrogen digestibility, were reviewed in Section 2.1.0 and will only be summarised here. The physicochemical effects of dietary fibre could lead to a depression in nitrogen digestibility due to its effects of both a reduction in transit time and a depressed absorption of amino acids. As a result of an increased supply of fermentable carbohydrate to the microbes in the gut, there will be an increased output of microbial matter which will have the effect of reducing the measurements of apparent digestibility. Rapid, extensive fermentation in the hind gut could be limited by the supply of nitrogen to the microflora, hence the digestibility of dietary fibre could be depressed when the nitrogen content of the diet is low.

In order to try and illustrate clearly the effects of protein level on fibre digestibility it is necessary to use a highly fermentable fibre source. This will have the effect of loading the microflora with a fermentable substrate and is likely to increase their nitrogen requirement. For this reason, unmolassed sugar-beet pulp was used since the NDF fraction of this material has been shown to be highly digestible. The mean digestibility measured in Experiment 1.1 was 0.84. Other workers have reported similar values; Zhu and Fowler (1987), 0.81; Morgan, Whittemore and Cockburn (1984), 0.75. By-products are usually low in protein and some of this protein may be unavailable. Sugar-beet pulp has undergone considerable heat treatment and this can lead to the formation of Maillard products in the form of artefact lignin. This reduces protein availability. Supplementary protein is therefore likely to be beneficial in the digestion of the fibre of beet pulp. Grower pig diets usually contain crude protein levels in the range 180-200 g/kg. To show the effect of crude protein level on fibre digestibility and nitrogen metabolism, in cases of inadequate and overadequate nitrogen supply, diets were formulated to contain crude protein levels below and above this range.

2.2.1 MATERIALS AND METHODS

Animals and Diets

The animals used in this experiment were Large White x Landrace entire males of initial mean bodyweight 48 kg. Two low fibre rations, based on wheat, barley and fishmeal were formulated to give crude protein levels of 140 g (CP14) and 240 g/kg DM (CP24). These diets were fed in combination with three levels of unmolassed sugar-beet pulp, which were calculated to provide NDF intakes of 40, 60 and 80 g/day from the sugar-beet pulp. The ingredient composition of the basal diets, CP14 and CP24, are given in Table 2.2.2.

Table 2.2.2 Ingredient composition of the basal diets (g/kg)

Ingredient	CP14	CP24
Wheat	659	556
Barley	285	240
Fishmeal	51	200
Salt	2	2
Vitamins and Minerals PT12C†	3	3
	1000	1000

†see Appendix 2

The basal rations fed alone with no added sugar-beet pulp were used as the control. There were a total of eight dietary treatments, summarised in Table 2.2.3.

Table 2.2.3 A summary of the dietary treatments

Treatment	Basal Diet (kg/day)	Added sugar-beet pulp (kg/day)
CP14/NDF40	1.0	0.13
CP14/NDF60	1.0	0.19
CP14/NDF80	1.0	0.26
CP24/NDF40	1.0	0.13
CP24/NDF60	1.0	0.19
CP24/NDF80	1.0	0.26
CP14 (control)	1.0	–
CP24 (control)	1.0	–

Trial Procedures

The adaptation period and balance procedures were exactly as described for Experiment 2.1 (Section 2.1.1). This experiment was also carried out over three balance periods. The first balance involved the use of twelve pigs, 2 pigs on each of the treatments CP14/NDF40, CP14/NDF60, CP14/NDF80, CP24/NDF40, CP24/NDF60 and CP24/NDF80. On the completion of the first balance, the pigs were maintained on the same level of sugar-beet pulp. The basal diets, and therefore protein levels, were crossed-over so that those pigs which had received CP14 received CP24, and *vice versa*. After a further 14 days the second measurement of digestibility was made. The pigs (6 per diet) were then fed on the basal diets alone, with no added sugar-beet pulp. These pigs were maintained on the basal diet which they had received for the second digestibility measurement. After 7 days the third measurement of digestibility was made.

2.2.2 ANALYTICAL PROCEDURES

All analytical procedures were as described for Experiments 1.1 and 2.1.

2.2.3 STATISTICAL ANALYSIS

Genstat V (Lawes Agricultural Trust, 1982) was used in the analysis following the recommended procedure of the Scottish Agricultural Statistics Service. The data were analysed using the technique of analysis of variance, and t-tests were used to compare values obtained for the control pigs with those from the pigs given the sugar-beet pulp supplemented diets. The analysis of variance of the results identified the effects of crude protein and the level of sugar-beet pulp with orthogonal (NDF), linear (NDF_L) and quadratic (NDF_Q) effects. The significance of each main effect was tested by comparison of the mean squares of NDF, NDF_L, NDF_Q and NDF * protein interaction with the error mean square. The statistical procedures used were as described by Snedecor and Cochran (1973).

2.2.4 RESULTS

The chemical compositions of the diets, CP14 and CP24, and the unmolassed sugar-beet pulp are detailed in Table 2.2.4.

Table 2.2.4 Chemical composition of the low and high protein basal diets, and the unmolassed sugar-beet pulp

	CP14	CP24	Unmolassed Sugar-beet pulp
DM (g/kg)	877	886	891
GE (MJ/kg DM)	18.4	18.8	16.6
Crude Protein (g/kg DM)	142	241	96
NDF (g/kg DM)	137	109	449
ADF (g/kg DM)	53	51	234
Ash (g/kg DM)	30.1	48.6	78.7

NDF and ADF digestibilities

The digestibilities of the NDF and ADF fractions of the low (CP14) and high (CP24) basal diets are shown below in Table 2.2.5.

The digestibility of the NDF of the CP14 diet was significantly greater than that of the CP24 diet, despite the fact that the latter diet was found to contain a lower content of NDF. The contributors of NDF were wheat and barley, and the ration of these two cereals was constant at approximately 2.3 wheat : 1 barley which would eliminate any differences in NDF digestibility due to variation in the degradation of NDF between cereal types. The digestibility of the ADF fraction was found to be similar for both diets when they were fed alone.

Table 2.2.5 **Effect of protein level on the digestibility of the NDF and ADF of the control diets**

(mean values for 6 pigs)

	DIET			
	CP14	CP24	SED	SIG.
Digestibilities				
NDF	0.469	0.346	0.0437	*
ADF	0.318	0.335	0.0417	NS

Table 2.2.6 shows the effects of feeding increasing amounts of sugar-beet pulp on the digestibility of the NDF and ADF of the whole diet, and of the sugar-beet pulp (as calculated by difference).

The digestibility of the NDF of the whole diet tended to increase with the level of sugar-beet pulp added to the diet, although the differences found between the NDF digestibility coefficients were not significant. However, a significant ($P<0.05$) linear trend was identified and when the digestibility of NDF was regressed against the level of added beet pulp (Figure 2.2.1) and the regression equation (with standard deviations shown in parentheses) was;

$$\text{NDF digestibility} = \underset{(0.0278)}{0.483} + \underset{(0.447)}{1.37} \times \text{added sugar-beet pulp (kg)}$$

The slope of the line was significantly different from zero and the correlation coefficient, $r = 0.54$.

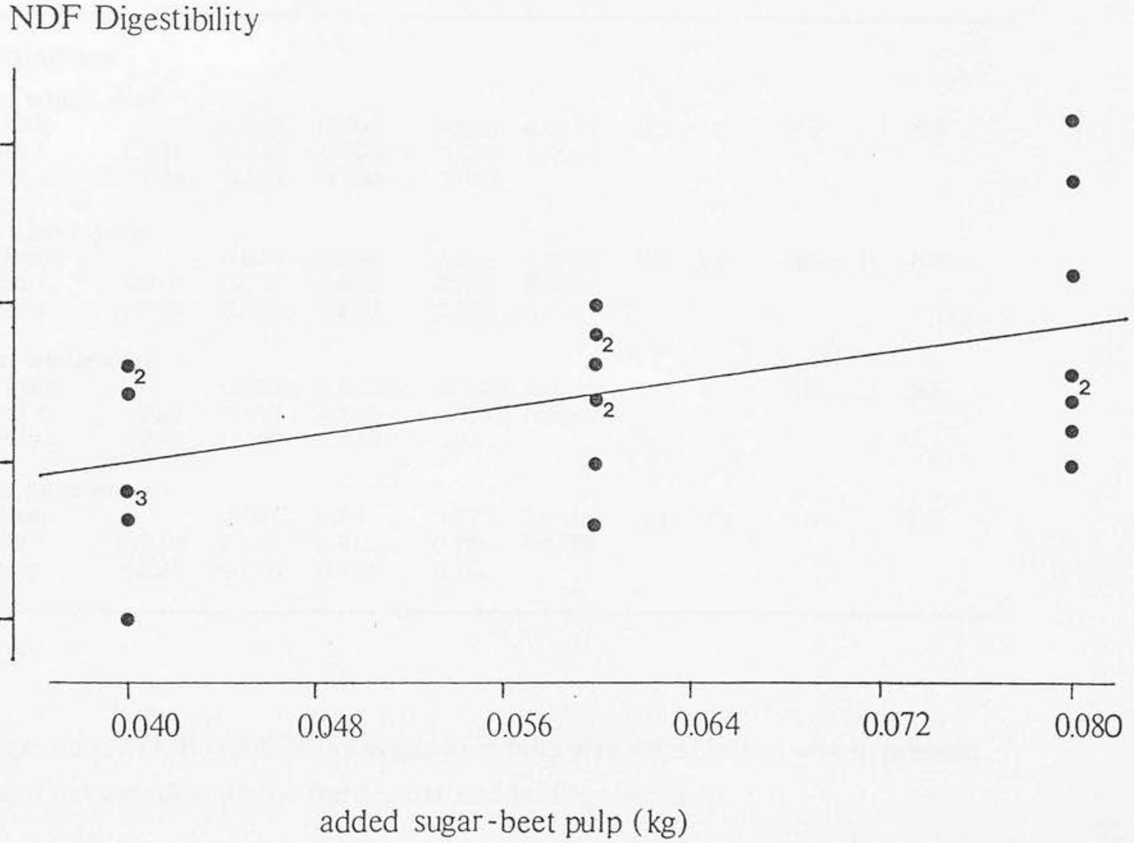


Figure 2.2.1 Relationship between NDF digestibility and level of added sugar-beet pulp

Table 2.2.6 Effect of level of added sugar-beet pulp on the digestibility of the NDF and ADF of the whole diet, and of the sugar-beet pulp (as calculated by difference)

(+mean values for 8 pigs; #mean values for 4 pigs; values in the same row with the same subscript are non-significantly different)

		Level of Beet Pulp				SIG			
		NDF40	NDF60	NDF80	SED	NDF	NDF_L	NDF_Q	NDF*Protein
Digestibilities									
NDF of whole diet									
+Beet Pulp		0.538	0.566	0.592	0.0215	NS	*	NS	NS
#Protein *	CP14	0.549	0.579	0.588	0.0267				
Beet Pulp	CP24	0.527	0.553	0.597					
NDF of beet pulp									
+Beet Pulp		0.828	0.754	0.801	0.0736	NS	NS	NS	NS
#Protein *	CP14	0.697	0.685	0.762	0.0957				
Beet Pulp	CP24	0.959	0.823	0.839					
ADF of whole diet									
+Beet Pulp		0.487a	0.519ab	0.543b	0.0233	*	*	NS	NS
#Protein *	CP14	0.477	0.523	0.545	0.0289				
Beet Pulp	CP24	0.480	0.516	0.541					
ADF of beet pulp									
+Beet Pulp		0.801	0.791	0.772	0.0516	NS	NS	NS	NS
#Protein *	CP14	0.824	0.819	0.790	0.0778				
Beet Pulp	CP24	0.778	0.762	0.753					

*, $P<0.05$

The digestibility of the NDF of the sugar-beet pulp was variable and was depressed although not significantly by the further addition of beet pulp.

The digestibility of the NDF of the beet pulp was measured to be greater than that for the whole diet, which confirms the findings of Experiment 1.1 (Chapter 1), suggesting that the NDF fraction of beet pulp was more degradable than that of wheat and barley in the basal diet. This explains the increasing digestibility of the NDF fraction of the whole diet with increasing additions of beet pulp to the diet.

The ADF digestibility of the whole diet also increased significantly ($P<0.05$) when the level of added beet pulp was increased from 40 to 80 g/day. The relationship was linear. The digestibility of the ADF of the whole diet was regressed against the level of added beet pulp (Figure 2.2.2) and the regression equation obtained was (standard deviations in parentheses);

$$\text{ADF digestibility} = \underset{(0.0290)}{0.417} + \underset{(0.467)}{1.61} \times \text{added sugar-beet pulp (kg)}$$

The slope was significantly different from zero and the correlation coefficient, $r = 0.59$.

Despite an apparent decrease in sugar-beet pulp ADF digestibility with increasing sugar-beet pulp supplementation, no significant differences were found between the digestibility coefficients, and a linear relationship could not be identified.

The effects of protein level on the digestibility of the ADF and NDF fractions of the whole diet and sugar-beet pulp are detailed in Table 2.2.7.

The level of protein in the basal diet did not significantly affect the digestibility of the NDF of the whole diet, but the NDF of the sugar-beet pulp fed in combination with the CP24 diet was digested significantly better than that fed with the CP14 diet. The crude protein content of the basal diet did not significantly affect the digestibility of the ADF of the whole diets or sugar-beet pulp.

Table 2.2.7 Effect of protein level on the digestibility of the NDF and ADF fractions of the whole diet and the sugar-beet pulp

(mean values for 12 pigs)

	DIET			
	CP14	CP24	SED	SIG.
Digestibilities				
NDF of whole diet	0.572	0.559	0.0129	NS
NDF of beet pulp	0.697	0.874	0.0617	**
ADF of whole diet	0.515	0.512	0.0140	NS
ADF of beet pulp	0.784	0.764	0.0422	NS

**, $P<0.01$

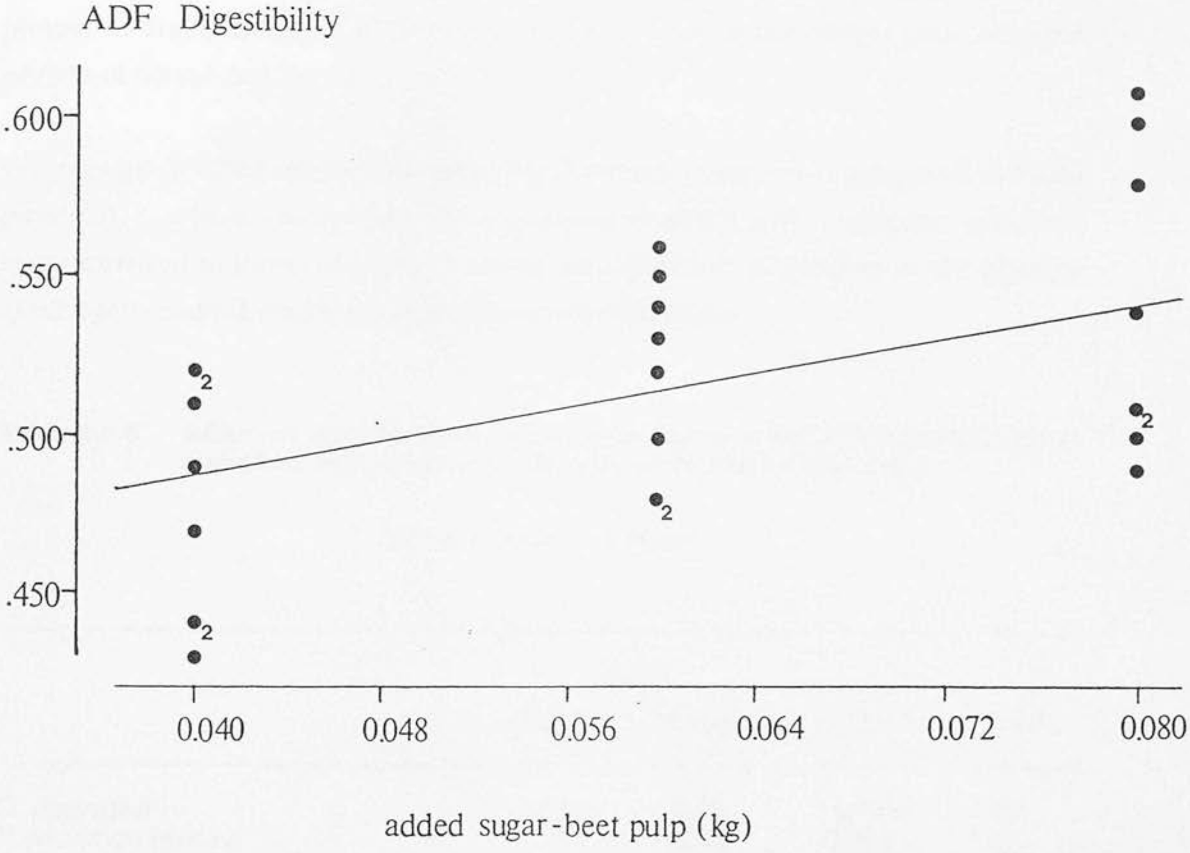


Figure 2.2.2 Relationship between ADF digestibility of whole diet and level of added sugar-beet pulp

Nitrogen digestibility, nitrogen retention and nitrogen excretion

The digestibility of nitrogen in the two control diets is shown in Table 2.2.8 with the values for the nitrogen retained, and excreted in the faeces and urine of the pigs given each diet.

The digestibility of the nitrogen of the CP24 diet was significantly (P<0.001) greater than that of the CP14 diet. This suggests that the fish protein, which replaced cereal protein in the formulation of CP24 from CP14, is more readily degradable than the protein of wheat and barley.

The pigs given CP24 retained an extra 3 g of nitrogen/day when compared to those given CP14, which was found to be significant (P<0.01). When nitrogen retention was expressed in terms of g N/g N intake, no significant differences in the amount of nitrogen retained could be found between the two diets.

Table 2.2.8 Effect of protein level on nitrogen digestibility, nitrogen retention and nitrogen excretion for the pigs given the control diets

(mean values for 6 pigs)

	DIET			
	CP14	CP24	SED	SIG.
N digestibility	0.833	0.902	0.0087	***
N retention (g/day)	6.24	9.24	0.911	**
N retention (g/g N intake)	0.32	0.29	0.035	NS
Faecal N excretion (g/g N intake)	0.17	0.10	0.009	***
Urinary N excretion (g/g N intake)	0.50	0.61	0.038	*

***, P<0.001; **, P<0.01; *, P<0.05

Faecal nitrogen excretion, expressed as a proportion of the nitrogen intake, was found to be significantly lower in those given CP24, which is consistent with the higher digestibilities of nitrogen recorded for these pigs. Urinary nitrogen excretion, expressed in the same way, was significantly higher (P<0.05) in those pigs given CP24.

The resulting effect of increasing the level of sugar-beet pulp supplementation on nitrogen digestibility, retention and excretion is shown in Table 2.2.9.

The digestibility of nitrogen decreased significantly ($P<0.01$) with the increasing level of added sugar-beet pulp. The relationship was found to be linear with no significant deviations from linearity. Nitrogen digestibility was regressed against level of added beet pulp (Figure 2.2.3) and the equation obtained (with standard deviations in parentheses) was;

$$\text{Nitrogen digestibility} = \underset{(0.0380)}{0.878} - \underset{(0.611)}{1.27} \times \text{added sugar-beet pulp (kg)}$$

The slope of the line was significantly different from zero and the correlation coefficient, $r = 0.40$.

Student t-tests were used to compare the digestibility of nitrogen in the control diets, CP14 and CP24 fed alone, with that in these two diets when they were supplemented with sugar-beet pulp. The results are shown in Table 2.2.10. The digestibility of the nitrogen in the CP14 diet was significantly greater in the diet fed alone than when it was supplemented with sugar-beet pulp. This was found for all levels of sugar-beet pulp inclusion. The same effect was observed for the CP24 diet supplemented with sugar-beet pulp.

Nitrogen retention, expressed as g/day or g/g N intake, was found to be variable and no significant differences could be found between the nitrogen retained by the pigs fed different levels of sugar-beet pulp.

Faecal nitrogen excretion (g/g N intake) increased significantly with the level of additional beet pulp fed. The relationship was linear, and the slope of the line was significantly different from zero. When t-tests were used to compare the faecal nitrogen losses of pigs given the beet pulp supplemented diets with those given the control diets, it was found that the pigs given beet pulp, irrespective of the level of supplementation, excreted greater proportions of their nitrogen intake in their faeces than the control pigs. The mean values and t values are given in Table 2.2.11.

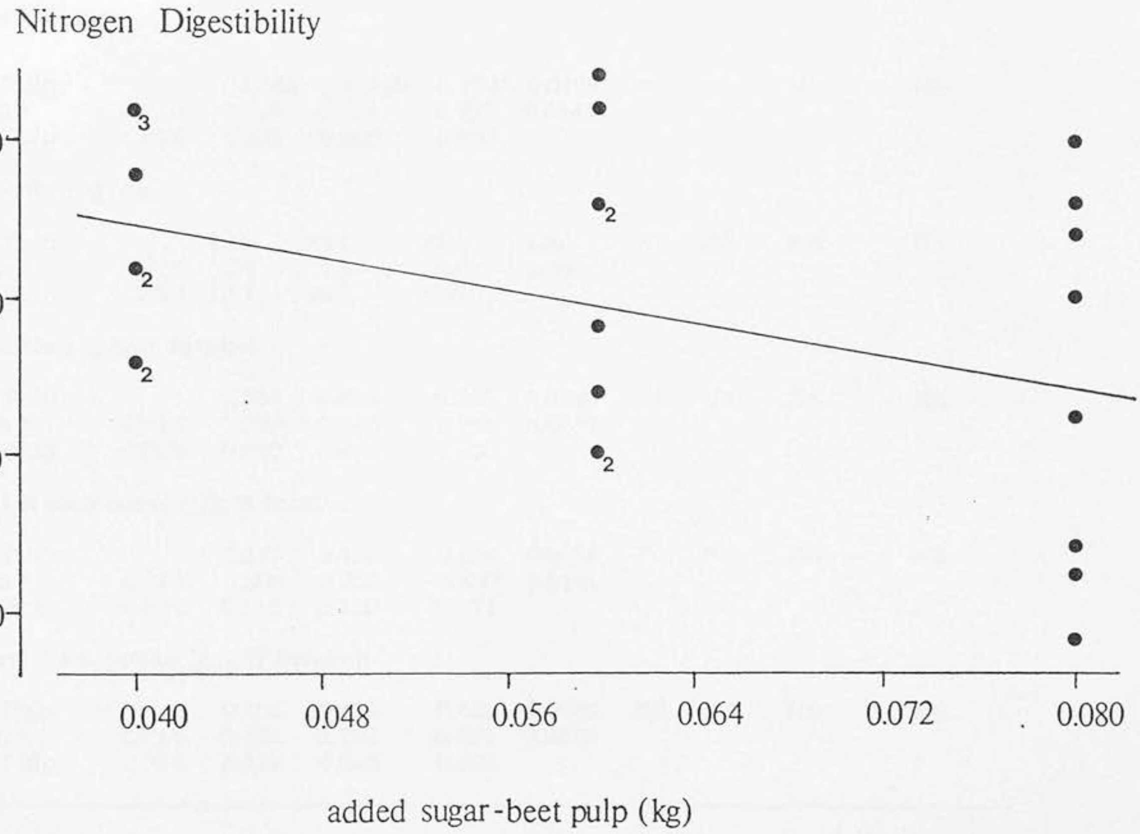


Figure 2.2.3 **Relationship between nitrogen digestibility and level of added sugar-beet pulp.**

Table 2.2.9 Effect of level of added sugar-beet pulp on nitrogen digestibility, nitrogen retention and nitrogen excretion

(+mean values for 8 pigs; #mean value for 4 pigs values in the same row with the same subscript are non-significantly different)

		Level of Beet Pulp				SIG			
		NDF40	NDF60	NDF80	SED	NDF	NDF_L	NDF_Q	NDF*Protein
N digestibility;									
+Beet Pulp		0.824a	0.807ab	0.774b	0.0129	**	**	NS	NS
Protein *	CP14	0.794	0.764	0.720	0.0141				
#Beet Pulp	CP24	0.855	0.850	0.827					
N retention (g/d);									
+Beet Pulp		10.4	12.1	11.1	1.07	NS	NS	NS	NS
Protein *	CP14	7.4	7.5	6.6	1.46				
#Beet Pulp	CP24	13.4	16.8	15.5					
N retention (g/g N intake);									
+Beet Pulp		0.358	0.393	0.365	0.0348	NS	NS	NS	NS
Protein *	CP14	0.338	0.330	0.280	0.0417				
#Beet Pulp	CP24	0.380	0.455	0.450					
Faecal N excretion (g/g N intake);									
+Beet Pulp		0.175	0.193	0.226	0.0128	*	**	NS	NS
Protein *	CP14	0.206	0.236	0.280	0.0141				
#Beet Pulp	CP24	0.145	0.150	0.173					
Urinary N excretion (g/g N intake);									
+Beet Pulp		0.465	0.414	0.408	0.0256	NS	NS	NS	NS
Protein *	CP14	0.454	0.432	0.438	0.0355				
#Beet Pulp	CP24	0.477	0.396	0.378					

**, $P<0.01$; *, $P<0.05$

Table 2.2.10 A comparison of the nitrogen digestibility of the pigs given the sugar-beet pulp supplemented and control diets

Diet	Nitrogen digestibility
CP14/NDF40	0.794
CP14	0.833
t	3.95
Level of Significance	**
CP14/NDF60	0.764
CP14	0.833
t	6.99
Level of Significance	***
CP14/NDF80	0.720
CP14	0.833
t	7.99
Level of Significance	***
CP24/NDF40	0.855
CP24	0.902
t	4.91
Level of Significance	***
CP24/NDF60	0.850
CP24	0.902
t	4.45
Level of Significance	***
CP24/NDF80	0.827
CP24	0.902
t	6.31
Level of Significance	***

Table 2.2.11 **A comparison of the nitrogen excreted in the faeces as a proportion of the nitrogen intake of the pigs given the sugar-beet pulp supplemented and control diets**

Diet	Nitrogen digestibility
CP14/NDF40	0.206
CP14	0.167
t	3.82
Level of Significance	**
CP14/NDF60	0.236
CP14	0.167
t	7.02
Level of Significance	***
CP14/NDF80	0.280
CP14	0.167
t	7.97
Level of Significance	***
CP24/NDF40	0.145
CP24	0.098
t	5.22
Level of Significance	**
CP24/NDF60	0.150
CP24	0.098
t	4.45
Level of Significance	**
CP24/NDF80	0.173
CP24	0.098
t	6.31
Level of Significance	***

Urinary nitrogen excretion, expressed in the same way, was unaffected by the level of beet pulp added to the diet. Student t-tests were applied to compare the nitrogen excreted in the urine of the beet pulp fed pigs as compared to the control pigs. For the pigs given CP14/NDF40, CP14/NDF60 and CP14/NDF80 there were no significant differences found on comparison with the pigs given CP14 alone. However, significant differences were found between CP24/NDF40, CP24/NDF60, CP24/NDF80 and CP24. The means and values for t are given in Table 2.2.12.

Table 2.2.12 **A comparison of the nitrogen excreted in the urine as a proportion of the nitrogen intake of the pigs given the sugar-beet pulp supplemented and control diets**

Diet	Urinary N/N intake
CP14/NDF40	0.454
CP14	0.500
t	0.48
Level of Significance	NS
CP14/NDF60	0.432
CP14	0.500
t	1.99
Level of Significance	NS
CP14/NDF80	0.438
CP14	0.500
t	1.73
Level of Significance	NS
CP24/NDF40	0.477
CP24	0.610
t	3.25
Level of Significance	**
CP24/NDF60	0.396
CP24	0.610
t	6.65
Level of Significance	***
CP24/NDF80	0.378
CP24	0.610
t	7.41
Level of Significance	***

Energy digestibility and the DE value of sugar-beet pulp

The effects of protein and sugar-beet pulp level on the digestibility of energy, and the DE values for sugar-beet pulp are given in Table 2.2.13.

The difference in digestibility between the two diets (CP14 and CP24) was not found to be significant. The addition of sugar-beet pulp to these diets appeared to depress the digestibility of the energy of the whole diet. The results of a t-test, which compared the energy digestibility of the beet pulp supplement diets with the basal diets are shown in Table 2.2.14. The only significant depression in energy digestibility was found when 160 g of sugar-beet pulp were added to the CP24 diet.

No significant differences could not be found between the digestibility coefficients at the different levels of beet pulp supplementation, and no significant linear relationship could be identified.

The DE values measured for the sugar-beet pulp showed a great deal of variation and although the DE values appeared to decrease with increasing beet pulp supplementation, no significant differences could be found and no linear relationship could be identified.

Although, the DE value of sugar-beet pulp appeared to be affected by the protein level of the diet, the values recorded for the supplementation of CP14 and CP24 were not significantly different despite the DE value of the CP24 diet being 0.11 proportionally less than that recorded for the CP14 diet.

The DE of the sugar-beet pulp was also obtained by linear regression. The DE values obtained for the whole diets were regressed against the level of beet pulp added. The regression equations (with standard deviations in parentheses) obtained for the beet pulp fed with CP14 and CP24 are shown below;

For CP14

$$\text{DE (MJ/kg DM)} = \underset{(0.272)}{14.4} + \underset{(2.193)}{12.2} \times \text{added sugar-beet pulp (kg)}$$

For CP24

$$\text{DE (MJ/kg DM)} = \underset{(0.334)}{15.9} + \underset{(2.683)}{10.6} \times \text{added sugar-beet pulp (kg)}$$

The DE values obtained for sugar-beet pulp fed with the CP14 and CP24 diets were therefore 12.2 and 10.6 MJ/kg DM. These values are in good agreement with those calculated by difference.

Table 2.2.13 Effect of protein and sugar-beet pulp level on the digestibility of energy and DE values of sugar-beet pulp

	DIET			
	CP14	CP24	SED	SIG.
Control diets;				
†Energy digestibility	0.850	0.867	0.0087	NS
Beet pulp Supplemented diets;				
§Energy digestibility	0.835	0.842	0.0044	NS
Control diet; †DE value (MJ/kg DM)	15.38	16.28	0.161	**
Beet pulp; †DE value (MJ/kg DM)	12.33	10.96	0.943	S

		Level of Beet Pulp				SIG			
		NDF40	NDF60	NDF80	SED	NDF	NDF$_L$	NDF$_Q$	NDF*Protein
Beet pulp supplemented diets;									
Energy digestibility									
#Beet Pulp		0.847	0.841	0.827	0.0090	NS	NS	NS	NS
+Protein*	CP14	0.842	0.839	0.825	0.0105				
Beet Pulp	CP24	0.851	0.844	0.829					
DE value									
#Beet Pulp		12.02	11.84	11.07	0.983	NS	NS	NS	NS
+Protein*	CP14	12.62	12.54	11.84	1.517	NS			
Beet Pulp	CP24	11.42	11.14	10.31					

†, mean value for 6 pigs; §, mean value for 12 pigs; #, mean value for 8 pigs; +, mean value for 4 pigs.

Table 2.2.14 A comparison of energy digestibility of the pigs given the sugar-beet pulp supplemented and control diets

Diet	Energy Digestibility
CP14/NDF40	0.842
CP14	0.850
t	1.43
Level of Significance	NS
CP14/NDF60	0.839
CP14	0.850
t	1.43
Level of Significance	NS
CP14/NDF80	0.825
CP14	0.850
t	0.68
Level of Significance	NS
CP24/NDF40	0.851
CP24	0.867
t	1.69
Level of Significance	NS
CP24/NDF60	0.844
CP24	0.867
t	2.08
Level of Significance	NS
CP24/NDF80	0.829
CP24	0.867
t	3.17
Level of Significance	*

*, $P<0.05$

2.2.5 DISCUSSION

The addition of sugar-beet pulp to the diet of the growing pig gives rise to a reduction in nitrogen digestibility and an alteration in the course of nitrogen excretion. A greater proportion of the nitrogen intake was excreted in the faeces at the higher levels of beet pulp inclusion, whilst nitrogen excretion in the urine decreased slightly. As a result of these relative changes in nitrogen excretion, the amount of nitrogen retained remained unchanged as the level of sugar-beet pulp supplementation increased.

The level of protein in the diet was important in determining the extent to which the NDF fraction was digested, since the digestibility of the NDF of the beet pulp, as calculated by difference, was significantly higher when fed with the CP24 diet. The level of food fibre added to the diet was not important in determining the digestibility of the ADF or NDF fractions of the added food fibre.

The effects of sugar-beet pulp on nitrogen metabolism are likely to be mediated through its physicochemical properties, and its effects on microbial proliferation and metabolism. Similarly, the effect of protein level ~~of~~ on fibre digestibility is also likely to be due to its effect on microbial metabolism.

The chemical analysis of the sugar-beet pulp fed in this experiment showed that it contained approximately 450 g NDF/kg DM. Approximately 0.5 of this fraction (234 g/kg DM) was ADF (cellulose and lignin), and by difference 216 g hemicellulose/kg. A more detailed analysis of the NSP of sugar-beet pulp was carried out by Graham, Hesselman and Aman (1986). The total NSP residues were 714.9 mg/g weight, of which 56.3 mg were soluble. The analysis is detailed in Table 2.2.15.

The NSP were mainly insoluble glucans, and pectins, indicated by the high content of arabinose, galactose and uronic acids. The NDF fraction is not, therefore, a particularly good method of estimating the dietary fibre content of sugar beet pulp. It fails to include the pectino-polysaccharides solubilised by the neutral detergent. This results in an underestimation of dietary fibre by approximately 200 g/kg DM.

The extent of dietary fibre fermentation varies between different fibre types and is dependent on the solubility and chemical structure of the fibre (Cummings, 1978). Hemicellulosic and pectic substances are completely fermented (Cummings *et al.*, 1979), whereas dietary fibre rich in lignin and cellulose is resistant to degradation by the microorganisms within the gut.

Table 2.2.15 Chemical composition of sugar beet pulp (Graham, Hesselman and Aman, 1986)

(content of soluble NSP (mg/g dry weight) shown in parentheses)

	mg/g dry weight	
Non-Starch Polysaccharides		
Total	714.9	(56.3)
Rhamnose	34.3	(0.9)
Arabinose	191.2	(7.2)
Xylose	15.5	(0.3)
Mannose	17.5	(2.3)
Galactose	54.2	(3.3)
Glucose	192.7	(1.1)
Uronic acids	199.5	(41.2)

The more detailed analysis of Graham *et al.* (1986) showed the dietary fibre of beet pulp to be high in pectin and hemicellulose. This would tend to suggest that the dietary fibre of beet pulp would be highly digestible, and the results of this trial reflected this; the digestibility of the NDF fraction of the beet pulp was found to lie in the range 0.697-0.959. The values obtained by other workers have also been found to lie within this range (0.75, Morgan *et al.*, 1984; 0.81 Zhu and Fowler, 1987; 0.84-0.92 Experiment 1.1 (Chapter 1, Section 1.1.4); 0.73, Experiment 3.1 (Chapter 3, Section 3.1.4) and 0.82 Experiment 3.2 (Chapter 3, Section 3.2.4)).

The mean digestibility of NDF at the two protein levels was measured as 0.697 and 0.874, thus indicating that sugar beet pulp acts as a good source of fermentable energy for the microbes of the hind gut. The ileal and faecal digestibilities (as determined by difference) of the NSP components of the sugar beet pulp fed to the pigs in the work of Graham *et al.* (1986) are shown in Table 2.2.16. Large between pig variation was observed. Approximately 0.5 of the beet pulp was degraded anterior to the ileum and the effect of beet pulp on reducing the digestibility of ash, crude protein and crude fat is clearly illustrated as was the extent of solubilisation of NSP from sugar-beet pulp in the small intestine.

Table 2.2.16 The apparent ileal and faecal digestibility (determined by difference) of components of sugar-beet pulp when fed to pigs. (Graham *et al.* 1986)

Component	Apparent Digestibility Ileum	 Faeces
Dry matter	0.138	0.628
Ash	-5.550	-0.917
Crude Protein	0.213	0.623
Crude Fat	-0.189	-0.534
Starch	0.939	1.424
Klason Lignin	0.223	-1.793
NSP Residues		
Arabinose	0.502	0.952
Xylose	0.757	-0.123
Galactose	0.378	0.827
Glucose	0.402	0.686
Uronic Acids	0.435	0.955
Soluble	-2.368	0.722
Total	0.439	0.819

The authors suggested that the solubilisation of fibre in the small intestine may have been underestimated as the soluble fibres were more susceptible to microbial attack, and whether insoluble NSP were degraded *per se*, or solubilised and then degraded in the small intestine could not be determined. Solubilisation could account for, at least in part, the apparent degradation of hemicellulose and cellulose determined by Keys and de Barthe (1974) and Sambrook (1979). Millard and Chesson (1984) found that vegetable fibre recovered at the terminal ileum had undergone partial hydrolysis; there were apparent losses of 0.46-0.50 uronic acid residues, 0.72-0.78 phenolic material and 0.10-0.24 cellulose initially present in the feed. There was also partial solubilisation of some hemicellulose components. Based on this evidence, it seems that the dietary fibre of sugar-beet pulp may undergo considerable modification anterior to the terminal ileum, which has implications for the digestion and absorption of other nutrients in this part of the gut.

The small intestine is the main site of protein digestion and absorption in the pig. Since fibre from beet pulp appears to be solubilised in this portion of the tract, its presence is likely to influence the digestibility of nitrogen and energy through its effects on the microflora, digestion and absorption. Sugar-beet pulp fibre will act as a source of fermentable energy for the microbes, which will result in increased microbial proliferation and metabolism. There will be increased incorporation of free amino acids into bacterial protein, thus reducing the amino acid absorption and increasing the flow of microbial nitrogen into the colon. This will have the effect of decreasing the ileal digestibility of nitrogen. Incompletely digested protein may come under the influence of bacterial proteases to yield free amino-acids which can either be absorbed or incorporated into the microbial protein. This may help to explain, at least in part, the depressed ileal digestibility of nitrogen when beet pulp is fed, compared to a low-fibre basal diet.

The effects of dietary fibre on the gastric, biliary and pancreatic secretions have been shown to be considerable (Zebrowska, 1983; Sambrook, 1981), and the increased output of these secretions is likely to enhance the flow of nitrogen into the large intestine still further. Increased exfoliation of the gut wall has been demonstrated in rats given high fibre diets (Southon, Livesey, Gee and Johnson, 1985), and similar effects have been seen in pigs given a protein-free diet (Sauer, Stothers and Parker, 1977; Taverner, Hume and Farrell, 1981). Sugar-beet pulp is likely therefore to increase endogenous nitrogen secretion so that the apparent digestibility of nitrogen is not only a function of the inherent digestibility of the dietary protein, but also of the presence of fibre in the diet. The pigs on the control diet would therefore be expected to show the highest nitrogen digestibility coefficients and those receiving the highest sugar-beet pulp supplements the lowest. These trends were reflected in the results obtained; nitrogen digestibility in the pigs given the CP14 and CP24 diets was 0.833 and 0.902 respectively as compared to 0.824 and 0.774 for the beet pulp supplemented diets.

Dietary fibre has been shown to ~~e~~affect digesta transit time through the gut which has implications for the digestion and absorption of proteins and amino acids. The mechanism by which this occurs remains unclear but it may act by increasing bulk since an inverse relationship has been demonstrated in humans between daily faecal weight and digestive transit time (Bardon & Fioramonti, 1983). The response to fibre in the diet is however variable, the variation in stool weight being a consequence of both the diet and an individual response to the diet. Studies by Cummings *et al.*, 1978, Eastwood *et al.*, 1983 and Wrick *et al.*, 1983 have shown that whilst cereal bran maintains its bulking potential during gut transit, the water-holding capacity of vegetable fibre is destroyed during transit due to fermentation of the fibre. Fermentation, therefore, appears to be the main factor determining the bulking capacity of fibre, and Stephen and Cummings (1980) demonstrated that a low bulking capacity of fermented fibre is due to increased bacterial mass. The dietary fibre of sugar-beet pulp was shown to be highly digestible (i.e. highly fermentable) in this current trial, and would be expected to have a low bulking capacity prior to extensive fermentation in the small intestine. Its effects on digestive transit time, thereafter are likely to be small.

Murray, Fuller & Pirie (1977) showed that the gel-forming polysaccharide, methyl cellulose, increased the rate of passage of digesta to the terminal ileum although cellulose had no effect. The results of this work suggest that bulk *per se* has no effect on protein digestion and that it is the hydrolysis of protein rather than the absorption of the products of digestion that is impaired when gel-forming polysaccharides are given.

This evidence suggests that fibre may also have the effect of carrying undigested/partially digested protein through the small intestine, its main site of digestion, into the caecum and colon.

The flow of nitrogen into the large intestine is also likely to be dependent on the crude protein content and quality of the diet fed, which will in turn effect microbial digestion in the hind gut, and the nitrogen balance of the pig.

The nitrogen excreted in the faeces, expressed as a proportion of nitrogen intake, was significantly affected by both the level of sugar-beet pulp fed and the crude protein of the diet, whilst the nitrogen excreted in the urine expressed in the same way) was not effected by the beet pulp or protein levels. (Table 2.2.9).

The pigs given the CP24 (control) diet showed a lower faecal nitrogen output and a higher urinary nitrogen output loss (when expressed as a proportion of nitrogen intake) than those pigs fed the CP14 (control) diet (Table 2.2.8).

The main contributor to the protein content of the CP24 diet was fishmeal, the protein of which is known to be more digestible than that of cereals, the main contributors to the protein content of CP14. Sugar-beet pulp was shown to be highly digestible and might therefore be assumed to act as a good source of fermentable carbohydrate for the gastrointestinal microflora, promoting its activity and proliferation. Nitrogen, in the form of partially digested protein or amino acids entering the hind gut will be available to the microflora for incorporation into microbial protein. This incorporation of amino acids into microbial protein, prevents their catabolism and therefore the flow of ammonia out of the large intestine into the bloodstream. Hence, urinary nitrogen excretion might be expected to be reduced. The relative magnitude of these changes in nitrogen excretion in the faeces and urine will determine the net effect on nitrogen retention. In this trial, the tendency for faecal nitrogen to increase was greater than the decrease in urinary excretion. This produced a slight depression in nitrogen retention at the higher levels of sugar-beet pulp addition.

When Morgan and Whittemore (1988) offered basal diets alone, or with increasing additions of straw, oatfeed or sugar-beet pulp, the excretion of nitrogen in the faeces – expressed as a proportion of nitrogen intake – tended to increase as the level of fibre addition increased. The effect was only measured to be significant in those pigs given straw diets. Urinary nitrogen excretion, expressed in the same manner, tended to fall as more fibre was eaten, the effect being significant for the oatfeed and sugar-beet pulp diets. Increasing the fibre content of the ration resulted in a significant increase in dietary nitrogen retained for the oatfeed diets and a similar trend with the other sources of fibre.

It has already been established that an increase in the fibre content of the diet results in a greater loss of faecal nitrogen by a number of mechanisms including an increased output of bacteria. Low (1985) concluded that an increase in nitrogen loss was usually balanced by a more or less equal reduction in urinary output. Malmlöf and Hakansson (1984), however, found that nitrogen output in the urine was reduced to a greater extent than the increase in faecal nitrogen output when straw was included in the diet of growing pigs. This had the effect of increasing nitrogen retention. Blood plasma urea concentrations have also been shown to be effected by the addition of dietary fibre to diets. Low (1985) showed that the amount of blood urea excreted into the large intestine is increased when dietary fibre increases, and work by Malmlöf (1985) showed that portal plasma urea and ammonia nitrogen were reduced on high fibre compared to low-fibre diets. It was concluded by Malmlöf and Hakansson (1984) that dietary fibre suppressed the liberation of ammonia in the colon by promoting the activity of the microflora, and reducing urinary nitrogen excretion. They proposed that the increase in nitrogen retention of pigs given high-fibre diets was due to a greater effectiveness of internal nitrogen metabolism. It could be that the removal of nitrogen waste products via the faeces and a suppression of the flow of ammonia reduces the loading on the nitrogen metabolism processes and increases nitrogen retention through a greater efficiency. This mechanism was not evident in this current study.

It has been established that the gut size increases when fibrous diets are fed (Pond, 1984; Stanogias and Pearce, 1985b; Low, 1985). Stanogias and Pearce (1985b) found that increased NDF intakes were associated with significantly higher wet weights of all gastrointestinal segments and increased lengths of the caecum. The source of NDF was the predominant factor influencing the length and weight of the distal colon. However, in cases where nitrogen retention has increased with fibre level, part or all of this increase could be due to an increase in protein in the large gut wall, leaving the protein deposition in the carcass unchanged.

NDF digestibility in the hind gut of the pig appears to be very much dependent on the protein content of the diet. In the ruminant the fermentation of fibrous feedstuffs can be limited by the supply of rumen degradable protein, and this concept appears to be applicable in the case of hind gut fermentation in the pig. On the low protein diet NDF digestibility of the beet pulp was measured to be 0.697, a low value when compared to previously measured values (0.84 Experiment 1.1; 0.81 Zhu and Fowler, 1987; 0.75 Morgan, Whittemore & Cockburn, 1984). In this situation, the nitrogen supply to the microbes in the hind gut could be limiting. The NDF of sugar-beet pulp has been found to be highly digestible in the pig and microbial activity will occur at a rapid rate. As a result the demand for nitrogen will be high. If the supply of amino acids is limited microbial activity may be reduced and the digestion of NDF less extensive. At the high protein level, the digestibility of NDF of the beet pulp was measured to be 0.874 and this indicates that the extra supply of nitrogen (which may have been in the form of undigested protein/amino acids, increased gut secretions or sloughed epithelial cells) can support a higher rate of microbial growth and breakdown of NDF. In the rat intestinal tract, Nyman and Asp (1984) found that at a level of dietary protein less than 50 g/kg that the fermentation of wheat-bran fibre was impaired, whereas a level higher than 100 g/kg did not increase the degree of fermentation of the fibre. The digestion of the more degradable fibre of sugar beet-pulp therefore appears more responsive to increasing levels of crude protein (see Table 2.2.17) than the more resistant fibre of wheat bran.

Table 2.2.17 **The response of NDF digestibility to increasing crude protein levels**

Crude Protein (g/kg DM)	NDF Digestibility Coefficient	Reference
140	0.697	Experiment 2.2
175	0.818	Experiment 3.2
220	0.735	Experiment 3.1
230	0.783	Experiment 1.1
240	0.874	Experiment 2.2

The results shown above (Table 2.2.17) show a general trend of increasing NDF digestibility with crude protein level in the diet. All of the experiments were conducted in the same way i.e. by adding unmolassed sugar-beet pulp to a low-fibre basal diet. The variability obtained even within this small group illustrates the variable nature of fibre digestibility in growing pigs.

The fact that sugar-beet pulp is well digested in the growing pig suggests that it acts as a good source of energy for the bacteria within the gastrointestinal tract of the pig. Zebrowska (1978) showed that the introduction of cellulose into the caecum of the pig decreased dry matter digestibility but had no effect on the digestibility of nitrogen. This seems to suggest that only a small part of the cellulose was fermented by the microorganisms and that cellulose is not the best source of energy for the microorganisms within the hind gut.

The metabolism of nitrogen in the large gut of the pig appears to confer little benefit to the host animal. Amino acids may be absorbed from this region but there is little evidence to suggest that the quantities involved are nutritionally significant once microbial activity is established. In the pig, infusion of enzymically-hydrolysed casein (Zebrowska, 1975), unhydrolysed heated or unheated casein (Zebrowska *et al.*, 1977), isolated soya-bean protein or lysine hydrochloride (Sauer *et al.*, 1976) into the terminal ileum of animals given low protein or protein-free diets, gave almost complete digestion in the large intestine but poor utilisation within the body when measured by nitrogen balance. Just *et al.* (1981) infused mixed protein, lysine or methionine into the caecum of pigs given lysine- and methionine-free diets. The effect was positive but small and at high rates of infusion much of the infused lysine was excreted in the urine.

The addition of a fibrous food to a diet has the effect of shifting the site of digestion, so that a greater proportion occurs by fermentation in the large intestine. The digestion of protein and amino acids in the hind gut of the pig, when it has been supplied with a diet adequate in protein, appears to confer benefit to the microflora only. This might be considered beneficial in terms of fibre degradation and energy supply, but the DE value of sugar-beet pulp was found to be similar when fed with both the low and high protein diets.

The digestibility of the NDF of the beet pulp was higher when it was fed with the diet high in protein, but the digestibility of the energy of the added beet pulp was not. This suggests that the energy released by the fermentation of the fibre was not absorbed, but passed out of the pig in the faeces, probably in the form of microbial matter, as was suggested by Partridge *et al.* (1982). It would appear, therefore, that the feeding of high levels of protein to promote fibre digestibility, benefits only the microbes, and is therefore highly questionable.

SECTION TWO

AN EVALUATION OF FIBROUS FEEDSTUFFS AS USEFUL INGREDIENTS IN THE DIETS OF GROWING PIGS

CHAPTER THREE

THE UTILISATION OF FIBROUS FEEDSTUFFS BY THE GROWING PIG

3.0 INTRODUCTION

In terms of feed evaluation the net energy obtained from of the digestible nutrients of a feed is of prime importance. On the basis of the production of volatile fatty acids (VFA) in the gut of the pig it would appear that the digestion of fibre could contribute significantly to the energy requirement of the pig. However, the efficiency with which the pig utilises absorbed VFA is still open to dispute.

This chapter aims to establish whether the energy released from the fermentation of unmolassed sugar-beet pulp is utilised by the pig, and if so, the efficiency with which it is utilised. The literature reviewed below presents recent information on VFA production and metabolism in growing pigs, and discusses the estimates which have been made of the contribution VFA make to the energy requirement of the pig.

Fermentation in the gut and VFA production

The most important products of bacterial fermentation, from a nutritional point of view, are VFA, generally present at concentrations of approximately 150-200 mM in the large intestine, compared to 5-40 mM in the stomach and small intestine (Argenzio and Southworth, 1975; Clemens, Stevens and Southworth, 1975). VFA produced by microbial fermentation of dietary fibre are predominantly found in the large intestine where there is a high density of cellulolytic bacteria. Such bacteria have also been detected in the ileum (Millard and Chesson, 1985) but their importance in this section of the gut is considered to be relatively minor.

VFA may be formed from any component of dietary fibre except lignin, as well as other dietary residues not digested by the host's enzymes, including starch, lipid and proteins which may enter the large intestine. The production of VFA in the hind gut, and the effects of diet type and the age of the animal have been studied by Horszczaruk and Sljivovacki (1971), Farrell and Johnson (1972), Ly (1974, 1975) and Imoto and Namioka (1978a). The relative proportions of the VFA vary but acetic acid tends to predominate with smaller amounts of propionic and butyric acids. The proportions vary according to the type of fibre and the site of fermentation within the gut. As the dietary fibre content of the diet increases, the proportion of acetic acid relative to the other VFA rises as illustrated by Kass *et al.* (1980) with alfalfa, and Gargallo and Zimmerman (1981b) with sunflower hulls. In adult pigs fitted with cannulas it was found that twice as much hydrolysis occurred in the caecum compared to the colon (Horszczaruk and Sljivovacki, 1966, 1971) and estimates of the VFA in the blood of veins draining the various regions of the gut confirm that the caecum is the main site of VFA absorption (Barcroft, McAnally and Phillipson, 1944). Diurnal variations in the portal and arterial VFA, which appeared to be related to time of feeding, have also been reported by Anderson and Northrop (1973).

Bowland, Young and Milligan (1971) studied the influence of dietary VFA mixtures on performance and fat composition of growing pigs. They found that pigs could utilise small amounts added to the diet but that larger amounts depressed performance and they were unable to prove conclusively that VFA from fibre hydrolysis contribute significantly to the energy economy of the pig. However, the rate of VFA production has been measured by a number of workers using a variety of methods in an attempt to estimate the contribution VFA may make to the energy supply of the pig. The results of this work are summarised in Table 3.1.0.

This table highlights the necessity for further research to quantify the contribution of VFA to the metabolism of the pig. All of the methods used rely on assumptions which lead to the introduction of errors in the final result obtained. Once again, the wide range of animal liveweights, diets and assumptions made are not condusive to comparisons of the results obtained from the different trials.

VFA metabolism and methane excretion in pigs

Despite the fact that some of the absorbed VFA appear to be metabolised in the gut wall (Imoto and Namioka, 1978a), substantial amounts have been shown to enter the blood. Latymer and Woodley (1984) introduced a tracer dose of U-^{14}C-acetate into the caecum of 22-28 kg pigs. The acetate was rapidly absorbed and peak levels were found in the blood within 30 minutes and ^{14}C was found in all major classes of lipid including cholesterol and cholesterol esters, plasma proteins and other water-soluble components. A second study was carried out by Latymer and Low (1984). Two pigs weighing 70-78 kg received U-^{14}C-acetate into the caecum and were killed following a 96 hour collection period. The recovery of the dose was as follows; small intestine and contents 0.008, large intestine contents 0.001, large intestine wall 0.015, liver 0.006, kidney 0.001, blood 0.001, carcase 0.236, faeces

Table 3.1.0 **Estimations of the rates of production of VFA and their contribution to net maintenance requirements of growing pigs**

Method	Reference	Diet (g/kg)	LW (kg)	Contribution to maintenance requirement	Comments
Portal-venous VFA concentration	Friend *et al.* (1964)	Barley-soya-fishmeal	30	0.15-0.28	Does not allow for hepatic VFA production
Regression of VFA conc. in caecum & colon 2, 4, 8 & 12 h after feeding.	Kass *et al.* (1980)	0 200 alfalfa 400 alfalfa 600 alfalfa	49	0.069 0.113 0.125 0.129	Underestimation of actual production and absorption rate to unknown degree
		0 200 alfalfa 400 alfalfa 600 alfalfa	89	0.048 0.231 0.285 0.245	
Continuous isotope dilution	Kennelly *et al.* (1981)	Barley-soya (hourly)	40-50	0.197	Isotope not contained within caecum ∴ pool of unknown size is obtained and sampled rom
		0 273 alfalfa 520 alfalfa (3 x daily)		0.101 0.155	
Short term *in vitro* incubations	Farrell & Johnson (1972)	80 cellulose 260 cellulose	33	0.055- 0.039	Relies on steady state assumption and must be related to entire pool of caecal/colonic contents, neither of which can be determined accurately.
	Imoto & Namioka (1978b)	low carbohydrate high carbohydrate	23	0.096- 0.116	
	Gargallo & Zimmerman (1981b)	20 sunflower hulls 100 sunflower hulls 200 sunflower hulls	95	0.062 0.056 0.050	
	Argenzio (1982)	High fibre High grain	49	0.19 0.25	

0.052 and losses of 0.635 were assumed to be $^{14}CO_2$ as calculated by difference. The results of this trial show that a substantial portion of the dose was retained in the carcase, mainly as subcutaneous fat. This was found to contrast with the situation in the newborn piglet which has minimal energy reserves and used the dose given orally as an immediate source of energy (Mohme, Molnar and Lenkheit, 1970). *In vitro* studies using tissues from various parts of the pig performed by Huang and Kummerow (1976) demonstrated the incorporation of U-^{14}C-acetate into fatty acids and cholesterol; the rate of incorporation was highest in adipose tissue.

The nutritive value of acetate has been estimated to be approximately 0.56-0.59 (in terms of use of ME) i.e. approximately 8.8 kJ were deposited per gram of supplementary acetate in growing pigs under thermoneutral conditions (Jentsch, Schiemann and Hoffman, 1968; Imoto and Namioka, 1983). The results of Jentsch *et al.* (1968) and Imoto and Namioka (1983) indicate that absorbed acetate is metabolised with an efficiency approximately 0.75 of that glucose when measured under conditions of growth.

Apparently digested energy from the fermentation of dietary fibre in the large intestine, in terms of its potential value to the animal, is less than that obtained from enzymic digestion of starch because some of the apparently absorbed energy is lost as heat of bacterial fermentation, and a further amount as CH_4 and the less efficient utilisation of the VFA produced.

Fermentation of carbohydrates in the hind gut results in the formation of gases including hydrogen, carbon dioxide and methane. Much of the methane is excreted in the flatus while a smaller amount is absorbed into the bloodstream and excreted in the expired air. Methane production in the hind gut of growing pigs has been shown to amount to only a few litres daily and has been calculated to represent an energy loss of about 0.002-0.012 of the gross energy of the diet (Verstegen, 1971; Hoffman, Jentsch, Klein and Schiemann, 1977; Jentsch and Hoffmann, 1977; Van der Honing, Jongbloed, Smits and Wieman, 1982; Thorbek and Christensen, 1987). This loss can be substantially higher in sows. Brierem (1935) found that 200 kg sows fed partly on grass lost up to a maximum of 0.035 of their gross energy intake as methane.

Generally methane production is not taken into consideration when estimating feeding values for pigs. However, for pigs given diets containing relatively high proportions of fermentable carbohydrate, energy loss as methane could become significant.

Evaluation of Feeds — energy retention

The energy content of a feed is metabolised within the body into other energy forms, only some of which are useful in the sense of growth and production. Much of the wasted energy is given off as heat and hence calorimetry can be used to estimate this loss.

Heat may be measured directly by physical means, or it may be inferred from quantitative measurements of some of the chemical by-products of metabolism i.e. indirect calorimetry. The measurement of heat production by means of animal calorimetry combined with the measurement of the chemical energy of food and excreta makes it possible to estimate energy retention by difference from the energy balance equation.

Energy is stored in growing animals mainly as protein and fat, since the carbohydrate reserves of the body are small and relatively constant. The quantities of protein and fat stored may be estimated from a carbon and nitrogen balance trial. By measuring the amounts of these elements entering and leaving the body, the amounts retained can be calculated by difference. The energy retained can then be calculated by multiplying the quantities of nutrients stored by their calorific values.

Two methods which have been used to test the ability of the animal to utilise the energy from VFA have been the growth bioassay in rats, and energy balance studies using pigs.

In studies with rats by Hove and King (1979) it was found that 0.25 cellulose and 0.75 pectin added to the diet was apparently digested resulting in VFA production. However, a growth bioassay for energy showed that these ingredients contributed to measurable energy to young rats. Lockhart, Lee, O'Mahony, Hensley and Houlihan (1980) measured the caloric value of fibre-containing cereal fractions and breakfast cereals in rats. They compared experimental results with values calculated by the Atwater method in which it was assumed that fibre has no energy value. For four test materials, Atwater values were slightly lower than experimental values which suggests some use of fibre energy, but for the four other sources the values were identical, indicating no VFA utilisation. When Atwater values based on NDF rather than crude fibre were used the authors reported that this modification gave much closer agreement between calculated and experimental values.

Partridge, Mitchell and Keal (1981) measured the energy value of cellulose for growing pigs. Two groups of pigs were grown from 20 to 80 kg liveweight on barley/soya diets according to restricted scales. The basal regime provided 0.15 less GE/day/kg LW but the same intake of all other nutrients as a conventional grower diet. One group of pigs received the basal ration alone whilst the second group were given solka-floc in addition at a level of 150 g/kg of total feed intake. Despite a suboptimal energy intake from the basal ratio there was no increase in growth rate as a result of feeding purified cellulose. The carcase composition was unchanged but dressing percentage was lower with added cellulose. Balance studies were conducted on each pig at 35 and 65 kg liveweight. There was a tendency for the fibre digestibility coefficient to be reduced with higher intake, but the weight of fibre digested was much higher. The results suggest that none of the energy released by the digestion of solka-floc was absorbed, or that any absorption of energy from solka-floc was off-set by reduced absorption of energy from other sources. Stephen and Cummings (1981) found that two sources of dietary fibre, cabbage and bran, increased faecal weight, faecal nitrogen and the excretion of bacteria in man. The nitrogen content of the bacterial fraction was constant at 0.06 independent of the diet, and therefore the increased output of bacteria accounted for the greater nitrogen excretion associated with the intake of fibre. Dietary fibre therefore appears to increase faecal weight and nitrogen through the same mechanism, that of increased microbial growth.

More recently, Zhu and Fowler (1987) carried out experiments to compare the growth responses of pigs to two increments of digestible energy resulting from additions to a control diet of either maize starch or unmolassed sugar-beet pulp. The responses to increments of DE were measured in terms of daily carcase gain. The results suggested that the apparent DE of sugar-beet pulp was used with an efficiency of between 0.58 and 0.65 relative to digestible energy from maize starch.

It therefore seems that there is still a considerable amount of uncertainty about the true net energy value of apparently digested energy in diets where a relatively large proportion of substrates are fermented in the gut.

From the point of view of feed evaluation, energy utilisation and the efficiency of conversion of feed to carcase gains are of particular interest. The effects of feeding fibrous foods on factors other than performance are also of importance. The composition of the carcase, in terms of backfat thickness, and the killing-out percentage are particularly important in determining the value of the carcase. Increased weights of the gastrointestinal tract, in response to the ingestion of fibrous foods have been reported (Pond, 1984; Low, 1985; Stanogias and Pearce, 1985b) and this could adversely affect the killing-out percentage of the pigs.

This chapter aims to address the questions;

- What is the net energy value of the digestible nutrients from the dry matter fermented in the gut?
- What is the effect of fibre on the composition of the carcase and the killing-out percentage?
- What is the effect of fibrous feedstuffs on gut fill and the empty wet weights of the gastrointestinal tract segments?

In order to answer these questions a number of different trials are required, namely;

1. A growth trial for the measurement of feed conversion ratio and the weight of the carcase, and backfat depths for the prediction of carcase composition.
2. Trials for the measurement of gut fill and the empty wet weights of the gastrointestinal tract segments at slaughter.
3. Metabolism studies for the measurement of digestibility, energy and nitrogen balances of the individual pigs, and the losses as methane and in the urine.

3.1 THE UTILISATION OF UNMOLASSED SUGAR-BEET PULP BY PIGS GROWN FROM 30-90 kg

3.1.0 INTRODUCTION AND AIMS

The objective of this experiment was to establish whether the energy released by the fermentation of unmolassed sugar-beet pulp is utilised by the growing pig. Experiments 1.1 and 2.2, reported in Chapters 1 and 2 respectively, have shown the fibre of sugar-beet pulp to be highly digestible. The digestibility of the NDF fraction in Experiment 1.1 was shown to be 0.84 and in Experiment 2.2, a digestibility coefficient of 0.87 was recorded for one of the treatments. Morgan *et al.* (1984) reported a value of 0.75. These digestibilities suggest that the fibre of sugar-beet pulp could contribute significantly to the energy requirement of the growing pig.

The response in growth rate to incremental increases in sugar-beet pulp will illustrate whether the energy released by fermentation is utilised by the pig. Maize was used as a reference source of energy. Maize starch is known to be digested enzymatically to produce glucose, anterior to the large intestine. By comparing the growth rates of pigs given sugar-beet pulp with those given maize, the efficiency of utilisation of fermented energy relative to glucose can be estimated.

The experiment also aims to examine the effects of increasing sugar-beet pulp inclusion level on killing-out percentage, the empty wet weights of the gastrointestinal tract segments and carcase characteristics.

3.1.1 MATERIALS AND METHODS

The experiment was conducted as two trials; A) a growth trial, to measure the daily liveweight gains and feed conversion ratios over the liveweight range 30-90 kg. The carcase weights of these pigs were recorded at slaughter to enable carcase gains and carcase feed conversion ratios to be estimated. Measurements of P2 backfat thickness and carcase length were also recorded for each pig; B) metabolism studies, for the measurement of nutrient digestibilities, digestible energy values and nitrogen retention.

A. Growth Trial

Animals and Diets

27 boars and 27 gilts of the Large White x Landrace breed, initially weighing approximately 30 kg, were used in this growth trial. Groups of nine pigs, of the same sex and similar weight, were allocated to six pens fitted with individual feeders.

Within each pen, each pig received one of 9 dietary treatments (manufactured and pelleted at the Lord Rank Research Centre, High Wycombe); a low-fibre control diet, 4 diets containing 48, 91, 130, and 167 g unmolassed sugar-beet pulp/kg and 4 diets containing maize at levels of inclusion of 38, 74, 107 and 138 g maize/kg (calculated to provide an equivalent intake of digestible energy to the sugar-beet pulp diets). The ingredient formulation of these diets and their expected chemical composition is given in Table 3.1.2.

The control diet was fed in accordance with the scale shown in Table 3.1.1.

Table 3.1.1 **The feeding scale for the control diet**

Bodyweight (kg)	Daily Feed (kg)
30	1.2
40	1.4
50	1.6
60	1.8
70	2.0
80	2.2

Table 3.1.2 **The ingredient formulation and predicted chemical composition of the diets (g/kg)**

		Beet pulp				Maize			
Ingredient	Control	50SBP	100SBP	150SBP	200SBP	40MAI	80MAI	120MAI	160MAI
Barley	285.9	272.2	259.9	248.8	238.2	275.1	264.8	255.3	246.5
Wheat	443.3	422.0	402.9	385.7	369.3	426.4	410.5	395.9	382.1
Unmolassed Sugar-Beet Pulp	–	48.0	91.0	130.0	167.0	–	–	–	–
Maize	–	–	–	–	–	38.0	74.0	107.0	138.0
Hi-pro Soya	200.0	190.4	181.8	174.0	167.0	192.4	185.2	178.6	172.4
Meat and Bone meal	64.8	61.7	58.9	56.4	54.0	62.3	60.0	57.9	55.9
Lysine-HCl	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04
Salt	1.9	1.8	1.8	1.7	1.6	1.9	1.8	1.7	1.7
P37B MZ	4.0	3.8	3.6	3.5	3.3	3.8	3.7	3.6	3.5
Oil	22.5	21.8	21.2	20.7	20.2	23.1	23.6	24.1	24.6
AHF	31.0	30.5	29.9	29.5	29.0	31.4	31.7	32.0	32.2
Protein	212.7	206.5	200.9	195.8	191.0	208.0	203.5	199.5	195.6
Crude Fibre	36.2	43.0	49.0	54.6	59.9	35.5	34.9	34.3	33.8
Ca	7.5	7.5	7.4	7.4	7.3	7.2	7.0	6.7	6.5
P	6.3	6.0	5.8	5.6	5.3	6.2	6.0	5.9	5.7
Salt	4.1	3.9	3.8	3.7	3.6	3.9	3.8	3.7	3.6
Ash	49.0	50.5	51.8	53.0	54.2	47.6	46.4	45.2	44.2
Lysine	9.8	9.4	9.0	8.7	8.4	9.5	9.3	9.0	8.8
Methionine	3.1	3.0	2.9	2.8	2.7	3.1	3.0	3.0	3.0
Methionine + cystine	6.4	6.2	5.9	5.7	5.5	6.3	6.2	6.1	6.0
Threonine	7.3	7.0	6.8	6.5	6.3	7.1	6.9	6.8	6.7
Cu (mg/kg)	126	121	115	111	107	122	117	113	110
Na	1.4	1.4	1.4	1.5	1.5	1.4	1.3	1.3	1.2
K	7.3	7.0	6.8	6.5	6.3	7.2	7.1	6.9	6.8
DE (MJ/kg)	13.81	13.69	13.59	13.50	13.41	13.84	13.86	13.88	13.90

The diets were formulated and fed at levels such that all pigs on all treatments received the same quantity of basal diet at a given liveweight. The diets containing sugar-beet pulp and maize were fed at different levels such that for an equivalent intake of 1 kg of the control diet, they provided an additional 50, 100, 150 or 200 g of sugar-beet pulp or 40, 80, 120 and 160 g maize (Table 3.1.3).

Table 3.1.3 **Levels of sugar-beet pulp and maize supplementation**

Diet	Feeding Level	Equivalent Intake to pigs on 1 kg control Control (kg)	 SBP/MAI (kg)
50SBP	Control x 1.05	1	0.05
100SBP	Control x 1.10	1	0.10
150SBP	Control x 1.15	1	0.15
200SBP	Control x 1.20	1	0.20
40MAI	Control x 1.04	1	0.04
80MAI	Control x 1.08	1	0.08
120MAI	Control x 1.12	1	0.12
160MAI	Control x 1.16	1	0.16

Trial Procedure

The pigs were fed twice daily and given free and continuous access to drinking water. The weights of the pigs were recorded weekly and the level of feeding adjusted accordingly. The pigs were slaughtered at a liveweight of approximately 90 kg. Measurements of carcase weight and length, and P2 backfat depth were made at slaughter.

Examination of the gastrointestinal tract

The gastrointestinal tracts of 6 boars, 3 fed on the diet 200SBP and 3 which had received 160MAI were collected at slaughter. These boars all received their last meal on the evening prior to slaughter, when they were fed the same quantity of each diet. The spleen and any remaining pieces of liver were removed. Since pieces of flesh of varying weights were always associated with the rectum as a result of degutting, the final 100 mm of the rectum were removed before weighing and measuring. The mesenteric and adhering fat was removed and its weight recorded. The gut was divided into four segments; stomach, small intestine, caecum and colon plus rectum. Each segment was opened using scissors and the digesta removed and weighed. The weight of each segment was recorded.

B. Metabolism Studies

36 Large White x Landrace boars of initial mean liveweight 47 kg were used in a series of metabolism trials to determine the digestibility of the nutrients and energy, and the nitrogen retention of the pigs given the 9 diets fed in the growth trial. 4 pigs were randomly allocated to each diet which were fed according to the scales detailed in Tables 3.1.1 and 3.1.3.

The adaptation and collection periods, and the techniques used for the collection and sampling of faeces were as described in Experiment 1.1 (Section 1.1.1, Chapter 1).

3.1.2 ANALYTICAL PROCEDURES

The diets, faeces and urine were analysed using the procedures described in Experiment 1.1.

3.1.3 STATISTICAL ANALYSIS

A Growth trial

Genstat V (Lawes Agricultural Trust, 1984) was used in the statistical analysis of the results. The effects of sugar-beet pulp and maize supplementation levels on performance factors (daily liveweight gain, daily carcase gains, feed conversion ratio and carcase feed conversion ratio) were analysed using the technique of analysis of variance. The analysis of variance identified the diet, the sex of the pig and the diet * sex interaction. The significance of each mean was tested by comparison of the mean squares of the diet, sex and diet * sex interaction with the error mean square.

Analysis of co-variance (to correct for any differences in final slaughter weight) was used to examine the effects of sugar-beet pulp and maize inclusion levels on killing-out percentage, carcase characteristics and the weight and lengths of the gastrointestinal tract segments.

The performance factors and carcase characteristics were regressed against the level of sugar-beet pulp or maize supplementation to try and identify the presence of linear relationships. The significance of the relationship was tested by comparing the mean squares of the linear and quadratic components with the error mean square.

B Metabolism studies

Analysis of variance (Genstat V) was used to examine the effect of diet on the digestibilities of dry matter, organic matter, NDF, nitrogen and energy, and the retention and excretion of nitrogen. The analysis of variance identified diet, and the significance of each mean was tested by comparison of the mean squares of the diet with the error mean square.

The digestibilities of the nutrients, nitrogen retention and excretion values were regressed against the level of sugar-beet pulp/maize supplementation to identify the presence of any linear trends. The significance of the relationship, was tested by comparing the mean squares of the linear and quadratic terms with the error mean square.

The DE of the basal diet, sugar-beet pulp and maize were determined by difference, linear regression and multiple regression using MINITAB.

3.1.4 RESULTS

The chemical compositions of the control, sugar-beet pulp and maize supplemented diets are shown in Table 3.1.4.

Table 3.1.4 Chemical composition of the diets

	DIET								
Component	Control	50SBP	100SBP	150SBP	200SBP	40MAI	80MAI	120MAI	160MAI
DM (g/kg)	910	920	922	921	919	919	917	921	917
GE (MJ/kg DM)	17.80	17.56	17.56	17.55	17.41	17.76	17.66	17.48	17.47
AHF (g/kg DM)	3.21	2.96	3.03	2.79	2.81	3.20	3.21	3.20	3.30
Crude Protein (g/kg DM)	236	226	226	213	214	229	226	214	213
NDF (g/kg DM)	125	139	157	154	163	117	115	108	114
Ash (g/kg DM)	62	63	66	65	65	61	59	56	54
Salt (g/kg DM)	0.34	0.36	0.34	0.35	0.35	0.33	0.34	0.31	0.32
Mg (g/kg DM)	0.13	0.12	0.13	0.13	0.13	0.12	0.12	0.12	0.11
Cu (mg/kg DM)	111	106	104	101	100	106	105	101	94
Mn (mg/kg DM)	66	70	78	72	73	64	66	61	58
Zn (mg/kg DM)	181	184	180	178	165	174	175	165	185
Ca (g/kg DM)	1.01	0.99	1.06	1.02	1.05	0.97	0.95	0.93	0.88
P (g/kg DM)	0.83	0.77	0.78	0.73	0.71	0.79	0.80	0.77	0.74
Na (g/kg DM)	0.13	0.12	0.12	0.13	0.13	0.13	0.12	0.11	0.11
K (g/kg DM)	0.76	0.72	0.75	0.77	0.74	0.73	0.74	0.70	0.68

A GROWTH TRIAL

Daily Liveweight Gain

Table 3.1.5 shows the mean daily liveweight gains of the pigs given the control, sugar-beet pulp and maize supplemented diets.

As sugar-beet pulp and maize were added to the diet daily liveweight gain increased.

Table 3.1.5 **Daily liveweight gains of the pigs given the control, sugar-beet pulp and maize supplemented diets over the liveweight range 30-90 kg**

(mean values for 6 pigs)

Diet	Test Material SBP	 MAI	SED	SIG
Control	0.721			
50SBP/40MAI	0.752	0.752		
100SBP/80MAI	0.753	0.792	0.0266	*
150SPB/120MAI	0.827	0.812		
200SBP/160MAI	0.809	0.830		
Linear	**	**		
Quadratic	NS	NS		

*, $P<0.05$; t value 2.04; **, $P<0.01$

For sugar-beet pulp, the pigs given the 50SBP and 100SBP diets gained liveweight at a similar daily rate which was not significantly different from that found for the control pigs. The pigs fed the 150SBP and 200SBP diets showed very similar daily liveweight gains which were both significantly ($P<0.05$) greater than the liveweight gains observed for the pigs which received the control, 50SBP and 100SBP diets.

The pigs given the 40MAI diet showed similar daily liveweight gains to those given the control diet. However, those pigs which received the 80MAI, 120MAI and 160MAI diets showed significantly ($P<0.05$) higher daily liveweight gains than those fed on the control diet. The pigs fed on the 160MAI diet showed the highest daily liveweight gain but their gain was not significantly higher than those given the 120MAI diet.

The relationship between daily liveweight gain and increasing sugar-beet pulp, and maize supplementation was linear (Figures 3.1.0 and 3.1.1). The slopes of the lines were significantly different from zero and the regression equations (with standard deviations in parentheses) were;

Sugar-beet pulp;

$$\text{Daily Liveweight Gain (kg)} = \underset{(0.0163)}{0.723} + \underset{(0.1330)}{0.499} \times \text{added beet pulp (kg)} \qquad r=0.58$$

Maize;

$$\text{Daily Liveweight Gain (kg)} = \underset{(0.0154)}{0.726} + \underset{(0.1569)}{0.693} \times \text{added maize (kg)} \qquad r=0.64$$

Since the 4 sugar-beet pulp diets and the 4 maize diets were formulated and fed at levels to provide equivalent digestible energy intakes, and assuming the composition of the diets to be consistent with the formulations, then the mean daily liveweight gains obtained when feeding 50SBP, 100SBP, 150SBP and 200SBP can be compared directly to those obtained for the 40MAI, 80MAI, 120MAI and 160MAI respectively. No significant differences were found between the daily liveweight gains of the pigs given the sugar-beet pulp diets or the maize diets at any levels of their inclusion when compared as described above. However, these values will be compared and discussed at a later stage in this section using in vivo digestible energy values obtained in the metabolism studies.

As would be expected the boars had higher daily liveweight gains (mean 0.805 kg/d) than the gilts (mean 0.761 kg/d). No significant diet * sex interaction was identified when considering daily liveweight gain.

Feed Conversion Ratio

Table 3.1.6 gives the mean feed conversion ratios (kg food/kg gain) for the pigs given the control, sugar-beet pulp and maize supplemented diet.

The addition of sugar-beet pulp to the control diet resulted in a deterioration in feed conversion ratio, although not significantly, for all of the diets, thus indicating a reduction in the efficiency of utilisation of the control diet for liveweight gain with increasing levels of sugar-beet pulp. The relationship was linear (Figure 3.1.2), and the slope of the line was significantly different from zero (Figure 3.1.2). The regression equation (with standard deviations in parentheses) was;

$$\text{FCR} = \underset{(0.043)}{2.40} + \underset{(0.3474)}{0.763} \times \text{added sugar-beet pulp (kg)} \qquad r=0.38$$

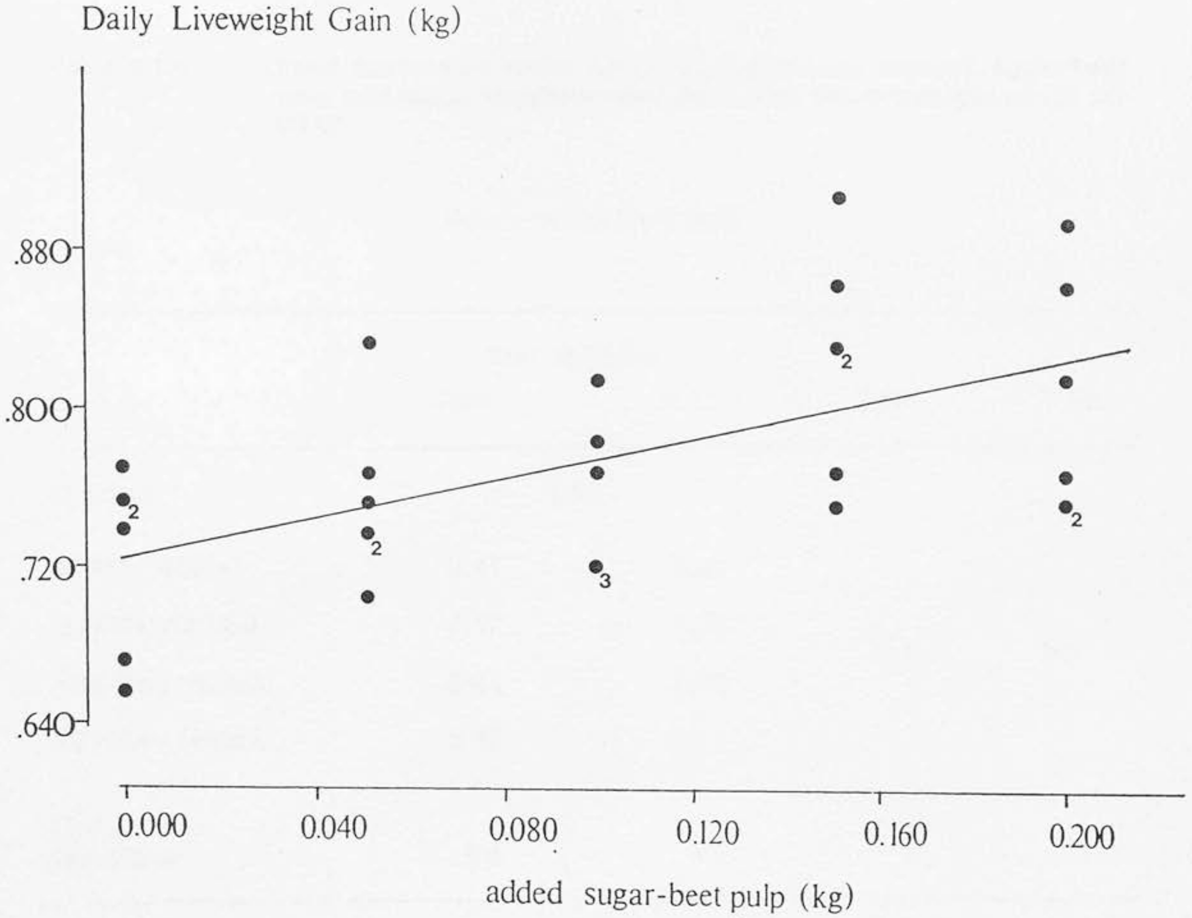


Figure 3.1.0 **Relationship between daily liveweight gain and level of added beet pulp**

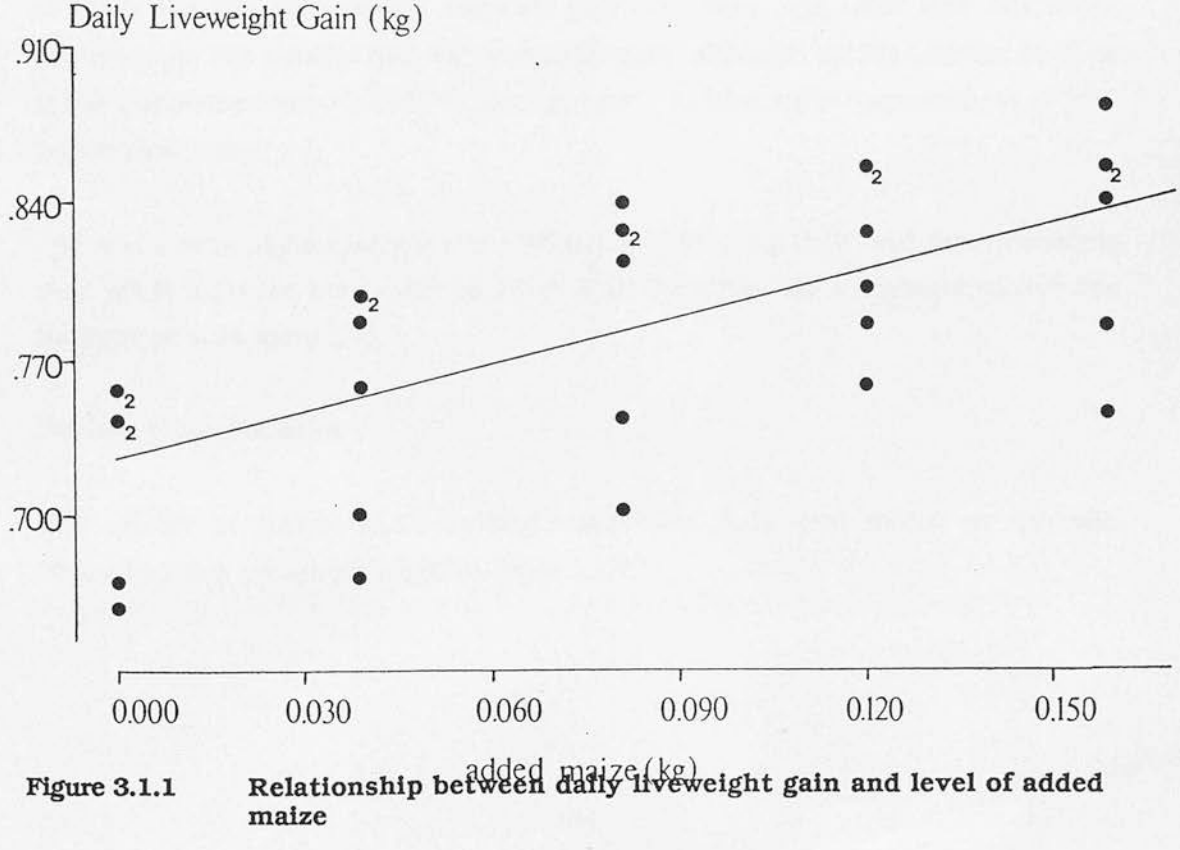


Figure 3.1.1 **Relationship between daily liveweight gain and level of added maize**

Table 3.1.6 **Feed conversion ratios for the pigs given the control, sugar-beet pulp and maize supplemented diets over the liveweight range 30-90 kg**

(mean values for 6 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	2.40			
50SBP/40MAI	2.41	2.40		
100SBP/80MAI	2.52	2.36	0.136	NS
150SPB/120MAI	2.49	2.40		
200SBP/160MAI	2.55	2.34		
Linear	*	NS		
Quadratic	NS	NS		

The addition of maize to the control diet had very little effect on the feed conversion ratios. No significant differences could be identified between the mean FCR for the five diets which suggests that the maize was used with the same efficiency as the control diet for liveweight gain, although at the highest level of maize supplementation (160MAI) there appeared to be a slight improvement in feed conversion ratio.

The boars were significantly better ($P<0.01$) at converting their feed into liveweight gain (FCR 2.36 for boars compared to 2.49 for gilts). No significant diet * sex interaction was identified.

Carcase characteristics

The effects of the level of feeding sugar-beet pulp and maize on carcase characteristics are summarised in Table 3.1.7.

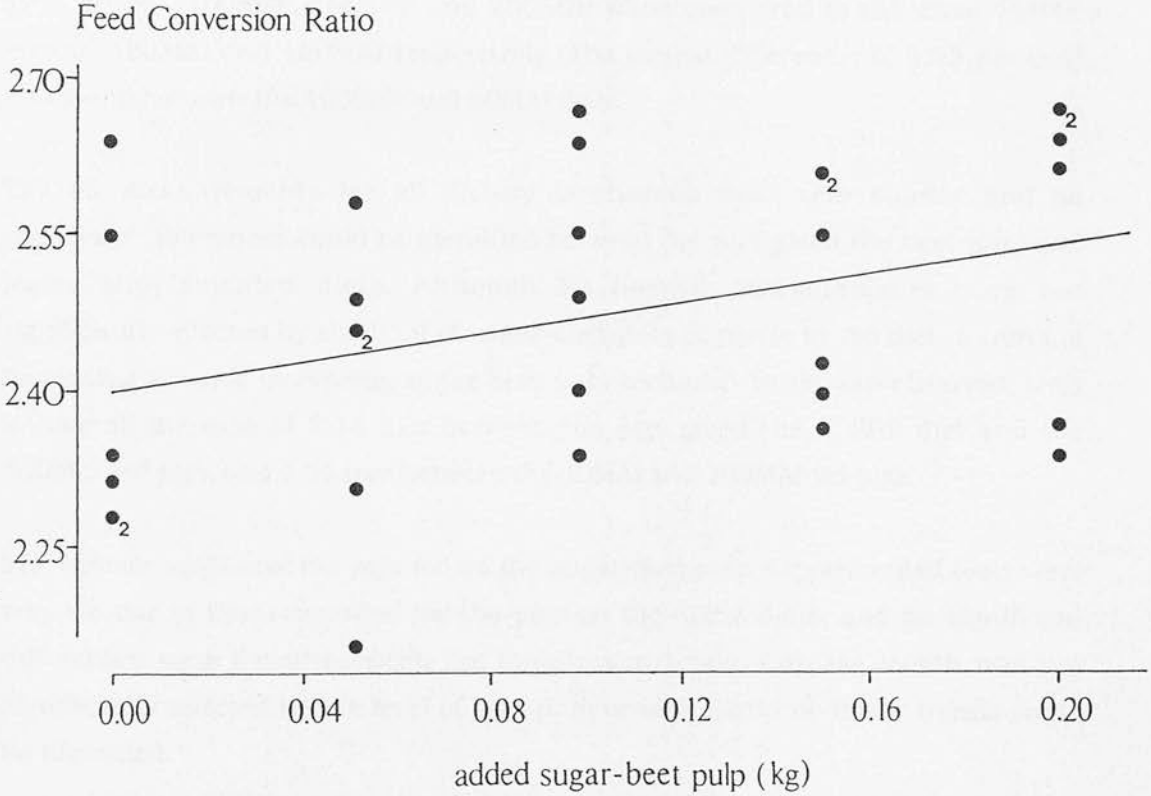


Figure 3.1.2 **Relationship between FCR and level of added sugar-beet pulp**

No significant differences could be identified between the mean slaughter weights of the pigs given the control, sugar-beet pulp and maize supplemented diets. However, there was a trend of increasing slaughter weight with increasing level of beet pulp and maize in the diet. For this reason the killing-out percentages, P2 measurements and carcase lengths were subjected to analysis of co-variance using slaughter weight as the covariate.

No significant differences were found between the killing-out percentages of the diets 50SBP, 100SBP, 150SBP and 200SBP when compared to the diets 40MAI, 80MAI, 120MAI and 160MAI respectively. The largest difference, of 2.05 per cent was found between the 100SBP and 80MAI diets.

The P2 measurements for all dietary treatments were very similar and no significant differences could be identified between the pigs given the beet pulp and maize supplemented diets. Although P2 backfat measurements were not significantly effected by the level of sugar-beet pulp or maize in the diet, a trend of increasing P2 with increasing sugar-beet pulp inclusion levels was observed, with an overall increase of 2.14 mm between the pigs given the 50SBP diet and the 200SPB fed pigs, and 2.31 mm between the 40MAI and 160MAI fed pigs.

The carcase lengths of the pigs fed on the sugar-beet pulp supplemented diets were very similar to those recorded for the pigs on the maize diets, and no significant differences were found between the supplement levels. Carcase length was not significantly affected by the level of beet pulp or maize, and no linear trends could be identified.

The level of beet pulp fed significantly ($P<0.01$) affected carcase growth rate and carcase FCR (kg food/kg carcase gain). The pigs given the 50SBP diet were the only group to show significantly ($P<0.01$) lower carcase gains than the control pigs. The pigs fed the 100SBP diet showed very similar carcase gains to the control pigs. The highest mean daily carcase gain of 0.641 kg was achieved by the pigs given 150SBP, which was significantly ($P<0.01$) greater than the carcase gains of the control and 50SBP fed pigs. Those which received the 200SBP diet showed similar gains to those which received 150SBP, but the mean value obtained was only significantly ($P<0.01$) greater than the 50SBP fed pigs. The relationship between carcase growth

Table 3.1.7 **The effect of sugar-beet pulp and maize level on carcase characteristics**

(mean values for 6 pigs)

		DIET								
		Control	50SBP 40MAI	100SBP 80MAI	150SBP 120MAI	200SBP 160MAI	SED	SIG	Lin	Quad
Slaughter Weight (kg)	SBP	88.85	89.88	90.52	91.33	92.00	1.582	NS	*	NS
	MAI		89.27	90.50	91.48	91.33			NS	NS
Killing-out (%)	SBP	76.96	76.22	75.77	76.03	76.32	0.931	NS	NS	NS
	MAI		76.19	77.82	77.74	76.78			NS	NS
P2 (mm)	SBP	13.22	12.79	13.16	13.72	14.93	1.215	NS	NS	NS
	MAI		12.74	13.66	13.40	15.05			NS	NS
Length (mm)	SBP	784	802	789	800	785	10.00	NS	NS	NS
	MAI		793	789	798	785			NS	NS
Carcase Growth Rate (kg/day)	SBP	0.577	0.509	0.584	0.641	0.634	0.0214	**	**	NS
	MAI		0.593	0.639	0.640	0.655			**	NS
Carcase FCR	SBP	2.99	3.06	3.25	3.22	3.26	0.0972	**	**	NS
	MAI		3.04	2.92	3.04	2.97			NS	NS

*, P<0.05; **, P<0.01, t value 2.46.

rate and level of added beet pulp was linear (Figure 3.1.3), and the slope of the line was significantly different from zero. The regression equation (with standard deviations in parentheses) was;

Sugar-beet pulp;

Carcase gain (kg/d) = 0.572 + 0.330 x added sugar-beet pulp (kg) r=0.53
(0.0121) (0.0988)

Carcase growth rate increased with increasing levels of maize in the diet. The control pigs showed the lowest carcase gains at 0.577 kg/day. The pigs given the 40MAI diet showed higher carcase gains than the control pigs, but the difference between the means was non-significant. The pigs fed on 80MAI, 120MAI and 160MAI all gave significantly greater (P<0.01) carcase gains than the control pigs, but the values obtained for these diets were not significantly different from each other. When the carcase growth rate was regressed against the level of added maize the relationship was found to be linear (Figure 3.1.4) and the regression equation (with standard deviations in parentheses) was;

Maize;

$$\text{Carcase gain (kg/d)} = \underset{(0.0109)}{0.580} + \underset{(0.1122)}{0.510} \times \text{added maize (kg)} \qquad r=0.65$$

Carcase FCR increased with increasing level of sugar-beet pulp in the diet indicating that the sugar-beet pulp added to the control diet was utilised less efficiently for carcase gains than the control diet.

The relationship was linear, and the slope of the line significantly different from zero (Figure 3.1.5). The regression equation (with standard deviations in parentheses) was

$$\text{Carcase FCR} = \underset{(0.054)}{3.02} + \underset{(0.443)}{1.35} \times \text{added beet pulp (kg)} \qquad r=0.50$$

Carcase FCR were very similar for the pigs on each of the maize diets and no significant trends or differences could be identified, thus suggesting that the addition of maize to the control diet did not affect its efficiency of utilisation for carcase gain.

Carcase FCR values were similar for the 50SBP and 40MAI diets, and also the 150SBP and 120MAI diet. However, the FCR values for the 80MAI and 160MAI diets were significantly ($P<0.01$) lower than the mean values obtained for the 100SBP and 200SBP diets respectively. This suggests that the maize diets fed at these levels led to a greater efficiency of conversion of feed to carcase gain.

The effect of the sex of the pig on carcase characteristics

The effect of the sex of the pig on carcase characteristics are presented in Table 3.1.8. No significant differences were found between the slaughter weights, killing-out percentages, P2 backfat measurements or carcase lengths of the boars or gilts. However, as would be expected, the boars had significantly higher ($P<0.05$) carcase gains and converted their feed significantly ($P<0.05$) more efficiently into carcase gain than the gilts.

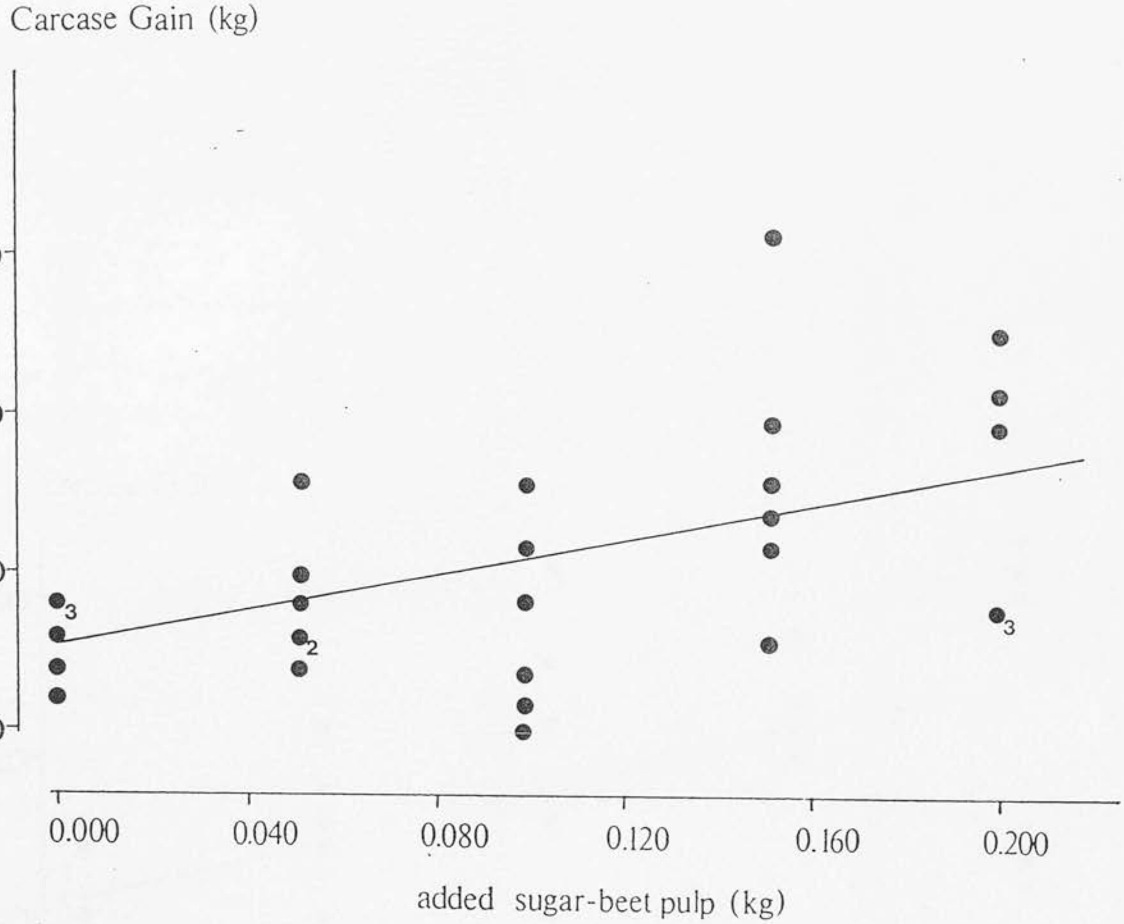


Figure 3.1.3 Relationship between carcase gain and level of added sugar-beet pulp

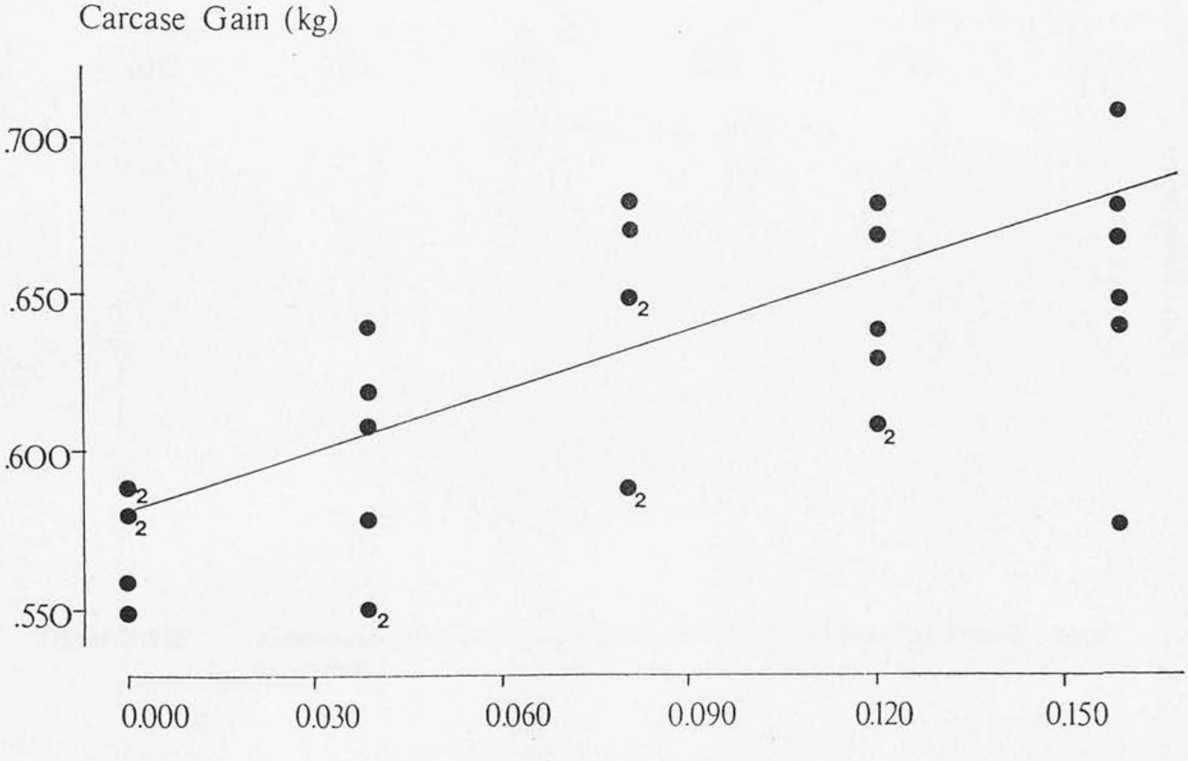


Figure 3.1.4 Relationship between carcase gain and level of added maize

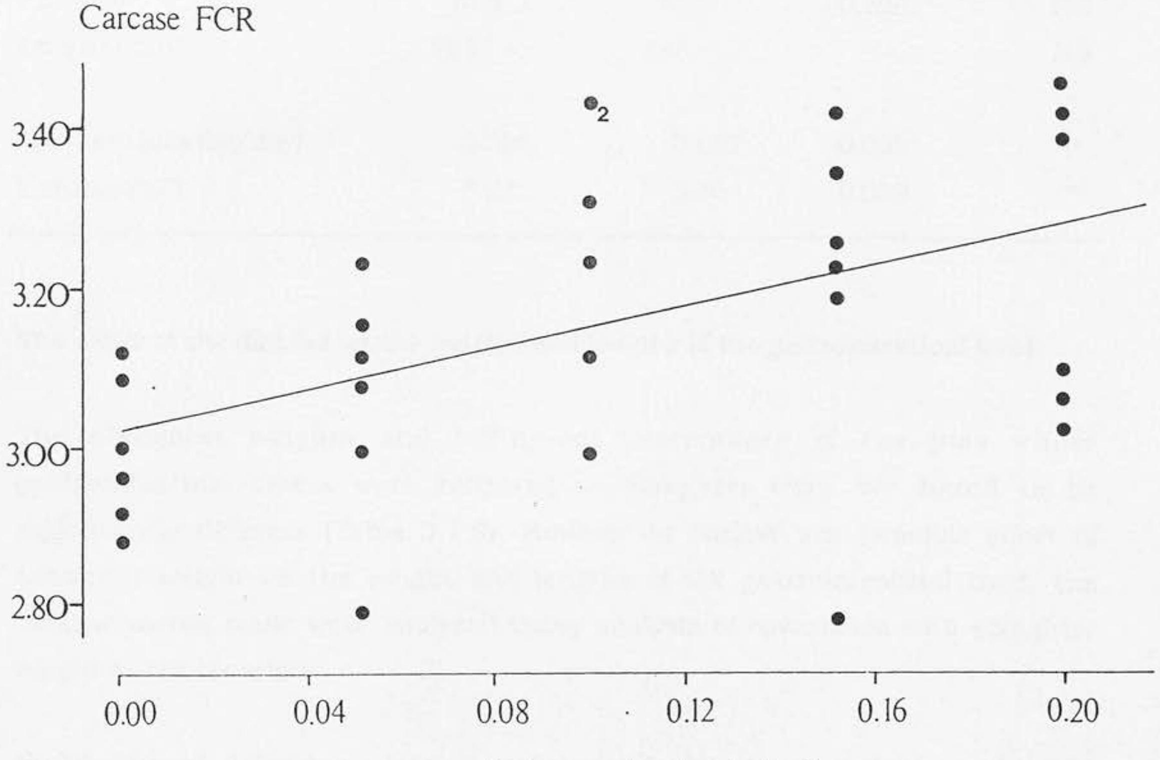


Figure 3.1.5 **Relationship between carcase FCR and the level of added sugar-beet pulp.**

Table 3.1.8 **Effect of the sex of the pig on carcase characteristics**

	SEX			
	Boar	Gilt	SED	SIG
Slaughter Weight (kg)	91.4	89.7	0.670	NS
Killing-out (%)	76.8	76.9	0.647	NS
P2 (mm)	13.4	13.9	0.220	NS
Length (mm)	795	788		NS
Carcase Gain (kg/day)	0.632	0.602	0.008	*
Carcase FCR	3.01	3.15	0.039	*

The effect of the diet fed on the weights and lengths of the gastrointestinal tract

The slaughter weights and killing-out percentages of the pigs whose gastrointestinal tracts were retrieved at slaughter were not found to be significantly different (Table 3.1.9). However to remove any possible effect of slaughter weight on the weight and lengths of the gastrointestinal tract, the measurements made were analysed using analysis of covariance with slaughter weight as the covariate.

No significant differences in the gastrointestinal segment weights or lengths between the two groups of pigs could be found (Table 3.1.9) and this was probably due to the extremely small sample of tracts which could be measured.

However, the gut contents were found to be significantly heavier in the sugar-beet pulp fed pigs.

B METABOLISM STUDIES

Dry matter (DM) and organic matter (OM) digestibility

The mean DM and OM digestibility coefficients for the pigs given each diet are shown in Tables 3.1.10 and 3.1.11.

Table 3.1.9 **A comparison of the weights and lengths of the gastrointestinal segments of pigs given diets 200SBP and 160MAI**

(mean values for 3 pigs)

	DIET			
	200SBP	160MAI	SED	SIG
Slaughter Weight (kg)	92.7	91.2	3.35	NS
Killing-out %	76.8	76.9	0.647	NS
Gut contents (kg)	4.06	2.26	0.498	*
Empty stomach (kg)	0.63	0.49	0.063	NS
Empty large intestine (kg)	1.09	1.07	0.074	NS
Empty caecum (kg)	0.14	0.13	0.020	NS
Empty small intestine (kg)	1.04	1.16	0.128	NS
Mesenteric fat (kg)	0.60	0.66	0.136	NS
Length large intestine (m)	5.29	4.85	0.651	NS
Length caecum (m)	0.267	0.264	0.0076	NS
Length small intestine (m)	23.23	22.11	0.725	NS

Table 3.1.10 **DM digestibility coefficients for the control, sugar-beet pulp and maize supplemented diets**

(mean values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.862			
50SBP/40MAI	0.864	0.867		
100SBP/80MAI	0.872	0.881	0.0085	NS
150SBP/120MAI	0.867	0.872		
200SBP/160MAI	0.865	0.872		
Linear	NS	NS		
Quadratic	NS	NS		

No significant differences were found in DM digestibility between the diets supplemented with sugar-beet pulp and those supplemented with maize. Increasing the level of sugar-beet pulp and maize fed did not significantly effect DM digestibility.

Table 3.1.11 **Mean OM digestibilities for the control, sugar-beet pulp and maize supplemented diets**

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.903			
50SBP/40MAI	0.890	0.893		
100SBP/80MAI	0.890	0.893	0.0048	**
150SBP/120MAI	0.886	0.894		
200SBP/160MAI	0.878	0.902		
Linear	**	NS		
Quadratic	NS	NS		

(**, $P<0.01$ t value, 2.72)

At the highest levels of sugar-beet pulp and maize supplementation (200SBP and 160MAI respectively) significant ($P<0.01$) differences were found between the mean OM digestibility coefficients.

The increasing addition of maize to the control diet did not significantly affect the digestibility of the organic matter of the whole diet. However, the addition of sugar-beet pulp in diet 50SBP was sufficient to produce a significant ($P<0.01$) reduction in OM digestibility which was further depressed in the 150SBP and 200SBP diets.

The relationship between OM digestibility and increasing level of beet pulp supplementation was linear (Figure 3.1.6). The slope was significantly different from zero, and the regression equation (with standard deviations in parentheses) was;

$$\text{OM digestibility} = \underset{(0.0029)}{0.900} - \underset{(0.0233)}{0.108} \times \text{added sugar-beet pulp (kg)} \qquad r=0.74$$

NDF digestibility

Table 3.1.12 **NDF digestibility coefficients for the control, sugar-beet pulp and maize supplemented diets.**

(mean values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.626			
50SBP/40MAI	0.626	0.508		
100SBP/80MAI	0.674	0.534	0.0196	***
150SBP/120MAI	0.659	0.502		
200SBP/160MAI	0.673	0.565		
Linear	*	**		
Quadratic	NS	*		

***, P<0.001; t value, 3.59

The digestibility of the NDF of the sugar-beet pulp diets was found to be significantly higher (P<0.01) than that of the maize at all levels of supplementation (Table 3.1.12).

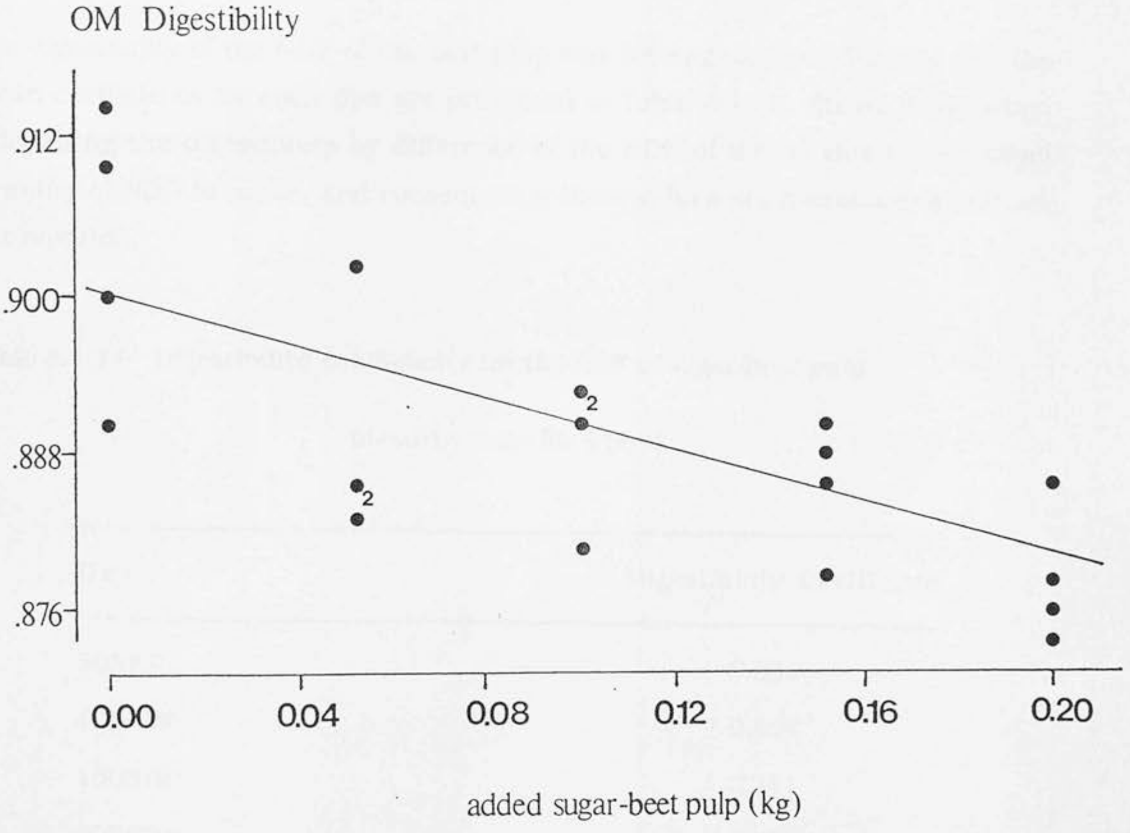


Figure 3.1.6 **Relationship between organic matter digestibility and level of added beet pulp**

Increased levels of sugar-beet pulp in the diets 100SBP, 150SBP and 200SBP, tended to increase the digestibility of the NDF of the whole diet. The relationship was linear, and the slope of the line was significantly different from zero (Figure 3.1.7). The regression equation obtained (with standard deviations in parentheses) was;

$$\text{NDF digestibility} = \underset{(0.0119)}{0.625} + \underset{(0.0972)}{0.258} \times \text{added sugar-beet pulp (kg)} \quad r=0.53$$

The digestibility of the NDF of the beet pulp was determined by difference and the mean coefficients for each diet are presented in Table 3.1.13. Errors arose when calculating the digestibility by difference of the NDF of maize, due to the small quantity of NDF in maize, and consequently these values are meaningless and are not reported.

Table 3.1.13 Digestibility coefficients for the NDF of sugar-beet pulp

(means values for 4 pigs)

Diet	Digestibility Coefficient
50SBP	0.635
100SBP	0.804
150SBP	0.741
200SBP	0.758
SED	0.0693
Level of Significance	NS

No significant differences in NDF digestibility for the sugar-beet pulp could be found between any of the feeding levels.

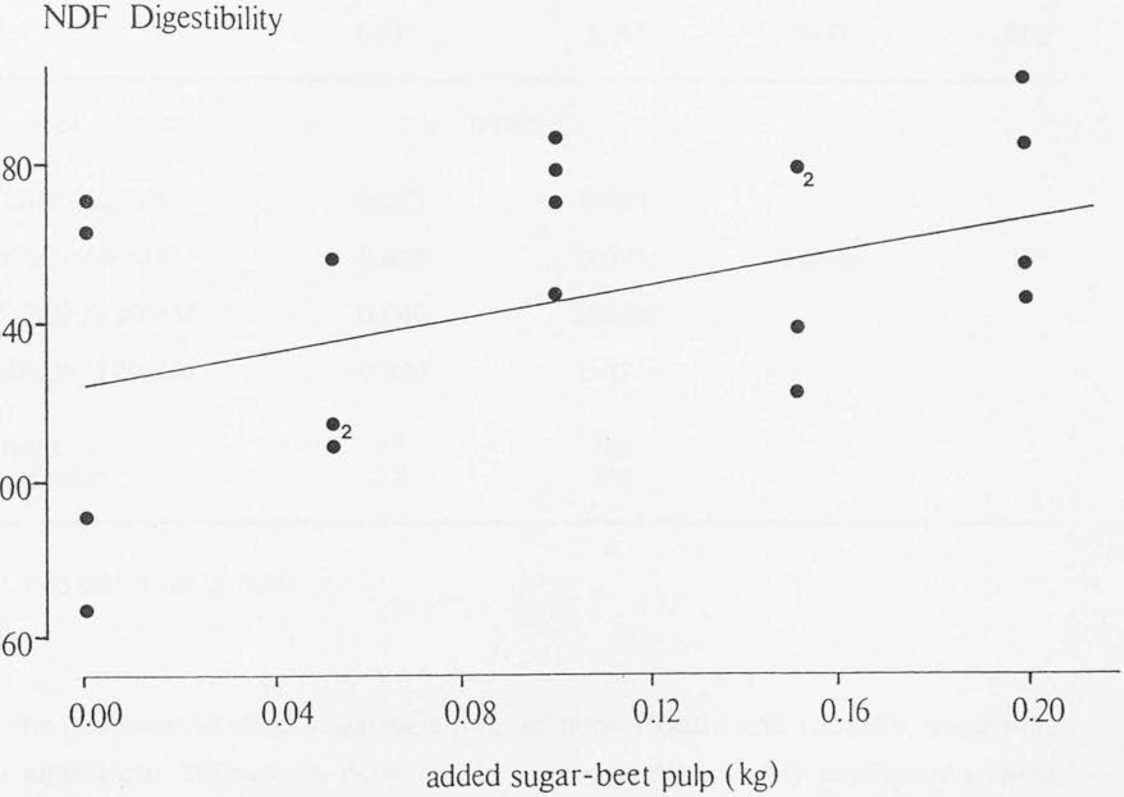


Figure 3.1.7 Relationship between NDF digestibility and level of added beet pulp

Nitrogen digestibility, nitrogen retention and nitrogen excretion

Table 3.1.14 Nitrogen digestibility coefficients for the control, sugar-beet pulp and maize supplemented diets.

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.884			
50SBP/40MAI	0.857	0.874		
100SBP/80MAI	0.859	0.873	0.0086	***
150SBP/120MAI	0.840	0.866		
200SBP/160MAI	0.820	0.874		
Linear	***	NS		
Quadratic	NS	NS		

***, P<0.001; t value, 3.59

At the two lower levels of sugar-beet pulp addition (50SBP and 100SBP), there were no significant differences between the nitrogen digestibility coefficients when compared to those measured for the diets 40MAI and 80MAI respectively (Table 3.1.14). However, at the higher levels of sugar-beet pulp addition (150SBP and 200SBP) nitrogen digestibility was found to be significantly (P<0.001) lower than for the diets 120MAI and 160MAI, respectively.

The addition of sugar-beet pulp to the control diet resulted in a significant depression in nitrogen digestibility at all levels of its inclusion when compared to the value obtained for the control diet. The lowest nitrogen digestibility coefficient (0.820) was found for diet 200SBP. This value was significantly (P<0.001) different from the values measured for the 50SBP and 100SBP diets.

The relationship was found to be linear with no significant deviations from linearity (Figure 3.1.8). When nitrogen digestibility was regressed against level of supplementary beet pulp the regression equation obtained (with standard deviations in parentheses) was

$$\text{Nitrogen digestibility} = \underset{(0.0048)}{0.881} - \underset{(0.0394)}{0.291} \times \text{added sugar-beet pulp (kg)} \quad r=0.87$$

Nitrogen digestibility coefficients obtained for the control and maize supplemented diets were similar, and increasing the level of maize did not significantly affect the digestibility of nitrogen.

Nitrogen retention, expressed as g N retained/day (Table 3.1.15) or as a proportion of the nitrogen intake (Table 3.1.16), was found to be highly variable and no significant differences were found between the mean values recorded for each diet. However, the pigs on the sugar-beet pulp supplemented diets tended to retain more nitrogen than those given the maize diets.

Table 3.1.15 Nitrogen retained (g/day) by the pigs on the control, sugar-beet pulp and maize supplemented diets.

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	24.60			
50SBP/40MAI	24.87	22.23		
100SBP/80MAI	23.40	19.53	3.468	NS
150SBP/120MAI	22.36	21.90		
200SBP/160MAI	24.05	22.00		
Linear	NS	NS		
Quadratic	NS	NS		

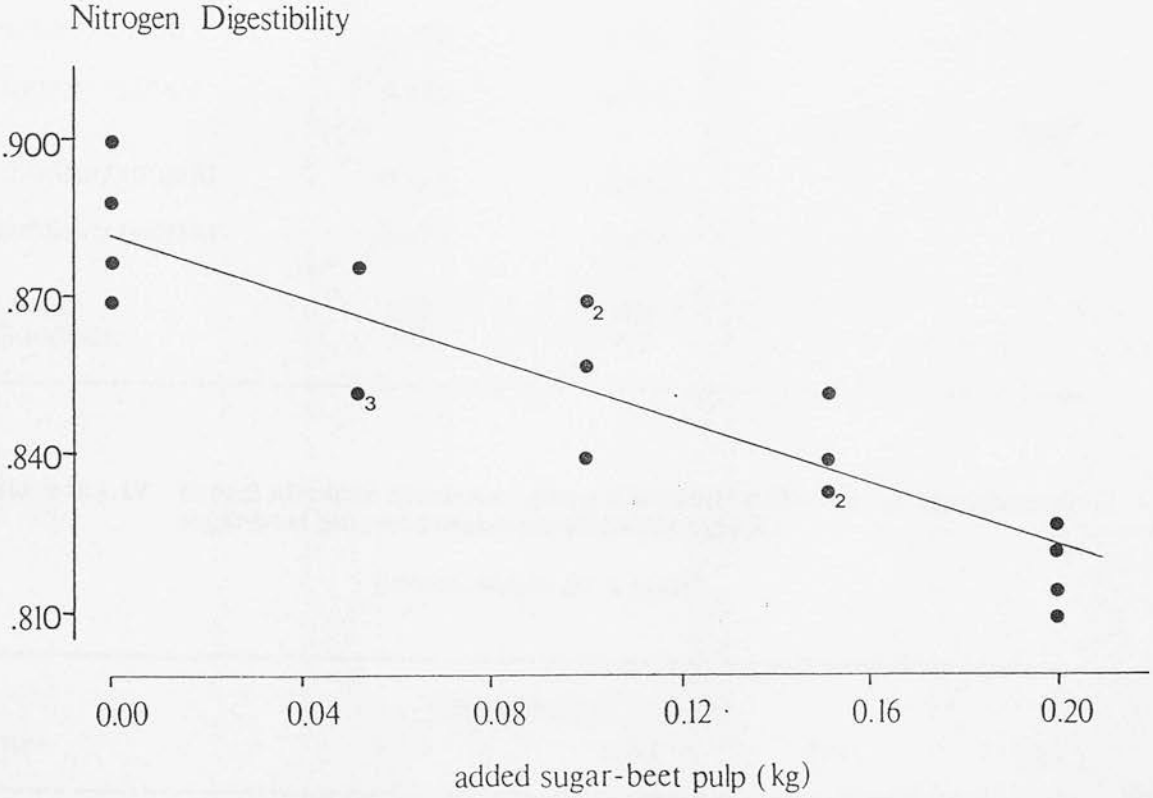


Figure 3.1.8 **Relationship between nitrogen digestibility and level of added beet pulp**

Table 3.1.16 Nitrogen retained (g N/g N intake) by the pigs on the control, sugar-beet pulp and maize supplemented diets.

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.478			
50SBP/40MAI	0.482	0.424		
100SBP/80MAI	0.424	0.366	0.0617	NS
150SBP/120MAI	0.418	0.412		
200SBP/160MAI	0.424	0.417		
Linear Quadratic	NS NS	NS NS		

Table 3.1.17 Faecal nitrogen excretion (g N/g N intake) by the pigs on the control, sugar-beet pulp and maize supplemented diets.

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.116			
50SBP/40MAI	0.143	0.127		
100SBP/80MAI	0.141	0.127	0.0086	***
150SBP/120MAI	0.160	0.135		
200SBP/160MAI	0.180	0.127		
Linear Quadratic	*** NS	NS NS		

***, P<0.001; t value, 3.59

The proportion of the nitrogen intake excreted in the faeces (Table 3.1.17) tended to be higher in the pigs fed the sugar-beet pulp supplemented diets as compared to the values for the maize diets. The pigs given the 200SBP diet excreted the greatest proportion of nitrogen in their faeces, which was significantly higher than the value for the pigs fed the 160MAI diet. The addition of 150 and 200 g of sugar-beet pulp to the control diet significantly increased the proportion of nitrogen excreted in the faeces above the value recorded for the control diet. Increasing levels of maize in the diet did not significantly effect the nitrogen excreted in the faeces, expressed as a proportion of the N intake.

The relationship between faecal nitrogen excretion (g N/g N intake) and the level of additional beet pulp was linear, and the slope of the line was significantly different from zero (Figure 3.1.9). The regression equation (with standard deviations in parentheses) was;

$$\begin{array}{lcccccl} \text{Faecal N excretion} = & 0.119 & + & 0.291 & \times & \text{added sugar-beet pulp (kg)} & r=0.87 \\ \text{(g N/g N intake)} & (0.0049) & & (0.0396) & & & \end{array}$$

Table 3.1.18 Urinary nitrogen excretion (g N/g N intake) by the pigs on the control, sugar-beet pulp and maize supplemented diets.

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.407			
50SBP/40MAI	0.375	0.450	0.0570	NS
100SBP/80MAI	0.435	0.508		
150SBP/120MAI	0.421	0.454		
200SBP/160MAI	0.396	0.457		
Linear	NS	NS		
Quadratic	NS	NS		

The nitrogen excreted in the urine, expressed as a proportion of the nitrogen intake (Table 3.1.18) was not significantly different between the sugar-beet pulp and maize diets, and increasing the level of sugar-beet pulp and maize in the diet did not affect the urinary nitrogen excretion.

Digestibility of energy and the DE values of the diets.

Table 3.1.19 The digestibility of the energy of the control, sugar-beet pulp and maize supplemented diets

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	0.890			
50SBP/40MAI	0.871	0.875	0.0090	*
100SBP/80MAI	0.881	0.874		
150SBP/120MAI	0.863	0.874		
200SBP/160MAI	0.854	0.884		
Linear	**	*		
Quadratic	NS	NS		

**, P<0.01; *, P<0.05; t value, 2.03

The only significant difference in energy digestibility (Table 3.1.19) between the sugar pulp and the maize diets was shown to occur at the highest level of inclusion of each material i.e. between 200SBP and 160MAI. The digestibility of the energy of the 100SBP, 150SBP and 200SBP diets was significantly lower than that of the control diet, thus indicating that the energy of the sugar-beet pulp is less well digested than the control diet. When energy digestibility was regressed against the level of added beet pulp, the relationship was linear, and the slope of the line significantly different from zero (Figure 3.1.10). The regression equation (with standard deviations in parentheses) was;

$$\begin{array}{lcccl} \text{Energy digestibility} = & 0.887 & - & 0.156 & \times \text{ added sugar-beet pulp (kg)} \quad r=0.60 \\ & (0.0061) & & (0.0496) & \end{array}$$

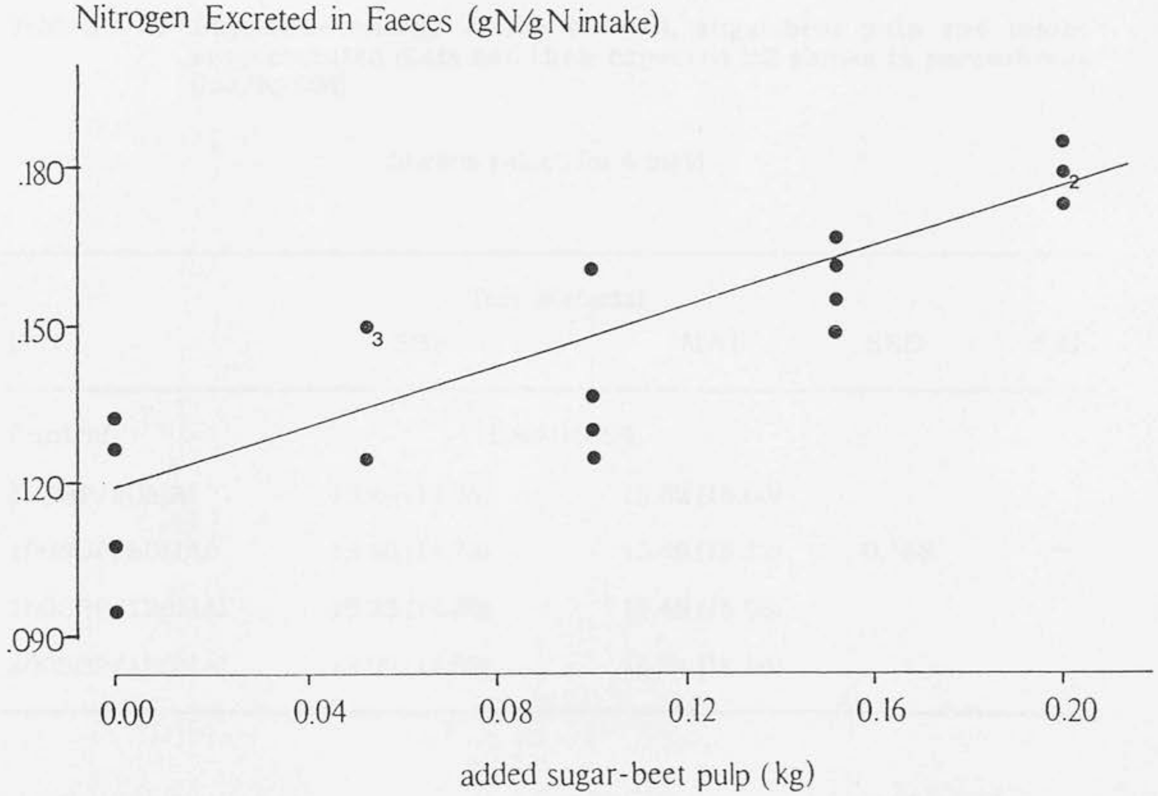


Figure 3.1.9 **Relationship between faecal nitrogen excretion and level of added beet pulp**

The increasing inclusion of maize in the diet did not significantly effect the energy digestibility of the diet at any level of inclusion.

The digestible energy values of the diets as measured *in vivo* are shown in Table 3.1.20 along with the expected values predicted from the ingredient composition of the diets. The *in vivo* DE values for the control and sugar-beet pulp supplemented diets were all higher than the expected values.

Table 3.1.20 Digestible energy of the control, sugar-beet pulp and maize supplemented diets and their expected DE shown in parentheses (MJ/kg DM)

(means values for 4 pigs)

	Test Material			
Diet	SBP	MAI	SED	SIG
Control	15.83 (15.18)			
50SBP/40MAI	15.46 (14.88)	15.52 (15.06)		
100SBP/80MAI	15.58 (14.73)	15.49 (15.12)	0.158	**
150SBP/120MAI	15.23 (14.65)	15.49 (15.08)		
200SBP/160MAI	15.02 (14.58)	15.64 (15.16)		

The differences between the actual and predicted DE ranged from 0.44 MJ/kg DM for the 200SBP diet to 0.85 MJ/kg DM for the 100SBP diet. This suggests that the energy of the beet pulp may have been under estimated in the formulations. The reduction in energy digestibility at high levels of beet pulp intake could help to explain the reduction in the difference between the predicted and measured DE value with increasing level of beet pulp inclusion.

The measured DE values for control and the maize supplemented diets were closer to the predicted values, the difference between these two values ranging from 0.65 for the control diet to 0.37 for the 80MAI diet.

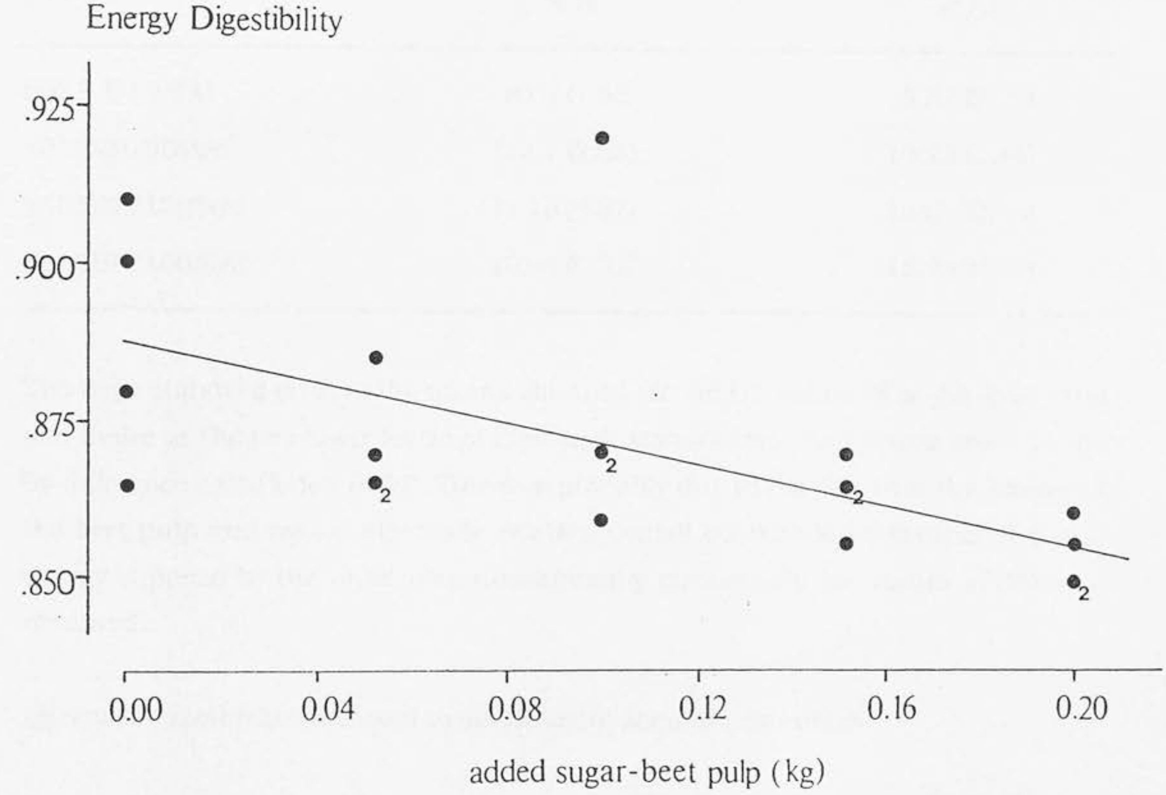


Figure 3.1.10 Relationship between energy digestibility and level of added beet pulp

The DE values for the maize and sugar-beet pulp at each level of their inclusion were calculated by difference and the values obtained are presented in Table 3.1.21.

Table 3.1.21 DE values (MJ/kg DM) for sugar-beet pulp and maize calculated by difference

(means values for 4 pigs; standard error of the mean shown in parentheses)

	Test Material	
Diet	SBP	MAI
50SBP/40MAI	8.09 (1.56)	8.31 (2.19)
100SBP/80MAI	13.07 (2.65)	10.23 (1.44)
150SBP/120MAI	11.16 (0.37)	12.61 (0.79)
200SBP/160MAI	10.98 (0.31)	15.23 (0.43)

The large standard error of the means obtained for the DE values of sugar-beet pulp and maize at the two lower levels of their inclusion indicate that errors arose in the by difference calculation of DE. This was probably due to the fact that the energy of the beet pulp and maize only made relatively small contributions compared to the energy supplied by the whole diet. Consequently erroneously low values of DE were obtained.

Alternative methods were used to obtain more accurate estimates.

Multiple Regression

The DE intake of the diet (MJ/kg DM) was regressed against the proportion of control diet and the proportion of beet pulp or maize in the diet. The regression equation obtained for the sugar-beet pulp (with standard deviations in parentheses) is given below;

$$\text{DE (MJ/kg DM)} = 15.8\ (0.11)\text{C} + 11.3\ (0.95)\text{SBP}$$

where C = proportion of control diet in the diet
SBP = proportion of beet pulp in the diet

The slope of the line was significantly different from zero ($P<0.001$). This equation estimates the DE (MJ/kg DM) of the control diet to be 15.8 and the beet pulp 11.3.

The regression equation obtained for the maize (with standard deviations in parentheses) is given below

$$\text{DE (MJ/kg DM)} = 15.7\ (0.08)\text{C} + 14.3\ (0.87)\ \text{MAI}$$

where C = proportion of control diet in the diet

MAI = proportion of maize in the diet

The slope of the line was significantly different from zero ($P<0.001$). The DE value obtained for the basal diet (15.7 MJ/kg DM) agreed well with the value found with the beet pulp. However, the value for the maize (14.3 MJ/kg DM) seems low when compared with those obtained by other workers.

This method relies on assumptions of dry matter intake which may have lead to the introduction of errors. For this reason linear regression was also used, regressing the total DE intake (MJ/day) against the fresh intake of sugar-beet pulp and maize.

Linear Regression

The total DE intake (MJ/day) was regressed against the fresh intake of sugar-beet pulp and maize. The regression equation for sugar-beet pulp (with standard deviations in parentheses) was;

$$\text{DE intake (MJ/day)} = 21.7\ (0.17) + 11.1\ (0.89) \times \text{fresh intake of beet pulp (kg)}$$

The slope of the line was significantly different from zero ($P<0.001$) and the correlation coefficient was 0.95. The pigs received 1.5 kg of the control diet/day which gives a DE value for the basal diet of 14.5 MJ/kg DM (15.9 MJ/kg DM). The DE value for beet pulp (MJ/kg DM) calculated using the value obtained in from this relationship was 12.36.

For maize, the regression equation (with standard deviations in parentheses) was

$$\text{DE intake (MJ/d)} = 21.5\ (0.10) + 13.9\ (0.68) \times \text{fresh intake of maize (kg)}$$

The slope of the line was significantly different from zero ($P<0.01$) and the correlation coefficient, $r=0.98$. Since the pigs received 1.5 kg of basal diet/day the DE value for the control diet obtained in this manner was 14.3 MJ/kg (15.75 MJ/kg DM) and for maize 13.9 MJ/kg or 15.9 MJ/kg DM.

3.1.5 DISCUSSION

The growth trial and digestibility studies used in this investigation have shown that the energy from sugar-beet pulp added to the diet can be used for carcase gains in growing pigs. Although the addition method used has the advantage of providing a constant base line, the results section identified errors in the energy balance and neutral detergent fibre digestion trials which increased the standard error of the values obtained. This was particularly highlighted at the low inclusion levels of the test materials, when difficulty was encountered in obtaining sufficient accuracy by difference to render the values meaningful. However, since four levels of each test material were fed, the use of linear and multiple regression allowed more accurate estimates of digestible energy to be obtained. Table 3.1.21 summarises the DE values obtained for unmolassed sugar-beet pulp and maize from experiments reported in Chapters 1 and 2, and also by other workers.

Table 3.1.21 A summary of the DE values for sugar-beet pulp and maize

Material	Reference	(method of calculation)	DE (MJ/kg DM)
Unmolassed sugar-beet pulp	Experiment 1.1	(By difference)	10.66
	Experiment 2.2	(By difference) (Linear regression) (Linear regression)	11.65 12.20 10.60
	Experiment 3.1	(By difference) (Linear regression) (Multiple regression)	10.82 12.36 11.30
	Morgan *et al.* (1984)	(Linear regression)	12.70
Maize	Wiseman and Cole (1979)		15.87
	Experiment 3.1	(By difference) (Linear regression) (Multiple regression)	11.60 15.90 14.30

The results show the highly variable nature of the digestibility of the beet pulp and the variation in the DE values obtained when calculations are carried out using different techniques.

The value for beet pulp obtained by linear regression is in good agreement with that of Morgan *et al.* (1984) and this method of calculating DE may therefore prove to be the most accurate.

For the maize, the value obtained by linear regression appears to be the most accurate when compared to the mean value reported by Wiseman and Cole (1979).

Having obtained *in vivo* DE values for each of the diets fed, and measured feed intake and carcase gains for individual pigs, carcase gains/MJ DE of sugar-beet pulp or maize over the liveweight range 30-90 kg could be calculated. DE intake (MJ/day) was regressed against daily carcase gain (kg/d) to quantify the growth promoting properties of maize and sugar-beet pulp (Figures 3.1.11 and 3.1.12).

The regression equation obtained for sugar-beet pulp (with standard deviations in parentheses) was;

$$\text{Carcase Gain (kg/d)} = 0.190\ (0.0912) + 0.0154\ (0.00337) * \text{DE intake (MJ/d)}$$

The slope of the line was significantly different from zero ($P<0.001$) and the correlation coefficient, $r=0.65$.

For the maize diets, the regression equation obtained (with standard deviations in parentheses) was;

$$\text{Carcase Gain (kg/d)} = 0.051\ (0.0126) + 0.0215\ (0.00476) * \text{DE intake (MJ/d)}$$

The slope of the line was significantly different from zero ($P<0.01$) and the correlation coefficient, $r=0.65$.

These equations indicate that for each extra 1 MJ of energy, produced by the fermentation of sugar-beet pulp, results in a daily carcase gain of 15.4 g, as compared to 21.5 g for 1 MJ of energy from maize.

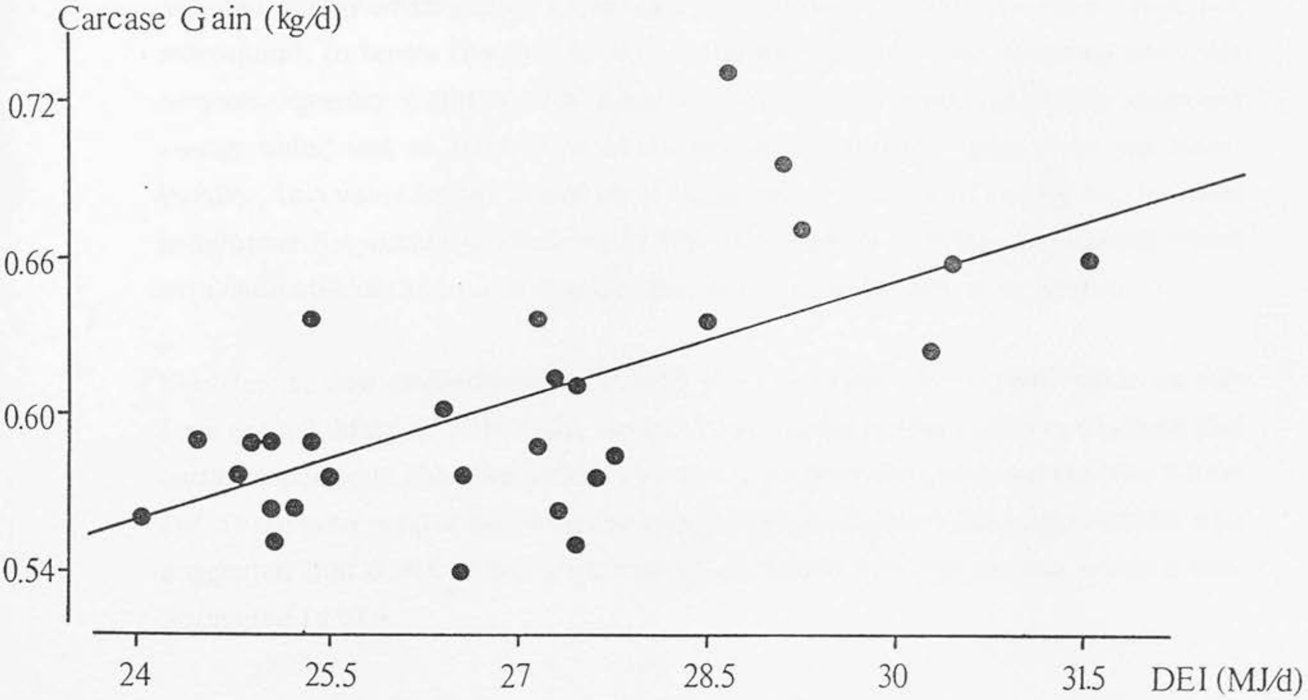


Figure 3.1.11 **Relationship between daily carcase gain and digestible energy intake of pigs fed on sugar-beet pulp supplemented diets**

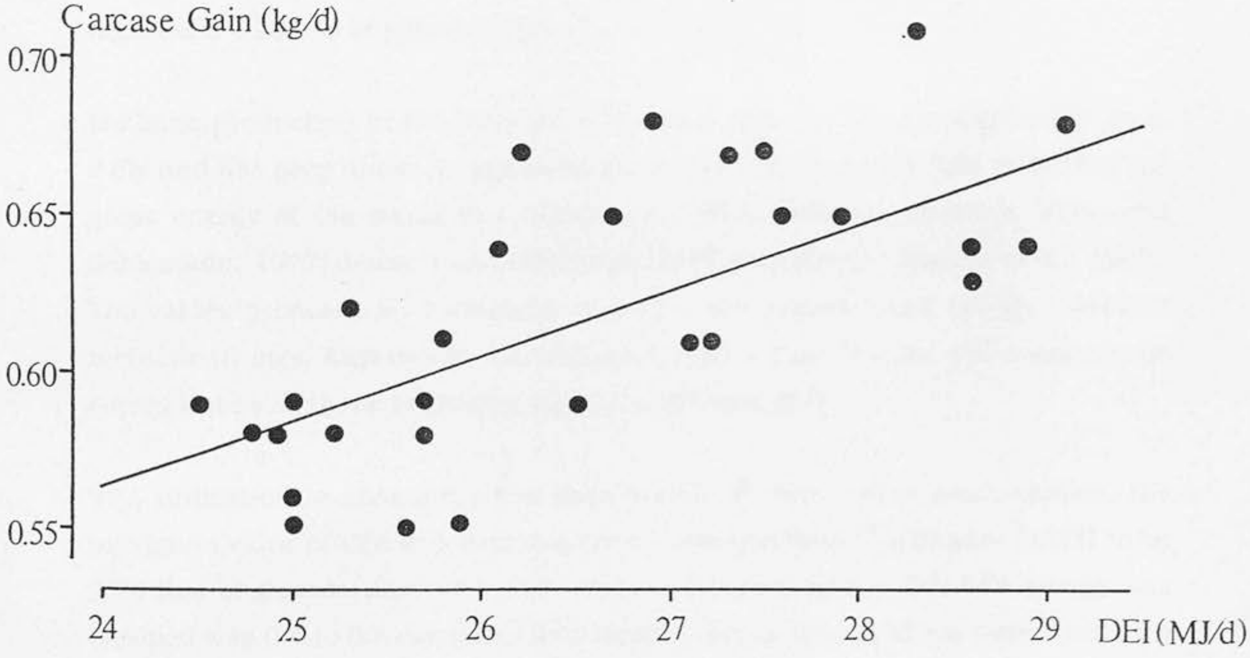


Figure 3.1.12 **Relationship between daily carcase gain and digestible energy intake of pigs fed maize-supplemented diets**

The ratio of the slopes of these two lines suggests that the apparently digested energy of sugar-beet pulp is used for carcase growth with an efficiency of 0.0154/0.0215 = 0.72 relative to the digested energy from maize. Apparently digested energy arising from fermentation of polysaccharides, therefore, does not correspond, in terms of potential use to the animal, with that obtained from the enzymic digestion of starch. This is due, in part, to some of the apparently absorbed energy being lost as heat of fermentation, and a further amount as methane. Further, this value for the efficiency of utilisation of fermented energy can be used to estimate the metabolic efficiency of VFA as compared to glucose, when combined with estimates of the heat of fermentation and the energy lost as methane.

Very few *in vivo* measurements of heat of fermentation have been made in any farm animal. Marston (1948) and Houpt (1968), using rumen contents of sheep and cattle respectively obtained values for heat of fermentation between 0.06 and 0.08 DE. These values agree well with the theoretical calculations of Hungate (1966) who suggested that 0.065 of the gross energy of hexose was lost as heat when it was fermented to VFA.

The loss of apparently digested energy as methane when fermentation occurs is open to dispute. Hungate (1966) suggested that 0.18 DE of hexose was lost whereas direct determination of methane by Blaxter (1962) and Webster, Osuji, White and Ingram (1975) suggests lower values of 0.08 and 0.11 DE. When feeding conventional diets to pigs, Fuller and Boyne (1971) showed that the loss to be very small, in the region of 8.3 kJ/MJ of apparent ME.

Methane production in the hind-gut of growing pigs amounts to only a few litres daily and has been shown to represent an energy loss of about 0.002 to 0.01 of the gross energy of the whole diet (Verstegen, 1971; Hoffman, Jentsch, Klein and Schiemann, 1977; Jentsch and Hoffmann, 1977 and van der Honing *et al.*, 1982). The values proposed for ruminants may therefore overestimate energy losses as methane in pigs. Experiment 3.2, reported later in this Chapter will measure the energy lost as methane in growing pigs fed sugar-beet pulp.

VFA utilisation in ruminants has been widely studies. Below maintenance, the maximum value of VFA in preventing energy loss was found by Blaxter (1971) to be 0.85 that of glucose. Above maintenance the efficiency with which VFA energy was retained was 0.3 to 0.6 compared with simple carbohydrates which were used with efficiencies in the range 0.70 to 0.75. Ørskov, Grubb, Smith, Webster and Corigall (1979) sustained animals entirely by gastric infusion of VFA, protein, minerals and vitamins, and found that VFA were used with an efficiency of 0.63 for energy retention which was independent of the ratio of acetic acid to propionic acids.

Hovell, Greenhalgh and Wainman (1976) suggested that variations in the efficiency of utilisation of VFA for energy retention in ruminants may depend on a sufficient glucose supply to provide NADPH necessary for the synthesis of fatty acids. This problem is likely to be academic in the case of the pig since it would be an extreme diet which did not provide some constituent capable of yielding a substantial amount of glucose.

ARC (1981) suggested that if the data described above was transposed by analogy to the metabolism of the pig, the value for the utilisation of absorbed VFA would be between 0.50 and 0.85 that of absorbed glucose. A factor of 0.80 was indicated as the best fit to current theories.

The metabolic efficiency described above can be combined with the losses due to the heat of fermentation and methane production to give an overall estimate of the relative utilisation of digested and fermented DE. The ARC (1981) assumed methane losses of 0.11 and the heat of fermentation as 0.06 DE in the calculation of the relative utilisation of VFA given as;

$$(1.00 - 0.11 - 0.06) * 0.80 = 0.67$$

It was suggested that this value, 0.67, is probably the highest efficiency that can be assumed from the present information but it could be as low as 0.43 if less optimistic values are used. However, if methane losses are lower than in ruminants this value could be higher.

In the literature the values for the efficiency of utilisation of fermented energy differ from that reported by the ARC (1981) and are highly variable.

Table 3.1.22 summarises the results of trials which have been carried out to estimate the efficiency of utilisation of fermented energy.

Table 3.1.22 A summary of the results of trials conducted to estimate the efficiency of utilisation of fermented energy in growing pigs.

Reference	Metabolic Efficiency of VFA relative to glucose	Relative utilisation of digested and fermented DE
ARC (1981)	0.80	0.67
Jentsch, Schieman & Hoffmann (1968); Imoto and Namioka, 1983)	†0.75	§0.62
Müller (1984)	§0.83	†0.70
Hoffmann & Schiemann (1986)	§1.07	†0.90
Zhu & Fowler (1987)	§0.69-0.77	†0.58-0.65
Current Trial	§0.86	†0.72

†measured values; §calculated value using ARC (1981)

Jentsch *et al.* (1968) estimated the nutritive value of acetate to be 0.59 in terms of the proportion used for metabolisable energy these authors observed that 2100 calories were deposited per gram of supplementary dietary acetate. This value corresponds well with the values of 0.56 and 0.59 obtained by Imoto and Namioka (1983). Using the data obtained in this trial the metabolic efficiency of the VFA produced by the fermentation of sugar-beet pulp was calculated to be 0.86. This value however is based on assumptions for the energy loss as methane which could lead to the introduction of errors. Experiment 3.2, the results of which are presented later in this Chapter, measured methane production form growing pigs given sugar-beet pulp and it may therefore be necessary to correct the value suggested by the ARC (1981) for the proportion of DE lost as methane.

Müller (1984), Hoffmann and Schieman (1986), van der Honing *et al.* (1986), and this current trial have all reported values for the relative utilisation of fermented digestible energy which are higher than the results of other workers, and the ARC (1981). Van der Honing *et al.* (1986) proposed two hypotheses which could lead to an increased utilisation of fermented energy over the predicted level. The fermentation of carbohydrates to lactic acid rather than VFA would result in a better utilisation of fermented energy. However, it is not known whether intensively fed growing pigs normally produce substantial amounts of lactate in their hind gut, which is subsequently absorbed. A second reason for better utilisation might be that VFA incorporation into body fat is more efficient than as a source of ATP, although Armstrong *et al.* (1958) found lower values in sheep.

Measurements made on the pigs at the beginning, and at the end of the growth trial, can be combined with measurements of food and DE intake to estimate the net energy of the diets, beet pulp and maize for both maintenance and production, and hence the total net energy of the foods.

The protein and fat compositions of the pigs at the start of the trial and at slaughter, were estimated using relationships suggested by the ARC (1981).

Protein; Protein in carcase = $0.16W$ where, W = bodyweight (kg)

Fat; Fat in carcase $\frac{P2}{(1.31 - 0.0058W)}$ where $P2$ = backfat (mm)
W = bodyweight (kg)

These measurements were used to predict the energy content of the pigs at the beginning and the end of the trial, and hence the total energy retained could be calculated. The net energy for maintenance (NE_m) was calculated, at the mean liveweight, from the relationship (ARC, 1981);

$$NEm = 0.723W^{0.569} \quad \text{where } W = \frac{W_{start} + W_{end}}{2}$$

This value, together with the daily energy retained as protein and fat was used to calculate the total NE of the food. The ratio of NE:DE was also calculated for each diet. The mean values are presented in Table 3.1.23

Table 3.1.23 NE:DE ratios for the diets

(mean values for 6 pigs)

Diet	NE/DE	
Control	0.67	
50SBP/40MAI	0.64	0.65
100SBP/80MAI	0.61	0.67
150SBP/120MAI	0.64	0.63
200SBP/160MAI	0.64	0.67

The NE of the diet measured for each pig was regressed against the proportion of basal and food supplement in the diet, and the NE of the control diet, unmolassed sugar-beet pulp and maize were determined by multiple regression. The multiple regression equations (with standard deviations in parentheses) were;

For sugar-beet pulp;

$$\text{NE (MJ/kg)} = \underset{(0.185)}{9.45} \times \text{basal (g/kg)} + \underset{(1.611)}{5.00} \times \text{beet pulp (g/kg)}$$

For maize;

$$\text{NE (MJ/kg)} = \underset{(0.179)}{9.49} \times \text{basal (g/kg)} + \underset{(1.924)}{8.04} \times \text{maize (g/kg)}$$

These data are similar to those of Taylor and Fisher (1980) in that they do not confirm the very large difference, in the efficiency of energy utilisation between enzymatically and fermented energy. The NE:DE ratios for wheat and wheatfeed in the work of Taylor and Fisher (1980) were 0.614 and 0.552 respectively as measured by indirect calorimetry, and 0.502 and 0.449 by comparative slaughter. The corresponding values for maize and unmolassed sugar-beet pulp in this trial were 0.578 and 0.450 respectively. The results of this trial and those of Taylor and

Fisher (1980) although not verifying the very low net energy of wheatfeed reported by Pals and Ewan (1978), still support the concept of a variable NE:ME ratio for different feeds. This was also supported by the work of Just (1980; 1982) which linked the crude fibre of the diet and the site of digestion of fibre to the NE:ME ratio.

The results of the digestibility studies illustrated an inverse relationship between the level of sugar-beet pulp added to the control diet and the digestibility of organic matter, nitrogen and energy of the diet. The addition of sugar-beet pulp to the low-fibre diet in Experiment 1.1 (Chapter 1) had a similar effect, and increasing levels of sugar-beet pulp fed in Experiment 2.2 (Chapter 2) also resulted in increasing depression of nitrogen and energy digestibilities with higher levels of sugar-beet pulp addition. These findings are also in accord with reports in the literature (DeGoey and Ewan, 1975; Kornegay, 1978; Kennelly and Aherne, 1980a, b). The depressive effect of the intake of sugar-beet pulp on the digestibility of organic matter, nitrogen and energy components of the diet have been discussed in Chapter 2 and might be the result of one or more factors. A decreased transit time through the gut, increased excretion of metabolic and microbial nitrogen, low availability of nitrogen and other nutrients in the sugar-beet pulp, or increased excretion of nitrogen and other nutrients bound or physically entrapped in the bulk of the fibrous digesta have all been implicated as possible factors.

The digestibility of NDF of the sugar-beet pulp supplemented diets was affected to a lesser extent, than the digestibilities of other nutrients in the diet by the increased intakes of NDF. Differences between the digestibility of the NDF of the control, sugar-beet and maize supplemented diets highlighted the non-uniformity of the NDF fractions of cereals and sugar-beet pulp. The results illustrate that the NDF fraction of unmolassed sugar-beet pulp was more digestible than that of the control diet and consequently increasing the level of beet pulp added resulted in an overall increase in the NDF digestibility of the whole diet.

When the digestibility of the NDF of the beet pulp was calculated by difference, the coefficients obtained varied with the level of inclusion. The coefficient obtained at the lowest levels of inclusion was lower than the values obtained for diets 100SBP, 150SBP and 200SBP. However, the small contribution the sugar-beet pulp made to the diet as a whole resulted in larger errors in the result of the by difference calculation.

The results of these metabolism studies therefore agree with those obtained within Chapters 1 and 2. The conclusion which can be drawn is that the addition of a fibre source to a diet has a far more depressant effect on the digestibility of the non-fibre components of the diet than it has on its own.

Nitrogen retention, expressed both as g/day and as g/g N intake, was found to be variable and no significant differences could be identified between mean values for the pigs on each diet. However, the pigs given the sugar-beet pulp tended to retain more nitrogen than those on the diets equivalent in maize. In Experiment 1.1 (Chapter 1) the same trend was observed, the addition of sugar-beet pulp and dried grass tended to increase nitrogen retention, yet the differences found were non-significant. Values obtained for the nitrogen retention of the pigs given increasing levels of beet pulp in Experiment 2.2 were also found to be greater than for the pigs given the control diets. The tendency for increased nitrogen retention with increased intakes of fibrous feeds have been discussed in Chapters 1 and 2, but measurements were not made on the carcases of the pigs used in those trials and therefore conclusions could not be drawn as to the nature of this increased nitrogen retention.

There are two possible explanations for this increased nitrogen retention. One is that the nitrogen could be retained as carcase gain, and the second is that there could be hypertrophy of the gut wall in response to increased bulk, and hence increasing nitrogen retention as protein in the gut wall. The analysis of covariance of the killing-out percentages of the pigs on each dietary treatment failed to show any significant differences between treatment means. This suggests that there has been no significant increase in lean deposition in the carcase as a result of an increased fibre intake. An increased deposition of nitrogen in the gut wall would tend to increase total gut weight and lead to a decreased killing-out percentage.

The measurements made on the gastrointestinal tracts of the pigs given the 200SBP and 160MAI diets did not reveal any significant adaptations of the gut to the ingestion of sugar-beet pulp. Empty stomach, small and large intestine, caecum and mesenteric fat weights were similar for the two groups of pigs, and the lengths of the small and large intestine, and caecum were not found to be significantly different. However, the gut contents of the pigs given the 200SBP diet were significantly heavier than those given 160MAI which is likely to be a reflection of the water holding capacity of the sugar-beet pulp.

These results suggest that any reduction in killing-out percentage is likely to occur as a result of increased gut fill rather than due to increased weights of the gastrointestinal tract, and do not allow any definite conclusions to be drawn about the nature of the increased nitrogen retention. Other workers have, however, been more successful in illustrating the effects of the amount and type of fibre on the physicl characteristics of the segments of the gastrointestinal tract. Stanogias and Pearce (1985b) determined the relative effects of feeding growing pigs with graded amounts of NDF from various sources on the empty wet weight and length of the gastrointestinal tract. Increased NDF intakes were associated with significantly higher wet weights of all gastrointestinal segments and increased lengths of the caecum. The lengths of both the small and large intestine were unaffected by the ingestion by pigs of different amounts of NDF from different sources. However, the caecum responded to these increased intakes of NDF by significant increases in length. The source of NDF in the diet was a factor which markedly affected both the weight and length of the distal colon. The morphological nature of these increases in weight and length, and their biological significance were not determined. The findings of Stanogias and Pearce (1985b) are in agreement with earlier reports in the literature (Coey and Robinson, 1954; Wussow and Weniger, 1954; Bohman *et al.*, 1955; Kass *et al.*, 1980) and the results of this trial appear to be in agreement with the work of Hochstetler *et al.* (1959), Cunningham *et al* (1961) and Gargallo and Zimmerman (1980) when only a small change occurred in the organs of the gastrointestinal tract of pigs given diets containing increased levels of lucerne, wheat bran, cellulose or sunflower hulls. These differences between investigations may have been due, at least in part, to differences in the genotype of the pig (Petersson *et al.*, 1979; Pond *et al.*, 1981), to individual variation among pigs in their ability to utilise fibre (King and Taverner, 1975) and differences in the source (Forbes and Hamilton, 1952; Hochstetner *et al.*, 1959; Komai and Kimirra, 1980; Van Soest, 1984) and the amount of fibre ingested.

The sample size for gut measurements in this trial was unavoidably small and it may therefore be that individual variation between pigs may have masked a real effect which would have been illustrated by a larger sample of pigs.

The excretion of nitrogen in the faeces and in the urine, expressed as a proportion of the nitrogen intake, was examined to identify any alteration in the route of nitrogen excretion when the beet pulp diets were fed. As was found in the previous experiments, the nitrogen excreted in the faeces increased with the level of sugar-beet pulp added to the diet, whilst the proportion of nitrogen excreted in the urine was similar between the sugar-beet pulp diets and was not significantly affected by the proportion of sugar-beet pulp or maize added to the diet. Chapters 1 and 2 discussed these findings in some detail and is therefore unnecessary to comment further on these results.

To summarise, this experiment has shown that the energy produced by the fermentation of sugar-beet pulp can be utilised for carcase growth by the growing pig with an efficiency of 0.72 relative to that of maize. Using this result, a value can be obtained for the metabolic efficiency of VFA relative to glucose (0.86). However, in calculating this value assumptions have been made about the production of methane and the proportion of the DE lost as this gas. The ARC (1981) based their calculation on methane production by ruminants, but the situation may be very different in the growing pig. In order to obtain a more accurate assessment of the metabolic efficiency of VFA in this current trial, methane production by growing pigs fed diets containing sugar-beet pulp were measured in a subsequent trial. Killing-out percentage were unaffected by the addition of beet pulp to the diet, and no significant responses of the gastrointestinal tract segments to increasing fibre level in the diet could be identified, although this could be due to the small number of tracts examined.

3.2 THE UTILISATION OF THE DIGESTED ENERGY FROM UNMOLASSED SUGAR-BEET PULP BY GROWING PIGS AS DETERMINED BY CALORIMETRY

3.2.0 INTRODUCTION AND AIMS

As described in the general introduction to this chapter (section 3.0), calorimetry can be used to estimate the efficiency of utilisation of a feed in terms of the energy retention it promotes, when combined with balance studies for the measurement of nutrient digestibilities, carbon and nitrogen retention. The technique of carbon and nitrogen balance, which involves measuring the amounts of these elements entering and leaving the body, allows the amounts of protein and fat retained in the animal to be calculated.

This experiment aims to measure the efficiency of utilisation of the energy produced by the fermentation of unmolassed sugar-beet pulp in the growing pig. It will also allow the quantification of the methane production resulting from the fermentation of beet pulp and lead to the calculation of a value for the proportion of the fermented DE lost as methane. In the light of this, it may be necessary to correct the ARC (1981) value for the metabolic efficiency of VFA utilisation.

3.2.1 MATERIALS AND METHODS

Animals and Diets

Eight Large White x Landrace entire male pigs were used in a series of energy and carbon balance trials using respiration calorimeters, and digestibility studies for the measurement of nutrient digestibilities and nitrogen retention.

The pigs were paired according to their liveweight at the start of the trial. All of the pigs were given a low-fibre basal ration (Table 3.2.0) composed of barley, wheat and Palmers 67 (fishmeal blend), at a rate of 1.25 kg/day. One pig from each pair was fed 0.5 kg of unmolassed sugar-beet pulp in addition to this. The ration was fed as a meal once a day and sufficient drinking water was added at an approximate feed : water ratio of 1:2.

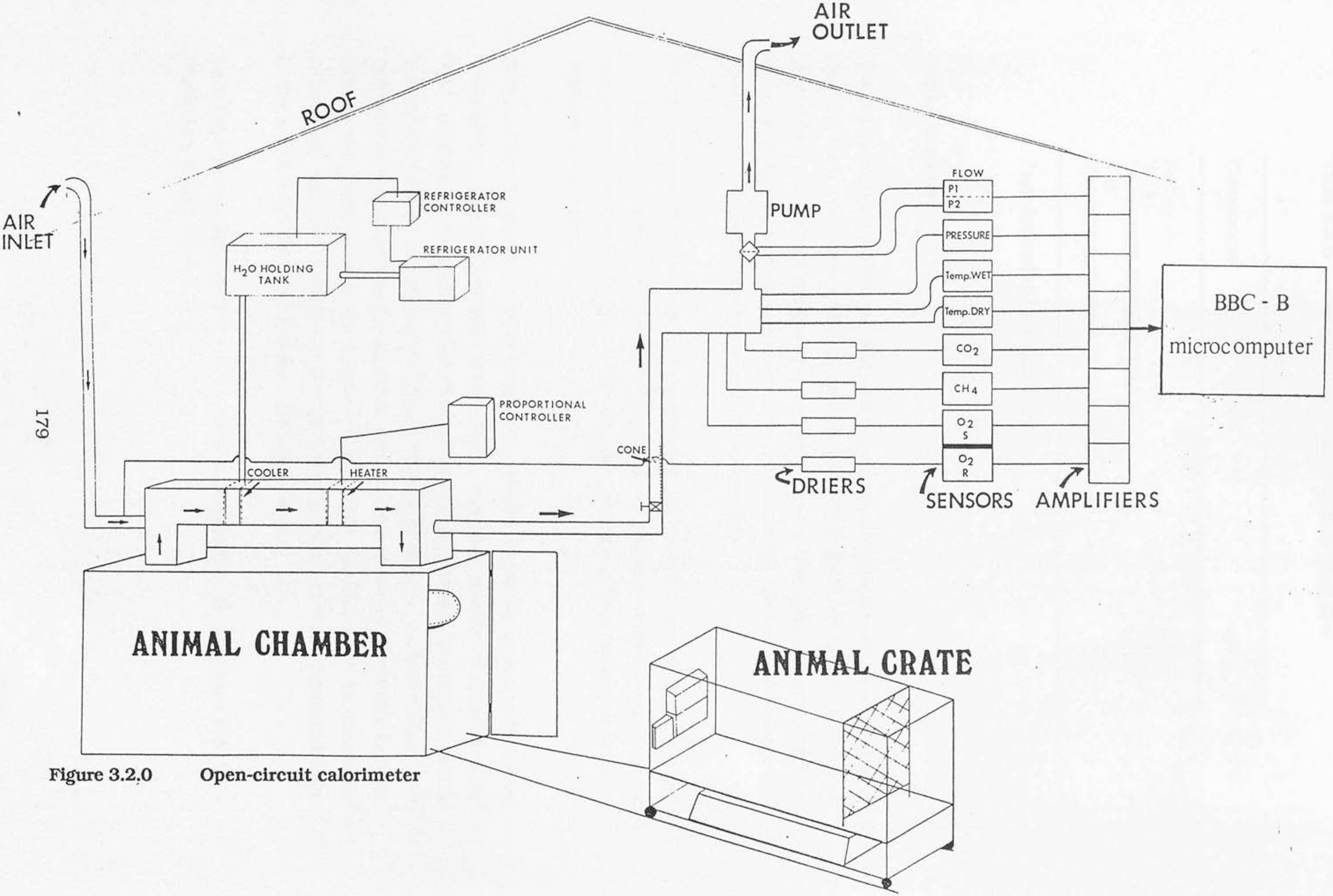


Figure 3.2.0 Open-circuit calorimeter

Table 3.2.0 Composition of the low-fibre basal diet

Component	g/kg
Barley	275.5
Wheat	600.0
Palmers 67 (fishmeal blend)	120.0
Salt	2.0
Vitamins and Minerals (PT12C)†	2.5

†see Appendix 2 for composition.

Trial Procedure

The pigs were used a pair at a time and were maintained in individual pens without bedding for a preliminary feeding period of 14 days. Then, each pair of pigs was placed in a metabolism crate which was moved into a respiration chamber for four days. Heat production was measured in an open-circuit, indirect calorimeter (see Figure 3.2.0), comprising of two respiration chambers.

The instrumentation was housed in a constant temperature room at 20 ± 2°C to try and minimise signal drift due to fluctuations in ambient temperature. Periodic calibration burns were carried out to test the recovery of heat using a mixture of propane and propene.

Within the calorimeter, the temperature, relative humidity and air flow were controlled to ensure thermoneutrality and a relative humidity of approximately 0.70. Continuous monitoring of air flow, pressure, dry and wet bulb temperatures was performed. At 10 minute intervals readings of oxygen, carbon dioxide and methane concentrations in the air exhausted from the chamber were made to allow oxygen consumption, carbon dioxide and methane production to be measured continually on small samples of dry gas. Heat production was calculated from gaseous exchanges using the Brouwer (1965) equation:

Heat Production = (Oxygen x 16.175) + Carbon Dioxide x 5.02) - (Methane x 2.167) - (nitrogen x 5.987) where Oxygen, Carbon Dioxide and Methane refer to litres at Standard Temperature and Pressure exchanged between the animal and the atmosphere, and nitrogen refers to grams of urinary nitrogen excreted during the same period.

The system was controlled, and the data collected and processed, using a BBC Model B microcomputer. The oxygen, carbon dioxide and methane analyses were calibrated daily using standard test gases and during data collection 100 readings per second on each channel were meaned and logged.

After 4 days in the calorimeter the pigs were transferred to metabolism crates (Whittemore and Elsley, 1976) for digestibility studies and the measurement of nitrogen retention. The procedures for the collection of faeces and urine were as described in Chapter One (Experiment 1.1, Section 1.1.1).

3.2.2 ANALYTICAL PROCEDURES

The analytical procedures were as described in Chapter One (Section 1.1.2). The carbon contents of the basal diet, unmolassed sugar-beet pulp, faeces and urine were determined by the method of Lawrence (1980).

The digestibilities of NDF, energy and nitrogen for the whole diets were calculated and the digestibilities of the NDF and energy of the sugar-beet pulp were calculated by difference.

Energy retention was calculated from the carbon and nitrogen balance data. The quantity of protein stored was calculated by multiplying the nitrogen retained by 1000/160, since body protein is assumed to contain 160 g N/kg. Protein also contains 512 g C/kg and the amount of carbon stored as protein could therefore be calculated.

The remaining carbon retained was assumed to be stored as fat, which contains 746 g C/kg. Fat storage was calculated by dividing the carbon retained, minus that stored as protein, by 0.746. The energy present in the protein and fat stored was calculated using average gross energy values for body tissues (23.6 MJ/kg for protein and 39.3 MJ/kg for fat). Heat production was then calculated by the difference between the ME intake and the total energy retained as protein and fat.

3.2.3 STATISTICAL PROCEDURES

Student t-tests were used to compare the results obtained for the pigs given the basal diet alone with those for the pigs given the beet pulp supplemented diets.

3.2.4 RESULTS

The chemical composition of the basal diet and unmolassed sugar-beet pulp are given in Table 3.2.1.

Table 3.2.1 The chemical composition of the basal diet and unmolassed sugar-beet pulp

Component	Basal diet	Unmolassed sugar-beet pulp
DM (g/kg)	895	898
GE (MJ/kg DM)	17.77	16.31
Crude Protein (g/kg DM)	175.2	86.6
Ash (g/kg DM)	42	80
NDF (g/kg DM)	174	447
Carbon (g/kg DM)	404.8	424.5

The mean weights of the pigs on entering the calorimeter are shown in Table 3.2.2.

Table 3.2.2 Mean weights of the pigs on entering the calorimeter

Pig No.	Diet	Weight (kg)
1	Basal	51.2
2	Basal + Beet pulp	46.0
3	Basal	54.0
4	Basal + Beet pulp	56.0
5	Basal	51.0
6	Basal	50.0
7	Basal + Beet pulp	51.5
8	Basal + Beet pulp	54.0

Production of carbon dioxide and methane

Table 3.2.3 shows the daily production of carbon dioxide of the pigs on each treatment. The values shown indicate that carbon dioxide production by some pigs was fairly constant over the four day measurement period, whilst in others it proved to be highly variable. Pig numbers 1, 3, 4 and 8 all showed good replication over the 4 days. However, pigs 2, 5, 6 and 7 showed variable carbon dioxide production between days, and it can be concluded from examination of the diets fed that this variability was not linked to the diet. For pigs 2 and 5, particular days can be identified when carbon dioxide production appeared to be significantly different from the other 3 days. In the case of pig 2, the carbon dioxide excreted on day 1 (7781) was not in line with the volumes recorded on days 2, 3 and 4. For this reason it may be more meaningful to omit this value when calculating the mean carbon dioxide production for this individual pig. For pig 5, the 8221 of carbon dioxide produced appear atypical. No clear outliers could be identified for pigs 6 and 7. The means and standard errors of the means for pigs 2 and 5, corrected for the outlying values are given in Table 3.2.4.

The volumes of methane produced by the pigs (Table 3.2.5) given the basal diet alone were relatively constant over the 4-day period when compared to the volumes recorded for the pigs given the sugar-beet pulp supplemented diets.

When t-tests were performed to try and identify any differences in carbon dioxide and methane production between the pigs on each diet (Table 3.2.6), no significant difference could be identified for carbon dioxide due to a considerable amount of overlap between the two groups. However, the pigs given the basal diet supplemented with beet pulp excreted significantly greater amounts of methane than those given the basal diet alone. Assuming methane has a gross energy of 39.5 kJ/litre, the proportion of the gross energy intake lost as methane by the pigs given the basal diet alone, and the basal diet supplemented with beet pulp was calculated to be 0.0055 and 0.011 respectively.

Heat Production

The daily heat production of each pig, calculated using the Brouwer (1965) equation is shown in Table 3.2.7. The mean heat production of the pigs given the basal diet

Table 3.2.3 **The daily production of carbon dioxide by each pig (expressed as litres of dry gas at STP)**

			CO_2 production (l)		
Pig Number	Diet	Day	Daily	Mean	SEM
1	Basal	1	632		
		2	617	620	15.0
		3	580		
		4	651		
2	Basal + Beet pulp	1	778		
		2	602	649	43.0
		3	608		
		4	608		
3	Basal	1	659		
		2	693	673	7.3
		3	667		
		4	674		
4	Basal + Beet Pulp	1	669		
		2	688	664	11.7
		3	632		
		4	668		
5	Basal	1	624		
		2	822	671	61.9
		3	531		
		4	708		
6	Basal	1	570		
		2	647	626	28.7
		3	590		
		4	697		
7	Basal + Beet pulp	1	708		
		2	835	695	61.1
		3	537		
		4	698		
8	Basal + Beet pulp	1	665		
		2	676	683	8.3
		3	704		
		4	685		

Table 3.2.4 The mean volumes of carbon dioxide (l of dry gas measured at STP) produced by pigs 2 and 5 following correction for atypical values

			CO_2 production (l)		
Pig Number	Diet	Day	Daily	Mean	SEM
2	Basal + Beet pulp	2	602	606	2.0
		3	608		
		4	608		
5	Basal	1	624	621	51.0
		3	531		
		4	708		

Table 3.2.5 The daily production of methane by each pig (expressed as litres of dry gas at STP)

			CH_4 production (l)		
Pig Number	Diet	Day	Daily	Mean	SEM
1	Basal	1	3.47	3.39	0.082
		2	3.23		
		3	3.48		
		4	—		
2	Basal + Beet pulp	1	6.89	6.15	0.364
		2	6.65		
		3	5.50		
		4	5.54		
3	Basal	1	2.51	2.45	0.049
		2	2.39		
		3	2.55		
		4	2.34		
4	Basal + Beet Pulp	1	7.28	6.73	0.366
		2	6.00		
		3	7.44		
		4	6.21		
5	Basal	1	2.39	2.39	0.056
		2	2.34		
		3	2.55		
		4	2.29		
6	Basal	1	2.66	2.98	0.167
		2	3.39		
		3	2.75		
		4	3.10		
7	Basal + Beet pulp	1	5.63	5.87	0.393
		2	6.79		
		3	4.93		
		4	6.14		
8	Basal + Beet pulp	1	4.13	4.14	0.153
		2	3.94		
		3	4.58		
		4	3.92		

Table 3.2.6 **The mean values for carbon dioxide and methane production by the pigs on each diet (expressed as litres of dry gas at STP)**

Diet	Pig Number	Carbon dioxide (1)	Methane (1)
Basal	1	620	3.39
	3	673	2.39
	5	621	2.98
	6	626	2.45
	mean	635	2.80
Basal + Beet Pulp	2	606	6.15
	4	664	5.87
	7	695	4.14
	8	664	6.73
	mean	657	5.72
t		0.98	4.82
Level of Significance		NS	**

Table 3.2.7 **The daily heat production of each pig as calculated using the Brouwer (1965) Equation**

			Heat Production (MJ)		
Pig Number	Diet	Day	Daily	Mean	SEM
1	Basal	1	12.31		
		2	10.19	10.91	0.499
		3	10.20		
		4	10.95		
2	Basal +	1	12.31		
	Beet pulp	2	10.49	11.91	0.735
		3	12.94		
		4	–		
3	Basal	1	11.91		
		2	13.99	12.96	0.430
		3	12.79		
		4	13.13		
4	Basal +	1	15.28		
	Beet Pulp	2	13.09	14.35	0.458
		3	14.57		
		4	14.47		
5	Basal	1	12.99		
		2	–	12.61	0.952
		3	10.80		
		4	14.03		
6	Basal	1	10.96		
		2	12.47	11.55	0.647
		3	10.01		
		4	12.76		
7	Basal +	1	14.60		
	Beet pulp	2	14.34	13.10	0.906
		3	10.66		
		4	12.78		
8	Basal +	1	14.18		
	Beet pulp	2	12.81	13.84	0.370
		3	14.52		
		4	13.84		

alone was 12.01 MJ (SEM 0.473) and for the pigs on the beet pulp supplemented diet the mean daily heat production was 13.30 MJ (SEM 0.530). When a Student t-test was performed on the data, no significant difference could be identified between the heat production of the two groups of pigs (t=1.24).

Digestibility Studies

The digestibilities of the organic matter (OM), NDF, nitrogen (N) and energy, and the nitrogen retention and excretion of the pigs given the two diets are shown in Table 3.2.8.

Table 3.2.8 Digestibilities of OM, NDF, nitrogen and energy, and the nitrogen retained and excreted by the pigs on each diet.

(mean values for 4 pigs)

	Diet				
	Basal	Basal + Beet pulp	SED	t (6 DF.)	SIG.
OM digestibility	0.890	0.850	0.0083	4.82	**
NDF digestibility of the whole diet	0.650	0.738	0.0251	3.51	*
N digestibility	0.803	0.648	0.0222	6.98	***
N retention (g/d)	12.21	12.26	1.217	0.04	NS
N retention (g/g N intake)	0.389	0.327	0.0356	1.74	NS
Faecal N excretion (g/g N intake)	0.198	0.352	0.0222	6.94	***
Urinary N excretion (g/g N intake)	0.413	0.323	0.0941	0.96	NS
Energy digestibility	0.864	0.812	0.0104	5.00	**

***, P<0.001; **, P<0.01; *, P<0.05

Organic Matter Digestibility

The digestibility of the organic matter of the basal diet was significantly (P<0.01) higher than that obtained for the beet pulp supplemented diet. This result is in agreement with the trend observed in Experiment 3.1 where increasing the levels of addition of unmolassed sugar-beet pulp to the diet resulted in a significant reduction in organic matter digestibility.

NDF Digestibility

The mean digestibility coefficient of the NDF of the basal diet was significantly (P<0.05) less than that obtained for the beet pulp diet. This indicates, as was found to be the case in Experiments 1.1, 2.2 and 3.1, that the NDF component of sugar-beet pulp was more digestible than that of wheat and barley.

The digestibility of the NDF fraction of the sugar-beet pulp was calculated by difference and the results are shown in Table 3.2.9. By including the beet pulp at a level of approximately 0.3, the contribution the beet pulp makes to the NDF of the diet as a whole was aimed to be adequate to minimise the introduction of errors in the calculation of digestibility by difference.

Table 3.2.9 The digestibility of the NDF of sugar-beet pulp

Diet	Pig	NDF Digestibility
Basal + Beet Pulp	2	0.798
	4	0.869
	7	0.791
	8	0.815
	mean	0.818
	SEM	0.0177

Nitrogen digestibility, nitrogen retention and nitrogen excretion

Nitrogen digestibility was significantly ($P<0.001$) depressed by the addition of the sugar-beet pulp to the basal diet.

The results showed the nitrogen retention of these two groups of pigs to be very similar and no significant difference was found between the mean values obtained. This indicates that none of the nitrogen supplied by the sugar-beet pulp was retained.

When the nitrogen retained was expressed as a proportion of the nitrogen intake the result was similar. No significant difference could be identified between the mean proportion retained by the pigs given the basal diet and that for the pigs given the basal diet supplemented with beet pulp.

The pigs on the beet pulp supplemented diet excreted a significantly ($P<0.001$) higher proportion of their nitrogen intake in their faeces compared to the pigs fed on the basal diet, whilst the nitrogen excreted in the urine, expressed in the same manner was not found to be significantly different between the two groups of pigs.

Energy Digestibility

The addition of beet pulp to the diet significantly reduced ($P<0.01$) the digestibility of the whole diet.

The energy digestibility coefficients and the DE values for the sugar-beet pulp were calculated for each pig by difference and are presented in Table 3.2.10. The mean digestibility of the energy of the beet pulp was 0.670. The DE values were found to vary between 9.99 MJ/kg DM to 11.80 MJ/kg DM for the beet pulp with a mean value of 10.94 MJ/kg DM.

Carbon and Nitrogen Balance

The carbon balance, protein and fat storage, energy retention, and heat production data for the eight pigs are given in the Appendix 3.

Table 3.2.10 Digestibility of the energy of the sugar-beet pulp and the digestible energy value of sugar-beet pulp (calculated by difference)

Diet	Pig	Energy Digestibility	DE (MJ/kg DM)
Basal +	2	0.718	11.72
Beet pulp	4	0.724	11.80
	7	0.613	9.99
	8	0.624	10.24
	mean	0.670	10.94
	SEM	0.0297	0.478

Table 3.2.11 summarises the partitioning of energy in the pigs given the basal diet alone. The results indicate that these pigs were retaining energy as protein (1.8 MJ) but that fat was being mobilised, resulting in an energy loss of 0.14 MJ. When these results were compared to those for the pigs fed on the basal diet plus beet pulp, the results for which are given in Table 3.2.12, it was found that the energy stored as protein was very similar and that the additional energy supply, resulting from the fermentation of beet pulp was stored as fat.

Table 3.2.11 A summary of the energy partitioning in the pigs given the basal diet

ENERGY (MJ)	PIG NUMBER				
	One	Three	Five	Six	Mean
DE	17.01	17.12	16.98	17.55	17.17
ME	16.22	16.41	16.40	16.78	16.45
Energy as Protein	1.51	1.76	2.09	1.84	1.80
Energy as Fat	0.35	-1.19	-0.22	0.50	-0.14
Total energy retention	1.86	0.57	1.87	2.34	1.66
Heat Production	14.36	15.84	14.53	14.44	14.80
Heat Production/kg $LW^{0.75}$	0.750	0.795	0.762	0.768	0.769

Table 3.2.12 A summary of the energy partitioning in the pigs given the basal diet plus beet pulp

ENERGY (MJ)	PIG NUMBER				
	Two	Four	Seven	Eight	Mean
DE	22.43	20.83	21.66	21.74	21.67
ME	21.51	19.80	20.62	20.94	20.72
Energy as Protein	2.08	1.79	1.45	1.92	1.81
Energy as Fat	7.44	6.04	4.72	4.80	5.75
Total energy retention	9.52	7.83	6.17	6.72	7.56
Heat Production	11.99	11.97	14.45	14.22	13.16
Heat Production/kg LW$^{0.75}$	0.679	0.585	0.752	0.714	0.683

The increase in energy stored as fat was 5.89 MJ and the total energy retained 5.90 MJ, was found to be 1.4 MJ greater than the extra DE supplied (Table 3.2.13). The total heat production, calculated from the carbon and nitrogen balance was reduced by 1.64 MJ from 14.80 to 13.16 MJ. When the heat production was expressed as MJ/kg LW$^{0.75}$, the mean values for the two pigs were very similar, although the pigs given the beet pulp diet produced slightly less heat than the pigs given the basal diet alone.

Table 3.2.13 The differences observed between the partitioning of energy in the two groups of pigs.

ENERGY (MJ)	Difference (MJ)
DE	4.50
ME	4.27
Energy stored as protein	0.01
Energy stored as fat	5.89
Total energy retention	5.90
Heat production	-1.64
Heat production/kgLW$^{0.75}$	-0.086

On the basis of these results the efficiency of utilisation of the DE supplied from the beet pulp is equal to 5.90/4.50 indicating a value greater than one. However, when a paired t-test was carried out to compare the difference between the extra DE from the beet pulp fed with the extra energy retained (Table 3.2.14), no significant difference could be found;

Table 3.2.14 A comparison of the extra DE from sugar-beet pulp with the extra energy retained

	Pig Number				
	2	4	7	8	mean
Extra DE supplied by Beet pulp (MJ)	5.26	3.66	4.49	4.57	4.50
Extra energy retained (MJ)	7.86	6.17	4.51	5.06	5.90
Difference	2.60	2.51	0.02	0.49	
Standard error of the mean		0.6711			
t		2.09			
Significance		NS			

The variability in the difference between the extra DE supplied by the beet pulp, and the extra energy retained will not enable any conclusions to be drawn about the efficiency with which DE was used for growth.

3.2.5 DISCUSSION

The results of this experiment have shown that unmolassed sugar-beet pulp is well digested, and that the energy produced by its fermentation is utilised, by the growing pig.

The addition of beet pulp to the basal diet produced similar results to those observed in Experiment 1.1 (Chapter 1), Experiment 2.2 (Chapter 2) and Experiment 3.1 reported earlier in this chapter. An inverse relationship was observed between the addition of beet pulp and the digestibility of the organic matter, nitrogen and energy, whereas the digestibility of the NDF of the whole diet was increased. The mean digestibility of the NDF fraction of the beet pulp (0.818), as calculated by difference, was similar to the value of 0.843 obtained in Experiment 1.1 (Chapter 1). The digestibility of nitrogen was very significantly reduced by the addition of beet pulp, the depression being approximately 0.10 when the beet pulp comprised almost 0.30 of the diet. However, this trial was not designed to investigate the extent to which this was due to a direct decrease in the apparent digestibility of nitrogen or an increased excretion in the faeces of microbial and endogenous material. The nitrogen retention of these two groups of pigs was very similar despite a slight increase in nitrogen intake and a rather larger increase in digestible energy intake when beet pulp was fed. This suggests that the protein intake was limiting the amount of nitrogen retained.

The ARC (1981) suggested that the growing pig had a requirement of 8.6 g ideal protein, 0.6 g lysine, 0.3 g methionine + cystine, and 0.36 g threonine/MJ DE in their diet. Table 3.2.15 shows the quantities of these amino acids supplied to the pigs in this trial. The mean DE of the basal diet was measured to be 13.7 MJ/kg and the recommended ideal protein content of the diet should therefore be 117.8 g.

Table 3.2.15 The supply of lysine, methionine + cystine, and threonine to the pigs on this trial by the basal diet

Ingredient	g/kg diet	CP	Lysine	g supplied Methionine + cystine	Threonine
Barley	275.5		0.96	1.02	0.91
Wheat	600.0		1.86	2.28	1.74
Palmers 67	120.0		5.70	2.92	3.12
Total		157	8.52	6.22	5.77
g/MJ DE		11.5	0.62	0.45	0.42

Table 3.2.15 shows that the basal diet just supplied the ideal protein requirement of the pigs but it is likely that if more of this diet had been fed, nitrogen retention would have been improved. The addition of a small amount of nitrogen from the beet pulp however, was not sufficient to affect nitrogen retention.

The fact that ideal protein was limiting helps to explain why all of the extra energy retained, when beet pulp was fed in addition to the basal diet, was retained as fat rather than as a combination of protein and fat.

The fermentation of carbohydrates in the rumen yields VFA, CO_2, and H_2 which is subsequently used in the reduction of CO_2 to methane (Hungate, 1968). Kidder and Manners (1978) found that the proportions of individual VFA in the hind-gut of pigs were very similar to those in the rumen and qualitatively the fermentative processes are the same as in the rumen. Both methane and hydrogen are expired in the pig, but breath concentrations of methane are approximately ten times greater than hydrogen concentrations (Fleming and Wasilewski, 1984). This suggests that hydrogen is being used in the formation of methane and also in the biohydrogenation of unsaturated fatty acids (Bayley and Lewis, 1965).

In the present study all of the pigs excreted methane. The volumes produced varied from 2.39 litres to 6.73 litres. These amounts represent a daily loss of 94 and 266 kJ which corresponds to no more than 0.011 of the gross energy intake. Under the dietary conditions used in this trial, it seems therefore, that this energy is non-significant in terms of feed evaluation. This was also the conclusion drawn by Christensen and Thorbek (1987) who found methane losses ranging from 1 to 12 litres, representing an energy loss of 40 - 480 kJ in pigs ranging from 20 - 120 kg liveweight.

The methane production can also be used to estimate the proportion of fermented energy from the beet pulp lost as methane. The typical composition of unmolassed sugar-beet pulp is detailed in Table 3.2.16 (ADAS, 1986).

Table 3.2.16 Chemical composition of Sugar-beet pulp

	g/kg DM
Non-Starch Polysaccharides (Graham *et al.*, 1986)	715
Water-soluble Carbohydrates	56
Crude protein	101
Ether extract	8
Ash	60

The water-soluble carbohydrate is likely to be present as sucrose which has a gross energy of 16.5 MJ/kg and such a small quantity will be rapidly and completely digested in the small intestine. Assuming that all of the energy from the digestion of sucrose is absorbed anterior to the large intestine the DE from the sucrose will be equal to;

DE from sucrose = GE sucrose x sucrose content of beet pulp x DMI beet pulp
= (16.5 * 0.056) * 0.449
= 0.42 MJ

The ether extract of unmolassed beet pulp is probably too small to be significant in terms of its contribution to the DE of sugar-beet pulp. The crude protein content of unmolassed beet pulp is also low, and it is likely to be associated with the cell wall material in such a way that it is rendered unavailable for enzymic digestion. The heat treatment used in the preparation of beet pulp can lead to the formation of Maillard products between protein and carbohydrate fractions which renders the protein less degradable. The following calculation, therefore assumes that the DE of the remaining fraction of sugar-beet pulp is produced by microbial fermentation.

The DE of sugar-beet pulp fed in this trial was measured as 10.94 MJ/kg DM. The energy produced by fermentation is equivalent to;

DE produced by fermentation = (DE of beet pulp x DMI) - 0.42
= (10.94 * 0.449) - 0.42
= 4.49 MJ

Therefore, the fermented DE/kg sugar-beet pulp dry matter = 4.49/0.449 = 10.0 MJ/kg DM.

The mean energy loss as methane by feeding the basal diet and the basal diet plus beet pulp were 0.13 and 0.23 MJ respectively. Therefore, the methane produced from the fermentation of beet pulp is equivalent to 0.10 MJ. This was the energy lost from the fermentation of 0.449 kg of SBP dry matter which is equal to 0.22 MJ/kg sugar-beet pulp DM. The proportion of the sugar-beet pulp fermented DE lost as methane is therefore 0.22/10.0 = 0.022. The ARC (1981) suggested a value of 0.11 based upon ruminant methane production which therefore appears to overestimate grossly the energy lost as methane in growing pigs. As a consequence of this, the metabolic efficiency of VFA utilisation, as calculated in Experiment 3.1, was underestimated. Assuming methane losses as 0.022 (this experiment), heat of fermentation as 0.06 (ARC, 1981) and the relative utilisation of fermented DE relative to DE of starch, (Experiment 3.1) the metabolic efficiency of VFA can be calculated as;

metabolic efficiency	=	relative utilisation / (1 - 0.022 - 0.060)
of VFA		fermented DE cf. starch DE
	=	0.72/0.918 = 0.78

This value agrees well with that derived by the ARC (1981) and from the data of Müller (1984) and Zhu and Fowler (1987).

Other workers have examined the fate of VFA absorbed from the caecum and colon in both young and growing pigs. Although it has been shown that a large proportion of absorbed VFA may be metabolised by the gut wall, substantial amounts have also been measured in the blood.

Möhme, Molnar and Lenkheit (1970) showed that acetate introduced orally, in the form of 1-^{14}C acetate, into young new-born piglets was metabolised rapidly to $^{14}CO_2$ within a very short period of time following its introduction. Within 12 hours, 0.89 - 0.92 was recovered in this form while less than 0.03 was excreted in the urine and faeces. Small amounts of radioactivity were found in most tissues. Latymer and Woodley (1984) also introduced ^{14}C, but in the form of U-^{14}C acetate injected into the caecum of 22-28 kg pigs at physiological levels. U-^{14}C acetate was found to be rapidly absorbed and peak blood concentrations were recorded 30 minutes later. After a five hour period, ^{14}C was found in all major classes of lipid including free cholesterol and cholesteryl esters, plasma proteins and other water soluble compounds.

A second study, carried out by Latymer and Low (1984) involved the infusion of U-^{14}C acetate into the caecum and total collections of urine and faeces were made for 96 hours. The pigs were killed and the mean distribution of radioactivity throughout the body determined. A substantial proportion of the dose was retained in the carcase, mainly in the subcutaneous fat which contrasts with the situation in the newborn piglet which has minimal energy reserves and where acetate given orally acts as an immediate source of energy. The *in vitro* studies using slices from various tissues of growing pigs carried out by Huang and Kummerow (1976) demonstrated the incorporation of 1-^{14}C acetate or U-^{14}C acetate into fatty acids and cholesterol. The rate of incorporation was found to be highest in adipose tissue. The results of these workers and those obtained in this trial suggest that the acetate produced by fermentation of fibre is incorporated into fatty acids and laid down in the adipose tissue rather than being used as a source of energy. It was suggested by van der Honing, Metz and Jongbloed (1986) that the incorporation of VFA into body fat may be a more efficient process than using VFA as a source of ATP. They found that the decrease in utilisation of ME due to the shift in digestion from the small intestine to the large intestine was lower than expected on theoretical grounds, although Armstrong *et al.* (1958) found lower values in sheep.

More generally, other authors have reported the results of calorimetric studies with pigs given fibrous by-products to examine the efficiency of utilisation of ME, heat and methane production. Just, Fernandez and Jørgensen (1983) provided evidence to suggest that DE values may be over estimated in animals given fibrous diets. They examined the relationship between diet composition, site of absorption of energy yielding substrates and the utilisation of ME in pigs using 6 semi-synthetic diets. The proportion of digested energy disappearing in the caecum-colon increased from 0.18 to 0.33 as the content of potato starch plus cellulose in the diets increased from 0.02 to 0.32. The digestibility of gross energy and the efficiency of utilisation of ME decreased with increasing content of potato starch and cellulose in the diets. The efficiency of utilisation of ME decreased with deceasing energy concentration which accounted for 0.9 of the variation in NE value. As the energy concentration decreased, more of the dietary nutrients were transferred to the caecum-colon, the formation of VFA increased and a larger part of the digested energy disappeared in the caecum-colon.

Experiment 3.1, in agreement with other workers (ARC, 1981; Imoto and Namioka, 1983), showed clearly that the end products of enzymic digestion of starch and fermentation of fibre have different metabolic values. Van der Honing, Jongbloed, Smits and Wieman (1982) examined the effect of substitution of cereals by carbohydrates from different fibrous by-products or by animal fat on energy utilisation by growing boars. The digestibility of nutrients and energy was significantly lower on the by-product based mixtures compared with cereals in the mixtures. Losses of energy as methane were low, varying from 0.001 to 0.007 of the gross energy consumed. There was only a slight tendency towards higher losses on the by-product based mixtures compared with the cereal based mixtures. Urinary losses did not vary much within the series of diets although in general the lowest losses were observed with the cereal based diets. Volatile fatty acids in the faeces caused higher energy losses on the by-product based mixtures. The utilisation of ME was studied using multiple regression analysis and no significant differences were observed in efficiency of utilisation of ME between cereal and by-product based mixtures. The authors concluded that nearly all variation in NE value of feedstuffs can be predicted from its digestibility. The utilisation of ME was used with similar efficiency for the different mixtures but it seemed to vary more with the genetic potential of the pigs and the partitioning of energy between maintenance, protein and fat deposition.

This trial has not been successful in determining the net energy value of the sugar-beet pulp due to errors in the experimental techniques. A comparison of the heat production based on respiratory exchange data using the Brouwer equation (1965) with that obtained by the carbon/nitrogen balance technique revealed large discrepancies. Table 3.2.17 shows the values obtained by each method.

Table 3.2.17 A comparison of the heat production calculated from respiratory exchange, with carbon/nitrogen balance data

		Heat Production (MJ/day)			
Diet	Pig Number	Brouwer (1965)	mean	C/N Balance	mean
Basal	1	10.91		14.36	
	3	12.96	12.40	15.34	14.67
	5	12.61		14.53	
	6	11.55		14.44	
Basal + Beet Pulp	2	11.91		11.99	
	4	14.35	13.30	11.97	13.16
	7	13.10		14.45	
	8	13.84		14.22	

For all the pigs (except pig number 4) the heat production calculated from the carbon/nitrogen balance was greater than that calculated from the respiratory exchange. An increase in food intake causes total heat production to rise and the basal metabolism is assumed to remain the same. The increase in heat production can thus be attributed to the heat increment of the extra food given, in this situation the sugar-beet pulp. The mean heat production of the pigs on the basal ration was 12.40 MJ/day as compared to 13.30 MJ for the pigs given the sugar-beet pulp supplement. Therefore, the increment of 4.27 MJ of metabolisable energy (Table 3.2.13) was associated with an increase in heat production of 0.90 MJ. The heat increment of the beet pulp, as a fraction was therefore 0.9/4.27 = 0.21. Similar calculations cannot be carried out using the heat production from the carbon/nitrogen balance since the pigs given sugar-beet pulp supplements appeared to produce less heat than those on the basal diet alone.

Taylor and Fisher (1980) examined the thermogenic effect in pigs of wheat and wheatfeed. The NE/DE ratios for wheat and wheatfeed were 0.614 and 0.552 respectively as measured by indirect calorimetry, and 0.602 and 0.449 by comparative slaughter. In general, heat production was apparently slightly underestimated by the indirect calorimetry although the estimates of NE were only vastly different at the higher level of wheatfeed inclusion. In conclusion, these authors were not able to confirm the very large differences in energy utilisation between wheat and wheatfeed suggested by Ewan (1976). There was however a small difference between these two feedstuffs in thermogenic effect. The explanations offered for this, which were not elucidated by the experiment include; 1. The overestimation of the true DE values in intact animals which may be higher on fibrous diets due to hind gut activity. 2. The end products of digestion from the two feedstuffs may have different metabolic values. 3. High fibre diets may increase protein turnover in the gut.

More recently, Longland, Close and Low (1988) found results which were very similar to those obtained in the current trial, during studies on the digestion of carbohydrates from sugar-beet pulp in pigs with ileo-rectal anastomoses, and energy balance by calorimetry. The pigs received diets containing 0 (diet C) or 30 (diet 30SBP) g unmolassed sugar-beet pulp/kg. Nitrogen balance, non-starch polysaccharide digestibility, energy balance and heat production were measured. The mean heat outputs of the intact pigs were 739 and 711 kJ/kg$^{0.75}$/day for the pigs given diets C and 30SBP respectively the corresponding values for the pigs with ileo-rectal anastomoses were 641 and 534 kJ/kg$^{0.75}$/day. The diets fed in this trial contained 285 g unmolassed sugar-beet pulp/kg and the heat production, calculated on the same basis, was 769 and 696 kJ/kg/$^{0.75}$ day for the pigs given the basal diet and basal diet plus beet pulp respectively. Clearly the same effect can be seen in the two trials. Longland *et al.* (1988) concluded that the differences in heat output were a reflection of both differences in food intake, and variations in the efficiencies with which the various components of these diets were used.

The discrepancy between the heat production based on respiratory exchange data using the Brouwer (1965) equation, and that calculated from the carbon and nitrogen balance produces a problem in the interpretation of the results; which heat production values represent a real effect? and what is causing this discrepancy?, are both questions which need to be investigated. The fact that the results of the carbon/nitrogen balance are similar to those obtained by other workers is encouraging.

The examination of the values in Table 3.2.17 reveals that there was good agreement between mean heat production calculated from respiratory exchange, and carbon and nitrogen balance data, for the pigs fed the basal diet supplemented with beet pulp. However, the difference between the two means was much larger for the pigs given the basal diet alone.

One factor which could be important in determining heat production as measured by respiratory exchange, is the activity of the pigs. Those pigs given the basal diet alone had a low feed intake, which might be expected to lead to restlessness. Pig 5, in particular was noted for its activity, and on one occasion escaped from the crate. This pig is likely to have used more oxygen and produced more carbon dioxide, which will lead to a higher heat production. If all of the pigs on this diet were more active, the heat production will be higher than expected. This would have the effect of increasing the difference between the two mean heat productions and therefore is not useful in explaining the somewhat higher heat production of these pigs when calculated from the carbon and nitrogen balance. This leads to the suggestion that errors in the balance methodology must be identified.

Errors in the carbon/nitrogen balance technique are most likely to occur as a result of losses of nitrogen, and possibly energy from the faeces or urine. Nitrogen will be lost as ammonia from the faeces or urine, and it is also possible that carbon, and hence energy, could be lost from the faeces as VFA.

If nitrogen is lost from the faeces then nitrogen retention will be overestimated, and in the carbon/nitrogen balance calculations, the energy stored as fat (calculated by difference) will be underestimated since protein has a lower GE than fat. As a consequence of this, the total energy retained will be underestimated. The loss of nitrogen would also result in a reduction in the energy content of the faeces. Since heat production was calculated by difference, the relative decreases in energy retention (predicted from protein and fat storage) and the losses of energy from the faeces will determine the magnitude of the heat production, but it is likely that the calculated heat production will be overestimated. If nitrogen is lost from the urine, a similar situation will arise. A greater proportion of the nitrogen excreted by the pig passes out in the urine and it could be that this is a more likely source of error. Heat production, as calculated by the carbon/nitrogen technique, appeared to be most grossly overestimated in the control pigs where a greater proportion of nitrogen was excreted in their urine (mean 0.413 compared to 0.323 for the beet pulp fed pigs).

Alternatively the loss of VFA from the faeces could lead to an overestimation of the carbon retention. The energy stored as fat will be overestimated, and as a consequence of this heat production will be underestimated. Faecal VFA will be higher in the pigs given fibrous diets and it is therefore more probable that errors will arise in this way in the calculation of the heat produced in the beet pulp fed pigs. However, the examination of the heat production data in Table 3.2.17 shows that the two methods used to calculate heat production gave very similar results for this group of pigs.

If losses were to occur as described above then the measurement of nutrient digestibilities would also be affected and would most certainly lead to large standard errors, and this was not found to be the case for the nitrogen and energy digestibilities measured in this trial.

It is quite clear from the results obtained that the experimental techniques used need careful examination to try and identify the source of these discrepancies in heat production between the two methods used, evident in the pigs fed on the basal diet alone. One major source of error could be the fact that the digestibility measurements were made outwith of the respiration chambers. The collection, of faeces and urine during the period of measurement of gases may well help to improve the accuracy of further work. Between pig variation may have been reduced by the use of a cross-over design.

The methane measurements were however reliable and this has allowed the calculation of the digestible energy lost as methane following the fermentation of sugar-beet pulp. In conjunction with the information obtained in Experiment 3.1, this value has given an estimate of the metabolic efficiency of VFA relative to glucose.

CHAPTER FOUR

AN EVALUATION OF WHEATFEED AS A USEFUL DIETARY INGREDIENT FOR YOUNG WEANED AND GROWING PIGS

CHAPTER FOUR

AN EVALUATION OF WHEATFEED AS A USEFUL DIETARY INGREDIENT FOR YOUNG WEANED AND GROWING PIGS

4.0 INTRODUCTION

Commercial compounders need to consider any feedstuff which could help to produce rations more competitively. The increasing and variable costs of conventional protein sources used by commercial feed compounders has lead to the search for alternatives. These materials must, however, be able to support pig growth and performance consistently. Wheatfeed, a fibrous by-product of the milling industry, maybe a particularly appropriate constituent of diets for growing/finishing pigs since its inclusion may help to restrict energy intake and improve the carcase quality of pigs produced by labour-saving systems based on *ad libitum* feeding. This chapter describes two trials which were designed to evaluate wheatfeed as a dietary component for both young weaned and bacon pigs, and discusses the results of measurements made of animal performance and carcase characteristics.

Any trial which is designed to evaluate a raw material must examine the effects of its inclusion on feed intake, daily liveweight gain and feed conversion ratio. Maintaining high growth rates must also be concomitant with achieving high killing-out percentages and an acceptable carcase quality in terms of P2 backfat, shoulder and loin fat thickness, and carcase length. The literature reviewed below details the information available on the effects of an increased dietary fibre intake on these performance and carcase characteristics.

The effects of dietary fibre on voluntary feed intake

It is a well known fact that the intake of simple stomached animals increases if the diet is diluted with indigestible material, and decreases when the energy content of the food is increased (Adolf, 1947). However, the compensation is not complete and Forbes (1986) discussed how the pig may have changed genotypically (in a similar way to the broiler) so that physiological control of intake appears to have given way to some extent to eating to bulk. In young animals, which have greater nutrient requirements per unit of body weight and stomach capacity, stomach distention may be the most important limit to food intake.

The addition of a fibrous material to a diet has been shown to increase voluntary feed intake (ARC, 1967). The magnitude of the increase was quantified in this review; for every 0.01 increase in dietary fibre content of the diet (up to 100 g/kg) an approximate increase of 0.03 in feed intake was found. There were, however, reductions in growth rate despite an increased intake which, therefore, did not appear to compensate fully for the lower digestible energy content of the diet. The data presented in the review did not allow an estimate to be made of the plateau of intake imposed by dietary fibre. The data reviewed by the ARC (1967) was highly variable, probably as a result of some of the factors discussed in Chapters 1 and 2, including the age of the pig, the source of the fibre and the way in which it was processed.

A number of authors have investigated the effects of dietary fibre on feed intake more recently. Owen and Ridgman (1967) found that intakes of high dietary fibre diets based on barley with the addition of sawdust and oatfeed, were consistently higher than those of low dietary fibre content when the pigs were in the finishing phase of growth only. The time spent eating corresponded with the weights of feed eaten. Between the liveweights of 27 and 50 kg, DE intakes were reduced but these were compensated for by higher intakes when diets of high dietary fibre were given in the 50 - 118 kg finishing phase. Owen and Ridgman (1968) further reported that the adaptive response of pigs to diets with a high dietary fibre content takes a long time to occur, especially in young pigs. Baker, Becker, Jensen and Harnson (1968) conducted trials with growing-finishing pigs fed on diets containing between 0 and 400 g cellulose/kg diet, on an *ad libitum* basis. The voluntary food intake fell from 2.63 to 1.50 kg/day, and gain fell from 760 to 250 g/day.

Contrasting daily voluntary feed intakes, of 7.79 and 5.80 kg of dry matter were also observed in lactating sows, given oat husks (400 g/kg) or straw (300 g/kg) by Zoiopoulos, English and Topps (1982). The properties of these two sources of fibre which led to these differences in feed intake have still to be elucidated. More information on the responses to different types of dietary fibre are of particular interest when attempts are made to control feed intake of breeding animals in which excessive weight gains can occur under *ad libitum* systems.

The results so far indicate the complexity of the mechanisms controlling voluntary feed intake. Taverner, Campbell and Biden (1984) presented further results illustrating this. The intakes of growing pigs fell from 2.18 to 1.92 kg/day as the digestible energy content rose from 11.8 to 14.4 MJ/kg diet. All diets contained 120 g acid detergent fibre/kg and fat was added to increase the energy density of the diet. Despite the fact that there was a 0.07 increase in digestible energy intake the maximum daily digestible energy intake was 27 MJ, when intakes of 34 MJ had been found by the same group when similar diets of low fibre content were fed (Campbell, Taverner and Curic, 1983).

Zoiopoulos, English and Topps (1983a) assessed fibrous agro-industrial by-products as protein sources for bacon pigs. Between 30 and 55 kg, the intake of pigs given a control diet, based on barley and soya, and a diet containing 605 g weatings/kg were very similar. Over the liveweight range 55-87 kg growing pigs ate different amounts of dry matter per day when offered food for 1 hour in the morning and 1 hour in the evening. The inclusion of 335 g of malt culms/kg or 465 g dark grains/kg depressed daily intake to 1.81 and 1.94 respectively, compared to an intake of 2.30 kg/day for the control diet and 2.05 kg/day for the diet containing the weatings.

It is therefore apparent that different types of dietary fibre influence voluntary feed intake in different ways; although pigs might be expected to eat more in order to compensate for a lowered digestible energy content caused by the presence of fibre, the reverse effect or trend has been seen to occur (Zoiopoulos *et al.*, 1983a). The results presented also suggest that pigs do not eat to maintain a strictly controlled energy intake. One hypothesis has been put forward by Bergner (1981) which explains how moderate amounts of dietary fibre may increase voluntary feed intake. The bacteria present in the large intestine are capable of hydrolysing undigested proteins to a wide range of products including tyramine and tryptamine, amine derivatives of tyrosine and tryptophan respectively. These can saturate the satiety centre within the hypothalamus of the brain and reduce feed intake. The inhibition of the formation of these compounds can be achieved by lowering the pH of the contents of the caecum and colon, below the high pH requirements of the amine-producing bacteria. The volatile fatty acids produced by the degradation of fibre may be capable of producing such an environment, therefore stimulating feed intake.

The effects of dietary fibre on growth and feed conversion ratio

The ARC (1967) reviewed the effects of dietary fibre on growth rate and feed conversion ratio. The trials included pigs which were mostly in the liveweight range 20-90 kg and the sources of fibre were variable; oats, oat hulls, oat mill feed, wheat bran, wheat straw, lucerne meal or ground maize cobs. It was concluded that increasing the proportion of crude fibre in the diet depressed the growth of pigs and was quantified as a 0.02 decrease in growth for every additional 0.01 crude fibre in the diet.

The addition of crude fibre to the diet resulted in a deterioration of the feed:gain ratio. It was estimated that for every 0.01 increase in crude fibre, a 0.03 increase in feed required per kg of gain was required.

The failure to characterise the types of fibre used in experiments since the ARC (1967) has not lead to any improvement or modification of these relationships.

The effects of dietary fibre on carcase characteristics and body composition

High-fibre diets given *ad libitum* have been shown to reduce carcase fat measurements or increase carcase lean, but there have been some exceptions. Some authors have recorded a reduction in dressing percentage with high fibre diets. The inclusion of lucerne meal at levels of 500 or 530 g/kg led to an extreme reduction in dressing percentage of 6.4 and 8.4 units respectively (Bohman, Hunter and McCormick, 1955; Merkel, Bray, Gummer, Phillips and Bohstedt, 1958). This is equivalent to about a 6.0 to 7.5 kg reduction in saleable carcase in a pig of 90 kg liveweight. The reduced dressing percentage may be associated with increased wet weights of the gastrointestinal segments or an increase in the water content, and hence weight of digesta. Gut fill is an element of liveweight and it will therefore affect the calculation of the maintenance requirement and the efficiency of utilisation of ME. Slaughter losses will also increase due to greater gut fill. It is therefore necessary to know the effect of the type and amount of fibre in the diet on gut fill.

A number of studies have been carried out to investigate the effects of cellulose on the carcase characteristics of growing pigs. The effect of purified cellulose on the growth and body composition of growing pigs fed on an *ad libitum* basis by

Cunningham, Friend and Nicholson (1961) was to decrease the dressing percentage and increase the saturation of the fatty acids in the backfat. Partridge, Keal and Mitchell (1982) measured the energy value of purified wood cellulose (solkafloc) added to a barley-soya diet at a rate of 150 g/kg diet when the basal diet was fed at a restricted level limiting in energy. Growth rates and nitrogen retention were unaffected by the addition of solkafloc, while the dressing percentage fell. Although there was a tendency for the fibre digestibility coefficients to be reduced with the addition of solka-floc, the weight of fibre digested was much higher. However, the total amounts of energy apparently digested and absorbed were the same i.e. the DE intakes for the basal diet and basal + solka-floc treatments were the same. The results obtained indicate that the energy from the solkafloc was either used in bacterial metabolism or lost as methane, and therefore not absorbed. Alternative explanations are that the energy released was used in the gut wall or that the energy absorbed from the fermentation of the cellulose was offset by reduced absorption from other sources.

Other materials have also been shown to influence carcase composition. Straw was found to result in fatter carcases by Kupke and Henkel (1977) in contrast to wood cellulose which was shown to reduce nitrogen digestibility, whilst urinary nitrogen output fell leaving the nitrogen balance unaffected. There is also evidence to suggest that sows are able to make better use of supplementary cellulose than growing pigs. Müller and Kirchgessner (1983) found that nitrogen balance was improved in sows given cellulose, urinary output falling whilst faecal nitrogen output was increased.

The results reviewed here and those obtained in Chapters 1, 2 and 3 have shown that increasing the dietary fibre content of the diet leads toward a greater faecal nitrogen loss which is probably largely due to an increased output of bacteria and endogenous matter (Mason, Kragelund and Eggum, 1982). Nitrogen retention has been shown to both increase and decrease as the net effect of the apparent alteration in nitrogen excretion, as described in previous chapters, but the reasons for these effects have not yet been elucidated. Gut size has been shown to increase in pigs given high fibre diet (Pond, 1984; Low, 1985) and it is therefore possible that part or all of the increase in nitrogen retention could be due to increased protein deposition in the gut wall with little, or no effect on edible carcase protein.

Wheatfeed - nutritive value and acceptability as a protein source

Wheatfeed is composed of small particles of bran along with part of the endosperm from the wheat grain. It has a lower crude fibre content (60-85 g/kg) and higher digestible energy value (11.8 MJ/kg) than wheat bran. The protein content lies in the range 150-180 g/kg, and in common with other cereal by-products wheatfeed is deficient in calcium (McDonald, Edwards and Greenhalgh, 1988). If wheatfeed is to be used successfully as a protein source, it must fulfil other criteria e.g. it must contain a comparable energy value to cereals or other protein sources, which it is likely to replace in a diet. Table 4.1.0 below compares the chemical composition of wheat, wheatfeed and soya-bean meal, a commonly used source of protein in growing pigs, as reported by MAFF (1986).

Table 4.1.0 A comparison of the chemical compositions of Wheat, Wheatfeed and Soya-bean meal (MAFF, 1986b)

Component	Wheat	Wheatfeed (g/kg)	Soya-bean meal
DM	860	870	880
AHF	15	36	13
CP	106	155	434
CF	26	84	67
NDF	100	386	290
Ash	18	46	55
DE (MJ/kg)	14.0	11.6	13.9
Lysine	3.1	5.8	28.9
Methionine + Cystine	3.8	4.2	13.2
Threonine	2.9	4.9	17.1

This table highlights the higher protein and lower DE contents of wheatfeed when compared to wheat. The shortfalls of wheatfeed as a protein source, in relation to soya-bean meal are also illustrated clearly by the quantity and quality of the protein fraction. The lack of the presence of the essential amino acids lysine, methionine, cystine and threonine in any appreciable quantities indicate that wheatfeed would not be able to replace completely a protein source such as soya-bean meal. It could however be used to replace a proportion of a cereal such as wheat, with the addition of a concentrated energy source to compensate for the lower DE value of wheatfeed.

Work at the Rowett Research Institute (1983) found that the nutritive value of wheatfeed for pigs, when determined in association with other materials, was less than would be expected from its chemical composition. A series of experiments were carried out to establish whether this was due to the fibre content or some other component. Wheatfeed, considered to be typical with an ADF content of 102 g/kg, was used as an entire diet for one group of pigs supplemented only with minerals and vitamins (Treatment 1). Treatments 2, 3, and 4 were formulated by adding lysine and threonine, or maize starch, or these combined to give the same concentrations found in the control diet of barley and soyabean meal (Treatment 5). Diets 1 to 4 were fed at 2.5 * maintenance, diet 5 at 2.0, 2.5, 3.0 and 3.5 * maintenance. There were 12 pigs on each treatment. Pigs given wheatfeed supplemented with amino acids and maize starch grew on average 1.15 times faster than those on the equivalent barley and soya bean diet. The results suggest that when given as a sole feed its energy is utilised with a higher efficiency than would be expected if book values were taken. It was suggested that this is due to the fact that estimates of feeding value of wheatfeed have been determined using it as a constituent of mixed diets.

In a study of Zoiopoulos *et al.* (1983a) which evaluated diets containing weatings, malt culms and dark grains for growing pigs, marked differences in the digestibility of nitrogen were observed. Pigs cannulated at the terminal ileum were used to study digestion in a second study by the same authors (Zoiopoulos, Topps and English, 1983b). Overall digestibility for a diet containing 650 g weatings/kg was found to be 0.625, as compared to 0.760 for a control diet based on barley and soya. The rate of passage of digesta was also increased in the pigs on the weatings diet (23.2 h for the weatings diet cf. 27.6 h for the control diet). Three out of the four values of nitrogen digestibility measured at the terminal ileum in the pigs on the weatings diet were higher than those overall which indicates that there was a net addition of nitrogen to the contents of the large intestine, probably due to nitrogenous secretions being incorporated into bacterial protein which is subsequently excreted as faecal nitrogen.

The apparent nutrient digestibilities of wheat middlings, near the end of the small intestine and over the total digestive tract, were also determined by Lin, Knabe and

Tanksley (1987). The proportion of the gross energy of the wheat middlings digested in the large intestine was 0.17, compared to 0.07 for wheat and 0.11 for barley. The starch in all products was completely digested by the end of the small intestine. Amino acid digestibilities determined over the whole tract were generally higher then ileal digestibilities. However, values for lysine, methionine and phenylalanine were lower indicating a net synthesis of these amino acids in the large intestine.

The two trials reported in this chapter were designed to investigate the effects of increasing wheatfeed level on;

- voluntary feed intake, daily liveweight gain and feed conversion ratio of young weaned pigs, aged 5-9 weeks.
- daily liveweight gain, feed conversion ratio, killing-out percentage, carcase characteristics and the lengths and empty wet weights of the gastrointestinal segments of pigs grown from 30-90 kg.

4.1 THE EFFECT OF WHEATFEED INCLUSION LEVEL ON THE FEED INTAKE AND PERFORMANCE OF YOUNG WEANED PIGS

4.1.0 INTRODUCTION AND AIMS

Over the past decade there has been a progression towards increasing nutrient density in growing pig diets and more intensive husbandry systems. With these changes have come reports of a rising prevalence of bacterial (*E. coli*) infections, gastic abnormalities (e.g. ulceration of the *pars oesophagea*) and more recently non-specific colitis. The aetiology of ulceration and colitis are as yet unknown but some factors which are likely to be involved are nutrition and stress. The need to be less dependent on drug therapy for the alleviation and control of these conditions is becoming more important, and it may therefore be necessary to manipulate the gut environment in order to reduce the high rates of morbidity and mortality resulting from these conditions.

The effects of differing types of polysaccharides on the gut environment vary for some of the reasons discussed in Chapters 1, 2 and 3. One of the most important factors controlling colonic motility is the volume of dietary residue entering the colon. An increased volume of digesta may be a prime way in which dietary fibre can affect the gut environment through its adsorptive properties. The overall effect of changes such as these is to affect the bulk of digesta in the tract and this in turn can affect rate of passage. The digestion and utilisation of other nutrients in the diet will be affected as shown in Chapters 1, 2, and 3 , and this could be particularly detrimental in young weaned pigs where a high potential for rapid growth must be exploited.

The role of dietary fibre in the diet of young pigs has been little studied and its effects remain unclear. Creep feeds usually contain highly digestible ingredients such as cooked cereals and skimmed milk, and are therefore relatively low in dietary fibre. However, intakes can be both poor and variable. At weaning diets of rather higher dietary fibre content are fed but again appetites are often poor. This change from a highly digestible creep feed to a less digestible grower diet could be an important factor in the development of colitis and the diarrhoea produced (B. Vernon, personal communication). However, Drochner, Hazem, Mayer and Rensmann (1978) suggested that a wood cellulose supplement may in fact depress bacterial activity and help to reduce diarrhoea. Other possible beneficial effects of fibre may include the maintenance of a normal gastrointestinal microflora and the buffering effect of fibre through cation exchange (McBurney *et al.*, 1983; Van Soest *et al.*, 1984). However, diets which combine such potentially beneficial effects with high digestibility must be fed however to promote maximum growth.

The aims of this trial were to examine the effects of wheatfeed inclusion levels of 0, 50, 100 and 150 g/kg on the voluntary feed intake, daily liveweight gain and feed conversion of pigs fed from 5-9 weeks of age (10-30 kg).

4.1.1 MATERIALS AND METHODS

Animals and Diets

96 five week old pigs (48 boars and 48 gilts) of approximate liveweight 10 kg were used in this trial. Groups of 6 pigs (3 boars and 3 gilts) of similar liveweight were allocated to each of 16 pens fitted with *ad libitum* hoppers in a flat deck house.

There were a total of 4 dietary treatments based on the specifications of a conventional weaner diet of Dalgety Agriculture Limited, which were manufactured and pelleted at the Lord Rank Research Centre, High Wycombe. A control containing no wheatfeed, and three diets containing 50, 100 and 150 g wheatfeed/kg were fed. The diets were formulated to be isonitrogenous and equivalent in digestible energy content in order to investigate the bulking effect of wheatfeed on feed intake, rather than a compensatory increase in feed intake in response to a dilution of the energy concentration of the diet by the addition of wheatfeed.

The dietary formulations and expected chemical composition of the wheatfeed and 4 diets are given in Table 4.1.1.

Trial Procedure

The pigs were given free and continuous access to feed and water. The weights of the pigs were recorded at 5, 7 and 9 weeks of age, and the feed intakes calculated at 7 and 9 weeks.

The digestibility of the energy and nitrogen in the diets was measured in growing pigs of approximate initial liveweight 25 kg. The pigs were placed into metabolism crates, similar to those used in the digestibility studies of previous experiments following the completion of a 14-day adaptation period. Faeces were collected over a 10 day period using an indigo carmine dye as a marker for the start and completion of the collection. The pigs were fed 1.5 kg of air-dried material with *ad libitum* water available.

4.1.2 ANALYTICAL PROCEDURES

The diets were analysed using the same procedures outlined in the previous chapters.

4.1.3 STATISTICAL PROCEDURES

The data was analysed as a randomised block using Genstat V. The analysis of variance identified the blocks and the diets, and each mean was tested by a comparison of the mean squares of the blocks and diets with the error mean square.

MINITAB (Minitab Inc., 1985) was used to determine the response in feed intake, daily liveweight gain and feed conversion ratio to increasing inclusion levels of wheatfeed in the diet using regression analysis. Feed intake, daily liveweight gain and feed conversion ratio were plotted against the level of wheatfeed in the diet (g/kg).

4.1.4 RESULTS

By comparing the chemical composition of the diet (Table 4.1.2) with the expected analysis (Table 4.1.1) it can be seen that there were two deviations from the formulated levels. Crude fibre levels were 7.5 to 11.5 g/kg lower than the target value suggesting that the crude fibre content of the wheatfeed was overestimated. Calcium levels were slightly higher than expected.

Table 4.1.1 Dietary Formulations and expected chemical composition (g/kg)

		Wheatfeed Level (g/kg)			
	Wheatfeed	0	50	100	150
Barley		150.0	150.0	150.0	150.0
Wheat		556.0	502.2	448.5	402.8
Wheatfeed		-	50.0	100.0	150.0
Hi-pro Soya		175.0	175.0	175.0	165.5
Chilean Fishmeal		60.0	60.0	60.0	60.0
Meat and Bone Meal		42.9	42.5	42.1	41.9
Lysine-HCI		1.8	1.7	1.6	1.8
Fat;Frank Fehr 310		9.9	14.2	18.5	23.6
Salt		0.5	0.5	0.5	0.5
P36A UWean UGain MZ		4.0	4.0	4.0	4.0
Oil	31.0	32.9	38.0	43.0	48.7
AHF	34.2	40.6	45.6	50.5	56.2
Protein	165.0	230.2	231.6	233.1	231.3
Crude Fibre	83.0	29.3	32.3	35.2	38.0
NDF	290.5	-	-	-	-
Ca	1.1	7.0	7.0	7.0	7.0
P	9.5	6.7	7.0	7.3	7.6
Salt	1.2	4.2	4.2	4.2	4.3
Ash	45.0	47.7	49.2	50.6	51.7
DE (MJ/kg)	11.8	14.35	14.35	14.35	14.35
Lysine	5.3	12.5	12.5	12.5	12.5
Methionine	2.7	4.0	4.0	4.0	4.0
Methionine + Cystine	6.3	7.3	7.4	7.5	7.4
Threonine	5.0	7.9	8.0	8.1	8.0
Na	0.04	1.8	1.8	1.8	1.8
K	10.8	7.2	7.5	7.9	8.0
Cu (mg/kg)	-	211	211	211	211

Table 4.1.2 Chemical composition of the diets (g/kg)

	Wheatfeed Level (g/kg)			
	0	50	100	150
Oil	35.6	37.7	44.4	50.1
AHF	42.0	44.3	51.4	56.7
Protein	235.5	235.0	243.0	236.0
Crude Fibre	22.3	23.1	27.7	26.5
NDF	74.5	79.5	93.5	110.0
DM (g/kg)	888	891	889	889
Ash	53.4	55.0	56.5	55.0
Salt	4.1	4.0	4.1	4.1
Mg	1.2	1.3	1.5	1.5
Cu (mg/kg)	198	200	203	207
Mn (mg/kg)	74	78	79	80
Zn (mg/kg)	190	201	199	203
Ca	9.3	9.1	8.7	8.9
P	8.4	8.5	8.7	8.9
Na	1.8	1.8	1.7	1.8
K	7.8	7.9	8.4	8.2

Digestibility studies

The results of the digestibility studies are given in Table 4.1.3.

All of the values for the digestibility of energy were similar, but the highest value was obtained for the control diet which contained no wheatfeed. No trend of decreasing energy digestibility with increasing wheatfeed level could be observed. The lowest energy digestibility coefficient was observed for the diet containing 100 g wheatfeed/kg.

The nitrogen digestibility coefficients were similar for all four diets but again the lowest value was recorded for the diet containing 100 g wheatfeed/kg. The DE values obtained for the diets in these digestibility studies were used to calculate the DE intakes of the pigs on the growth trial.

Table 4.1.3 **Energy and nitrogen digestibility for growing pigs given diets containing 0, 50, 100 and 150 g wheatfeed/kg**

		WHEATFEED (g/kg)			
		0†	**50†**	**100#**	**150#**
Gross Energy (MJ/kg DM)		18.68	18.69	18.90	19.05
Energy Digestibility	mean	0.892	0.885	0.884	0.888
	SD	0.013	0.011	0.004	0.010
Digestible Energy (MJ/kg DM)		16.62	16.54	16.71	16.92
Protein Digestibility	mean	0.875	0.870	0.856	0.878
	SD	0.017	0.026	0.016	0.022

† mean value for 3 pigs; #mean value for 4 pigs

Growth Trial

Feed intakes, growth rates, feed conversion ratios and digestible energy intakes for the pigs given each diet in the periods 5-7, 7-9 and 5-9 weeks are given in Table 4.1.4.

Feed Intake

No significant differences were found between the mean daily intakes of the pigs on each diet in any of the three time periods. Feed intake was regressed against the level of wheatfeed in the diet to try and identify any change in feed intake with the variation in the wheatfeed content of the diet. The regression equations obtained for the three periods are given in Table 4.1.5.

An inverse relationship was found between the wheatfeed level in the diet and feed intake in the period 5-7 weeks, but in the period 7-9 weeks, and overall (5-9 weeks) the trend was that of increasing feed intake with increasing wheatfeed in the diet. None of the slopes were found to be significantly different from zero, and the correlation coefficients were small and non-significant. This confirms that the level of wheatfeed in the diet did not significantly affect feed intake.

Table 4.1.4 **The effect of wheatfeed level on feed intake, daily liveweight gain (DLWG), feed conversion ratio (FCR) and digestible energy (DE) intake**

PERIOD	**WHEATFEED (g/kg)**					
(weeks)	0	50	100	150	SED (9 DF)	SIG.
5-7						
Feed Intake (kg/d)	0.689	0.675	0.653	0.675	0.0412	NS
DLWG (kg)	0.529	0.515	0.517	0.551	0.0508	NS
FCR	1.32	1.32	1.26	1.23	0.0723	NS
DE Intake (MJ/d)	11.49	11.16	10.91	11.42	1.050	NS
7-9						
Feed Intake (kg/d)	1.186	1.220	1.240	1.320	0.1495	NS
DLWG (kg)	0.677	0.648	0.654	0.644	0.0202	NS
FCR	1.75	1.88	1.89	2.05	0.222	NS
DE Intake (MJ)	19.75	20.18	20.72	22.38	2.627	NS
5-9						
Feed Intake (kg/d)	0.938	0.948	0.946	0.999	0.0694	NS
DLWG (kg)	0.603	0.581	0.586	0.598	0.0271	NS
FCR	1.56	1.64	1.61	1.67	0.128	NS
DE Intake (MJ/d)	15.62	15.67	15.81	16.90	1.532	NS

Table 4.1.5 **Regression Analysis: Data plotted was Feed Intake (y) against Wheatfeed Level in the diet (x)**

Period (weeks)		**Regression Equation**	**r**
5-7	Feed Intake (g/d) =	683 - 1.31 x Wheatfeed	0.095
	SD	(34.89) (3.73) (g/kg)	
7-9	Feed Intake (g/d) =	1177 + 8.62 x Wheatfeed	0.241
	SD	(86.85) (9.29) (g/kg)	
5-9	Feed Intake (g/d) =	930 + 3.65 x Wheatfeed	0.176
	SD	(50.79) (5.43) (g/kg)	

Daily Liveweight Gain (DLWG)

The level of wheatfeed in the diet did not significantly affect the liveweight gains in any of the time periods measured and consequently regression analysis was used to try and illustrate any significant trend between the daily liveweight gain and the level of wheatfeed in the diet. The regression equations obtained for the three time periods are shown in Table 4.1.6.

Table 4.1.6 Regression Analysis: Data plotted was Daily Liveweight Gain (y) against Wheatfeed Level (g/kg) in the diet (x).

Period (weeks)	Regression Equation	r
5-7	DLWG (kg/day) = 0.517 + 0.00144 x Wheatfeed SD (0.0338) (0.003631) (g/kg)	0.105
7-9	DLWG (kg/day) = 0.671 - 0.00212 x Wheatfeed SD (0.01352) (0.001445) (g/kg)	0.365
5-9	DLWG (kg/day) = 0.594 - 0.00021 x Wheatfeed SD (0.0203) (0.002173) (g/kg)	0.032

None of the slopes of the regression lines were found to be significantly different from zero and the correlation coefficients were all small and non-significant. This confirms that increasing the level of wheatfeed in the diet had no significant effect on the daily liveweight gains of the pigs. However, in the early stages of the feeding trial the slope of the line was found to be slightly positive, whereas as this situation was reversed in the period 7-9 weeks, so that overall there was a negative, but non-significant, relationship between DLWG and wheatfeed inclusion level.

Feed Conversion Ratio (FCR)

Feed conversion ratio was not significantly affected by the addition of wheatfeed in any of the three time periods examined. The regression equations for the three periods are given in Table 4.1.7.

As with the feed intake and DLWG there was no significant trend in FCR with increasing levels of wheatfeed in the diet. The slopes obtained for the three regression equations were all non-significantly different from zero and the correlation coefficients were also found to be non-significant. The magnitude of the correlation coefficients indicate that FCR was the factor most highly correlated with the level of wheatfeed inclusion in the diet. During the first two weeks of the trial, FCR was seen to improve with increasing wheatfeed in the diet, but during the second phase (7-9 weeks and overall, FCR tended to deteriorate as the level of wheatfeed in the diet increased.

Table 4.1.7 **Regression Analysis: Data plotted was Feed Conversion Ratio (y) against Wheatfeed Level (g/kg) in the diet (x).**

Period (weeks)		Regression Equation	r
5-7	FCR =	1.34 - 0.007 x Wheatfeed	0.435
	SD	(0.036) (0.0039) (g/kg)	
7-9	FCR =	1.75 + 0.0185 x Wheatfeed	0.366
	SD	(0.117) (0.0125) (g/kg)	
5-9	FCR =	1.57 + 0.0062 x Wheatfeed	0.217
	SD	(0.069) (0.00743) (g/kg)	

Digestible Energy Intake (DEI)

The metabolism studies showed that the DE of the diets were not exactly as formulated; all diets were formulated to contain 14.35 MJ DE/kg and the DE values measured *in vivo* were 14.76, 14.73, 14.86 and 15.04 MJ/kg for the diets containing 0, 50, 100 and 150 g wheatfeed/kg respectively. Since pigs are known to adjust their intake according to the DE of the diet, the DE intakes of the pigs were calculated to examine the effect of DE level on intake which is likely to mask any effect of the wheatfeed. The results presented in Table 4.1.4 of the effect of wheatfeed level of DEI showed no significant differences between the pigs on the different diets in any of the growth periods 5-7, 7-9 or 5-9 weeks. The regression equations for these periods are given in Table 4.1.8 and confirm the non-significant effect of wheatfeed level.

Table 4.1.8 Regression Analysis: Data plotted was Digestible Energy Intake (y) against Wheatfeed Level (g/kg) in the diet (x).

Period (weeks)	Regression Equation	r
5-7	DEI (MJ/d) = 11.3 - 0.0091 x Wheatfeed SD (0.584) (0.06244) (g/kg)	0.045
7-9	DEI (MJ/d) = 19.5 + 0.168 x Wheatfeed SD (1.45) (0.1550) (g/kg)	0.279
5-9	DEI (MJ/d) = 15.4 + 0.0799 x Wheatfeed SD (0.85) (0.09080) (g/kg)	0.228

4.1.5 DISCUSSION

This trial has shown that wheatfeed inclusion levels of up to 150 g/kg did not result in any significant adverse effect on feed intake, growth rate or feed conversion ratio. However, there was a slight trend for feed intake to increase and feed conversion ratio to deteriorate at the highest level of wheatfeed inclusion, particularly in the period between 7 and 9 weeks of age. Since at its maximum level of inclusion wheatfeed comprised only 0.15 of the diet, it is possible that the effects of wheatfeed may be difficult to determine in terms of finding significant differences, resulting only in the identification of trends. The pigs given this diet showed the highest intake of digestible energy (22.38 MJ) and the poorest food conversion ratio (2.05). This suggests that the energy produced by the digestion of wheatfeed is used less efficiently for liveweight gain than that of the wheat it replaced in the diet. This is in agreement with the findings of Taylor and Fisher (1980), and Experiment 3.1 which showed that the digested energy from sugar-beet pulp was used with an efficiency which was less than that of maize.

The efficiency of conversion of DE into liveweight gain, when calculated from the mean values detailed in Table 4.1.4, is shown below in Table 4.1.9.

Table 4.1.9 The efficiency of conversion of DE into liveweight gain (MJ DE/kg gain)

	Wheatfeed Level (g/kg)			
Period (weeks)	0	50	100	150
5-7	21.72	21.67	21.10	20.73
7-9	29.17	31.14	31.68	34.75
5-9	25.90	26.97	26.98	28.26

In the early stages of the trial (5-7 weeks) the efficiency of conversion of DE into liveweight was relatively constant with increasing wheatfeed inclusion. However, during the period 7-9 weeks, and over the whole period of the trial (5-9 weeks) there was a deterioration in the efficiency of utilisation of DE for liveweight gain with increasing wheatfeed inclusion level. This supports the suggestion made above that the DE from wheatfeed is used with an efficiency which is less than that produced from the digestion of wheat.

The pigs might have been expected to eat more of the wheatfeed diets in order to compensate partially for a reduced utilisation of digestible energy from these diets. This was found to be the case over the period 7-9 weeks, and also over the whole trial period (5-9 weeks). The reverse effect was seen in very young pigs (5-7 weeks) where the physical limitation imposed by the size of the gut, and the rate of passage of food through the gastrointestinal tract may have been more important than the physiological control of food intake.

In Experiments 1.1 (Chapter 1), 2.1 and 2.2 (Chapter 2) and 3.1 and 3.2 (Chapter 3) an inverse relationship was established between the addition of food fibre to a diet and the digestibility of the energy and nitrogen of the diet. The fact that fat was added to the diet in increasing quantities as the level of wheatfeed rose, to maintain the DE level of the diets probably accounts for the lack of effect of wheatfeed on energy digestibilities in this trial. The addition of wheatfeed to the diet of 25 kg pigs does not appear to significantly alter the digestion and absorption of other nutrients in the diet. Alternatively, it is possible that the level of inclusion of wheatfeed in the diet was insufficient to illustrate the effect of the wheatfeed. How well the situation in the 25 kg pig reflects that in the young weaned pig cannot be determined from the results of this trial, but it is likely that digestibilities will be greater in the older pig by virtue of a more developed gut and digestive enzyme system.

The conclusion which may be drawn from the feed intake data is that the bulking effect of wheatfeed does not appear to be sufficient to act as a physical limitation to intake when fed to young pigs at inclusion levels of 50 to 150 g/kg. Based on these results, wheatfeed might be considered to be an acceptable ingredient in diets for young pigs when offered in a finely ground state in the form of a pellet, since performance was maintained by the addition of either 50, 100 or 150 g wheatfeed/kg. It is generally recognised that coarsely ground material has a greater water-holding capacity than when it is finely ground (Van Soest, 1985), and the bulking effect of the wheatfeed used in this trial was probably minimised by fine grinding.

Partridge, G.G. (personal communication) recently investigated the effect of feeding diets containing wheat bran and sugar-beet pulp on the performance of young pigs. A low fibre basal diet based on micronised wheat, skimmed milk powder, white fishmeal and soya oil, was compared to diets containing 150 or 300 g wheat bran/kg, and 100 and 200 g sugar-beet pulp/kg. These diets were offered to groups of 24 pigs over a growth period from 3 to 6 weeks of age. The diets were formulated to be similar in crude protein and digestible energy contents. The results obtained are detailed below in Table 4.1.10.

Table 4.1.10 The effect of wheat bran and sugar-beet pulp inclusion level on the performance of young weaned pigs

(mean values for 24 pigs)

Diet	DMI (g/day)	DLWG (g)	FCR
Basal	415	397	1.05
WB15	427	391	1.09
WB30	416	353	1.18
SBP10	408	342	1.19
SBP20	416	337	1.23

The results obtained by Partridge appear to be similar to those obtained in the current trial. The addition of up to 300 g wheatbran/kg or 200 g sugar-beet pulp/kg did not depress feed intake, as might have been expected by virtue of the bulking characteristics of dietary fibre, as was found to be the case for the addition of 150 g wheatfeed/kg. The bulking effect of these materials therefore does not appear to be an important limitation to feed intake. Alternatively, if the adaptative response of young pigs to diets high in dietary fibre takes a long period of time, as was suggested by Owen and Ridgman (1968), the growth period may have been too short to illustrate an affect. However, daily liveweight gains appear to have been significantly depressed for the diets containing 300 g wheat bran, or 100 or 200 g sugar-beet pulp/kg. Feed:gain ratios were seen to deteriorate significantly with the inclusion of 300 g wheatbran, 100 or 200 g sugar-beet pulp/kg. This suggests that either the diets were not as formulated, or that the energy from the wheat bran and sugar-beet pulp was used with an efficiency which was less than that of micronised wheat and skimmed milk which it replaced in the diet.

A factor, other than the fibre content of the food, which will influence the performance of pigs given diets containing high levels of wheatfeed, is the availability of the nitrogen in the wheatfeed. Lin *et al.* (1987) examined the apparent digestibilities of amino acids and gross energy, in a number of cereals and cereal by-products, including wheatfeed, in growing pigs. They found that approximately 0.21 of the dietary dry matter and 0.17 of the dietary gross energy were digested in the large intestine of pigs given wheatfeed, as compared to 0.08 for the dry matter and 0.07 for the gross energy in pigs given wheat. The amounts digested in the large intestine were inversely related to measurements of digestibility determined at the end of the small intestine. This relationship agrees with that reported by Sauer, Stothers and Parker (1977) who evaluated wheat, wheatfeed and wheatflour. The apparent digestibility of nitrogen near the end of the small intestine was lower for wheatfeed than wheat (0.706 *cf.* 0.848). All amino acid digestibilities were numerically lower for wheatfeed than in any of the other cereals or by-products measured, and of the essential amino acids isoleucine, leucine, methionine, phenylalanine, threonine and valine were less digestible in wheatfeed. The digestibilities of the amino acids were 0.037 to 0.14 units lower for wheatfeed than wheat. Valine, leucine and isoleucine were less digestible gradable than lysine and tryptophan, which for cereals are of practical importance since they are two of the three most limiting amino acids in these grains. Wheatfeed generally had the lowest faecal amino acid digestibilities with the exceptions of arginine, histidine, lysine and tryptophan. The extent of microbial degradation of amino acids in the large intestine was of the same order of magnitude for corn, wheat and barley, which contrasts remarkably with the two fold greater disappearance of dry matter and gross energy in the large intestine for wheatfeed. It suggests that the protein from wheatfeed is not as readily degraded by the intestinal microflora as the non-protein fraction. In summary, these data indicate that there are differences in the apparent digestibility of amino acids between wheat and wheatfeed. The diets used in this trial were formulated to be equivalent in digestible energy and to be isonitrogenous. If, as suggested above, the bioavailability of the nitrogen from the wheatfeed is less than might be predicted, then performance is likely to be depressed at higher levels of wheatfeed inclusion. This implicates the use of ileal digestibilities of amino acids for the formulation of diets where a considerable amount of fermentative digestion occurs to aid the accuracy of formulations. However, since the content of limiting amino acids in cereals and cereal by-products is low, the degree of improvement in formulation is only likely to be small. By-products are also prone to be variable by virtue of their method of preparation, thus making accurate formulation even more difficult.

The health of the pigs on this trial was good with an extremely low incidence of scour (2 pigs in a total of 96 showed clinical signs of diarrhoea and were treated accordingly). It would therefore seem correct to assume that the addition of wheatfeed to the diet of young pigs is not significantly detrimental to their health. The positive effects of fibre may include the maintenance of a normal gastrointestinal microflora, thus making it more difficult for pathogenic organisms to become established, and also the buffering effect of fibre, through cation exchange may also be beneficial (McBurney, Van Soest and Chase, 1983; Van Soest, McBurney and Russell, 1984). Another possible suggestion put forward by Drochner *et al.* (1978) was that the feeding of a poorly digested source of fibre eg. wood cellulose could in fact reduce bacterial activity and help to reduce the problem of diarrhoea in young pigs.

Growth in these early stages is also likely to influence growth in the growing-finishing phase. The subsequent performance of the pigs on this trial was not monitored and it is therefore not possible to draw any conclusions regarding this. Zoiopoulos *et al.* (1983a) however, showed that pigs given a diet containing 605 g wheatfeed/kg from 30-90 kg did not perform as well as pigs given a conventional barley, soya and fishmeal diet from 30-55 kg, followed by the wheatfeed diet described above. Further trials feeding wheatfeed diets over the whole of the growing-finishing phase could reveal differences in performance. Experiment 4.2

described below will compare the performance and killing-out percentage of pigs given a conventional diet up to a liveweight of 30 kg, followed by diets containing two different levels of wheatfeed.

4.2 THE EFFECT OF WHEATFEED INCLUSION LEVEL ON THE PERFORMANCE AND KILLING-OUT PERCENTAGE OF PIGS GROWN FROM 30-90 kg

4.2.0 INTRODUCTION AND AIMS

A previous trial (Dalgety Agriculture Limited, unpublished) investigated the effect of fibre type and level on the performance of pigs fed a grower/finisher diet, formulated to the specifications of Dalgety Agriculture Limited, over the liveweight range 30-90 kg. Four wheatfeed levels 80, 145, 210 and 275 g/kg were examined and it was found that there was a linear increase in backfat thickness with increasing wheatfeed usage whilst other performance factors were not affected. Since the diets were formulated to be equivalent in DE, it was concluded that this may have been due to an underestimation of the energy value of wheatfeed (considered atypical with a crude fibre content of 100 g/kg), along with an overestimation of the lysine content of the wheatfeed. A review of other Research and Development trials involving wheatfeed suggested that increasing levels of wheatfeed in the diet tended to reduce killing-out percentage. Increased intakes of NDF (Stanogias and Pearce, 1985) and more generally plant fibre (Pond, 1984) have been associated with increases in intestinal tract weight, and also increased lengths of the caecum and colon (Stanogias and Pearce, 1985). The water adsorbing properties of plant fibre will also lead to increased bulk and gut fill. This coupled with hypertrophy of the gut, is likely to produce a reduction in the killing-out percentage of a pig fed a high fibre diet.

The objectives of this experiment were to compare the performance and killing-out percentage of pigs fed diets containing 100 g and 300 g wheatfeed/kg on a restricted scale. Examinations of the gastrointestinal tract were carried out to determine the relative effects of the level of NDF on the empty wet weights of the segments of the gastrointestinal tract.

4.2.1 MATERIALS AND METHODS

Animals and Diets

80 pigs (40 boars and 40 gilts), of approximate initial liveweight 30 kg were used in this trial. Groups of 5 pigs were allocated to 16 pens according to their sex. There were two dietary treatments based on the commercial specifications of Dalgety Agriculture Limited which were manufactured and pelleted at their Poole mill. Each diet (100 or 300 g wheatfeed/kg) was fed to 8 pens of pigs (4 pens of boars and 4 pens of gilts). The dietary formulations and expected chemical composition of the diets are given in Table 4.2.0.

Table 4.2.0 The dietary formulations (g/kg) and expected chemical composition (g/kg) of the diets containing 100 and 300 g wheatfeed/kg

	WHEATFEED (g/kg)	
	100	300
Barley	200.0	175.0
Wheat	343.6	183.4
Wheatfeed	100.0	300.0
Chinese Sweet Potato	50.0	50.0
Rapeseed Extract	20.0	20.0
Hi-pro Soya	200.0	200.0
Meat and Bone Meal	50.5	42.4
Lysine-HCl	0.6	0.3
Frank Fehr-310	4.8	22.8
Salt	1.8	2.1
Bentonite Claybind	14.8	-
P37B-Ugrade Exfin MZ	0.4	0.4
Oil	37.0	47.9
AHF	43.5	53.7
Protein	212.0	216.4
Crude Fibre	36.4	47.4
Ca	7.0	6.4
P	6.7	7.6
Salt	3.8	3.8
Ash	63.0	54.0
DE (MJ/kg)	13.82	13.81
Lysine	10.2	10.2
Methionine	3.1	3.2
Methionine + Cystine	6.4	6.7
Threonine	7.3	7.5
Cu (mg/kg)	126.44	127.27
Na	1.4	1.4
K	8.2	9.6

Trial Procedure

The daily feed allowances for the pigs at different liveweights are shown below;

Daily Feed Allowances

Liveweight (kg)	Daily Feed (kg)
30	1.2
40	1.4
50	1.6
60	1.8
70	2.0
80	2.2

The pigs were fed their daily feed allowance as two equal sized meals at 08.00 and 16.00 hours. Access to drinking water was free and continuous. The pigs were weighed at weekly intervals and the daily feed allowance adjusted accordingly.

Examination of the gastrointestinal tracts

The gastrointestinal tracts of 8 boars, 4 per treatment, were collected at slaughter. The techniques used for taking weights and measurements were as described in Experiment 3.1 (Chapter 3, Section 3.1.1).

4.2.2 ANALYTICAL PROCEDURES

The diets were analysed using the experimental procedures detailed in the previous chapters.

4.2.3 STATISTICAL PROCEDURES

Genstat V (Lawes Agricultural Trust, 1982) was used for the statistical analysis of the results, following the recommended procedures of the Scottish Agricultural

Statistics Service. The effect of wheatfeed level on killing-out percentage, and on the weights and lengths of the gastrointestinal segments was analysed using the technique of analysis of covariance to correct for differences in slaughter weight, and to assist in the interpretation of the results. Performance factors (daily liveweight gain, feed intake, and feed conversion ratio) were analysed using the technique of analysis of variance.

4.2.4 RESULTS

A comparison of the chemical composition of the diets (Table 4.2.1) with the expected chemical composition derived from the formulations (Table 4.2.0) shows that there were two deviations from the formulations. AHF and crude fibre levels were both found to be higher than expected. This suggests that the crude fibre content of the wheatfeed used was underestimated in the formulation of the diets. The increased AHF level measured in the diets was only small and not considered significant.

PERFORMANCE FACTORS

The effects of wheatfeed inclusion level and the sex of the pig on food intake, daily liveweight gain and food conversion ratio are shown in Tables 4.2.2 to 4.2.7.

Feed Intake

Increasing the wheatfeed inclusion level from 100 to 300 g/kg did not significantly effect feed intake at 35 or 42 days from the start of the trial (Table 4.2.2). After 49 days, the pigs given the diet containing 100 g wheatfeed/kg showed a small but significantly ($P<0.05$) higher daily feed intake than those given the diet with 300 g wheatfeed/kg. This effect was due to the fact that the pigs on the 300 g wheatfeed/kg diet spent a longer time on the lower feed allowance since they grew at a slightly slower rate than those pigs fed the diet with a lower wheatfeed inclusion level. At bacon weight, however, the average daily feed intakes over the whole growth period for the two groups of pigs were not significantly different. The boars and gilts had very similar feed intakes over the whole of the experimental period (Table 4.2.3).

Table 4.2.1 **Chemical composition of the diets (g/kg)**

	WHEATFEED (g/kg)	
	100	300
DM	880	878
Oil	40.8	43.7
AHF	47.5	55.4
Protein	213.0	218.0
Crude Fibre	51.9	62.7
NDF	123.9	160.2
Ash	62.4	55.9
Salt	3.2	3.7
Mg	1.5	1.9
Cu (mg/kg)	97	89
Mn (mg/kg)	81	94
Zn (mg/kg)	164	154
Ca (mg/kg)	8.1	7.4
P (mg/kg)	6.8	7.8
Na	1.1	1.2
K	8.4	10.6
Starch	337.2	274.2
Sugar	98.0	84.0

Table 4.2.2 **The effect of wheatfeed level (WF) on feed intake (kg/day)**

		DAYS FROM START			
DIET	START WEIGHT (kg)	35	42	49	BACON; 87
100 g WF/kg	31.4	1.27	1.33	1.38	1.65
					BACON; 89
300 g WF/kg	30.2	1.25	1.30	1.36	1.64
SED (11 D.F.)		0.012	0.012	0.012	0.010
SIG		NS	NS	*	NS

Table 4.2.3 The effect of sex of pig on feed intake (kg/day)

		DAYS FROM START			
DIET	START WEIGHT (kg)	35	42	49	BACON; 86
BOAR	31.2	1.26	1.31	1.37	1.63
					BACON; 90
GILT	30.4	1.27	1.32	1.37	1.65
	SED (11 D.F.) 0.010		0.012	0.012	0.012
SIG		NS	NS	NS	NS

Daily Liveweight Gains

The pigs given the diet containing 300 g wheatfeed/kg were able to maintain the same daily liveweight gains as those given the diet with 100 g/kg (Table 4.2.4). No significant differences were found at 35, 42 or 49 days after the start of the trial, and the difference at slaughter in the mean daily liveweight gain (0.702 kg/day for 100 g/kg cf. 0.683 kg/day for 300 g/kg) was not found to be significant.

The sex of the pigs was found to be more important in determining the daily liveweight gains, as would be expected (Table 4.2.5). After 35 days the boars were gaining liveweight at a significantly higher rate ($P<0.05$) than the gilts. However, after 42 and 49 days the differences in liveweight gain were not significantly different. By the time the pigs reached bacon weight the boars showed a significantly ($P<0.01$) higher rate of daily gain than the gilts.

Table 4.2.4 The effect of wheatfeed level (WF) on daily liveweight gain (kg/day)

		DAYS FROM START			
DIET	START WEIGHT (kg)	35	42	49	BACON; 87
100 g WF/kg	31.4	0.509	0.541	0.577	0.702
					BACON; 89
300 g WF/kg	30.2	0.497	0.530	0.557	0.683
SED (11 D.F.)		0.0130	0.0121	0.0123	0.0091
SIG		NS	NS	NS	NS

Table 4.2.5 The effect of sex of pig on daily liveweight gain (kg/day)

		DAYS FROM START			
DIET	START WEIGHT (kg)	35	42	49	BACON; 86
BOAR	31.2	0.517	0.547	0.580	0.716
					BACON; 90
GILT	30.4	0.489	0.523	0.554	0.669
SED (11 D.F.)		0.0130	0.0121	0.0123	0.0091
SIG		*	NS	NS	**

Feed Conversion Ratio

Feed conversion ratios were not significantly affected by increasing levels of wheatfeed in the diet (Table 4.2.6). No significant differences could be found at any time during the trial period and at bacon weight the difference in mean FCR was not significant. There was a tendency for those pigs on the diet containing 300 g wheatfeed/kg to convert their feed into liveweight gain less efficiently than those receiving the diet with 100 g wheatfeed/kg.

As expected the boars were significantly (P<0.05) more efficient at converting their feed into liveweight gain than the gilts at all stages of the trial, except after 49 days from the start (Table 4.2.7). At this point the FCR obtained for the boars was still better than that of the gilts but not significantly so.

Table 4.2.6 The effect of wheatfeed level (WF) on Feed Conversion Ratio

DIET	START WEIGHT (kg)	DAYS FROM START			
		35	42	49	BACON; 87
100 g WF/kg	31.4	2.46	2.43	2.37	2.38
					BACON; 89
300 g WF/kg	30.2	2.49	2.43	2.41	2.42
SED (11 D.F.)		0.058	0.053	0.054	0.029
SIG		NS	NS	NS	NS

Table 4.2.7 The effect of sex of pig on feed conversion ratio

		DAYS FROM START			
DIET	START WEIGHT (kg)	35	42	49	BACON; 86
BOAR	31.2	2.40	2.37	2.33	2.30
					BACON; 90
GILT	30.4	2.55	2.49	2.45	2.51
SED (11 D.F.)		0.058	0.053	0.054	0.029
SIG		*	*	NS	*

Carcase Characteristics

The effects of wheatfeed level on carcase characteristics, growth rate and FCR are shown in Table 4.2.8. The slaughter weights of the two groups of pigs were not significantly different, but those given the diet with 100 g wheatfeed/kg were slightly heavier. As a consequence of this the statistical analysis of the measurements made on the carcase was carried out by analysis of covariance using slaughter weight as a co-variate to assist in the interpretation of the results. The mean carcase weight of the pigs fed the diet with 300 g wheatfeed/kg was significantly lighter than those given the diet with 100 g/kg. Since the slaughter weights were similar, and carcase weight was reduced by the addition of further wheatfeed to the diet, a significant reduction in killing-out percentage resulted. The pigs given 300 g wheatfeed/kg diet showed a killing-out percentage which was 1.2 percentage units lower than that obtained for pigs given 100 g wheatfeed/kg.

Table 4.2.8 The effect of wheatfeed level on carcass characteristics

	WHEATFEED LEVEL (g/kg) 100	300	SED (10 DF)	SIG
Slaughter Weight (kg)	90.2	89.2	0.906	NS
Deadweight (kg)	68.7	68.0	0.721	*
Killing-out (%)	76.3	75.1	0.454	*
P2 (mm)	13.5	12.1	0.405	**
Loin Fat (mm)	20.2	20.1	0.047	**
Shoulder Fat (mm)	40.5	40.3	0.275	NS
Length (mm)	785	793	7.0	NS
Carcase Growth Rate (kg/day)	0.531	0.508	0.0084	*
Carcase FCR	3.11	3.23	0.055	NS

Increasing the wheatfeed inclusion level of the diet from 100 to 300 g/kg lead to a significant reduction in mean P2 backfat depth of 1.4 mm which is equivalent to a reduction of 0.10. Loin fat was also significantly reduced ($P<0.05$) by increasing the wheatfeed content to 300 g/kg, but practically the magnitude of this difference was not considered significant. Shoulder fat depth was similar for both groups of pigs.

Carcase length, which is determined more by genotype than nutrition, was very similar for the pigs given the two diets.

Carcase growth rate was significantly ($P<0.05$) higher in the pigs given the diet containing 100 g wheatfeed/kg, in spite of showing similar liveweight gains to those fed the diet with 300 g wheatfeed/kg. Carcase FCR, although poorer for the pigs given the 300 g/kg wheatfeed diet, did not deteriorate significantly with increased wheatfeed level.

The effects of the sex of the pig on carcase characteristics are shown in Table 4.2.9. The boars tended to be slightly heavier than the gilts at slaughter but the difference in final weight was not significant. The mean carcase weight of the gilts was slightly higher than that for the boars, but the difference again was not significant. As a consequence of this, the killing-out percentage of the gilts was significantly higher ($P<0.05$) by approximately 1.5 percentage units, than that of the boars. P_2 backfat and shoulder fat depths were not significantly affected by the sex of the pigs, but loin fat was found to be significantly greater ($P<0.05$) in the gilts, although the magnitude of this difference, 0.3 mm, was not considered to be of practical importance.

Table 4.2.9 The effect of sex on carcase characteristics

	SEX			
	BOAR	GILT	SED (10 D.F.)	SIG
Slaughter Weight (kg)	90.6	88.9	0.906	NS
Deadweight (kg)	67.7	68.0	0.721	NS
Killing-out (%)	74.9	76.4	0.492	*
P2 (mm)	12.7	12.9	0.439	NS
Loin Fat (mm)	20.0	20.3	0.05	**
Shoulder Fat (mm)	40.2	40.6	0.30	NS
Length (mm)	792	785	7.60	NS
Carcase Growth Rate	0.458	0.450	0.0085	NS
Carcase FCR	3.57	3.68	0.075	NS

The carcase growth rates of the boars and gilts were found to be similar. The boars tended to convert their food into carcase gains more efficiently than the gilts, but the mean food conversion ratios obtained for the two sexes were not significantly different.

Measurements made on the Gastrointestinal tract

The mean values for the measurements made on the gastrointestinal tracts are summarised in Table 4.2.10. The pigs fed the diet containing a higher level of wheatfeed showed a significantly heavier (P<0.05) total weight of intestines (ie. small intestine + caecum + colon + rectum) than those on the lower wheatfeed diet. However, no significant differences in gut contents, or the weights and lengths of the individual segments were found.

Table 4.2.10 The effect of wheatfeed level on the weights and lengths of the gastrointestinal segments

	WHEATFEED (g/kg) 100	300	SED between means (5 D.F.)	SIG.
Slaughter weight (kg)	91.7	89		
†Killing-out (%)	74.99	73.29	0.864	NS
†Gut contents (kg)	5.44	5.37	0.618	NS
†Empty stomach (kg)	0.54	0.64	0.057	NS
†Empty large intestine (kg)	1.02	1.27	0.122	NS
†Empty caecum (kg)	0.12	0.45	0.282	NS
†Empty small intestine (kg)	1.45	1.54	0.100	NS
†Mesenteric fat (kg)	0.40	0.51	0.049	NS
#Total weight of intestines (kg)	2.62	2.97	0.112	*
†Length large intestine (m)	4.92	5.52	0.380	NS
†Length caecum (m)	0.25	0.30	0.027	NS
†Length small intestine (m)	21.10	19.70	2.50	NS
#Total length of intestines (m)	26.3	25.6	2.82	NS

†means and SEDs adjusted for covariate (slaughter wt.)
#Total = small intestine + caecum + colon + rectum;
*P<0.05

4.2.5 DISCUSSION

The pigs given the diet containing 300 g wheatfeed/kg maintained the same performance as those on the 100 g wheatfeed/kg diet but their killing-out percentage was adversely affected. Similar results have been found in other trials (Dalgety Agriculture Limited, unpublished). The decrease in killing-out percentage is likely to be a result of the physicochemical effects of the food fibre added to the diet in the form of wheatfeed. There are two possible ways in which these effects may result in a reduced killing-out percentage. Firstly, the weight of the contents of the gastrointestinal tract may be increased due to the water adsorbing properties of certain polysaccharides, and secondly, there may be some response of the small and large intestines to the ingestion of a diet containing a higher proportion of fibrous material producing a higher total weight of gastrointestinal tract.

It is conceivable that the weight of gut contents may be increased due to the water adsorbing properties of certain polysaccharides. However, no significant differences in gut contents could be found between the pigs given the different levels of wheatfeed. There are a number of factors which could have influenced the level of gut fill and caused discrepancies in its measurement.

As was mentioned in the discussion (Section 4.1.5) of Experiment 4.1 the physical treatment of a fibrous feedstuff can affect its water-holding capacity. Finely grinding the wheatfeed fed in this trial may in fact have minimised the water adsorbing potential, and therefore differences in gut fill between the two diets due to the retention of water, are likely to have been small and non-significant.

An analysis of the dietary fibre found in wheatfeed is also likely to be useful in revealing whether the material will have strong water adsorbing properties. Detailed below (Table 4.2.11) are the NDF, ADF, Lignin, cellulose and hemicellulose contents of wheatfeed as reported by MAFF (1986).

Table 4.2.11 The composition of the dietary fibre of wheatfeed (MAFF, 1986)

Component	g/kg DM
NDF	360
ADF	108
Hemicellulose	252
Cellulose	70
Lignin	38

This analysis shows that a fairly low proportion of the NDF fraction was composed of cellulose and lignin (0.3) and therefore, by difference, 0.7 of the NDF fraction is hemicellulosic. The main contributor of NDF to wheatfeed is likely to be wheat bran. As a consequence of this, the effects of wheatfeed fibre on the processes of absorption and digestion will, qualitatively, be very similar to those of wheat bran. However, wheatfeed will contain considerably more starch than wheat bran with the result that a higher proportion of wheatfeed will be digested anterior to the terminal ileum. In Chapter 2 (Experiment 2.1, Section 2.1.5), a detailed examination of the non-starch polysaccharides of wheat bran showed that only a small fraction was found to be soluble. Since the extent of polysaccharide fermentation is linked directly to its solubility, the fibre of wheat bran, and hence wheatfeed, would not be expected to be extensively fermented. A reasonable value to assume for the digestibility of the NDF fraction of wheatfeed is in the region of 0.45-0.50, very similar to that for wheat bran. It was also suggested in Chapter 2 that the extent to which the hemicellulose fraction swells may be limited if it is contained within an insoluble matrix of less hydrophilic substances such as lignin. At the most, 0.5 of the NDF of wheatfeed is likely to be digested, an insoluble matrix will persist in the gut, and the presence of indigestible residues in the gut may have some effect on bulk and transit times.

One of the effects of an increased bulk in the gastrointestinal tract is an increased rate of passage of digesta. If this was the situation in the pigs given the diet with a higher wheatfeed content, then the effects of an increase in gut contents due to increased water retention are likely to be counteracted by an increased rate of passage, and differences in gut contents would therefore not be expected to be detected.

Since slaughter losses appear to be increased with the feeding of diets high in dietary fibre it would be useful to know more about the effect of type and amount of fibre in the diet on gut fill. Jongbloed and Hoekstra (1985) carried out experiments to examine the effect of fibre type and amount on the gut fill of pigs grown from 30-110 kg. Three by-product diets containing up to 79 g CF/kg DM were compared with a cereal based diet containing 36 g CF/kg DM. During 5 periods of 21 days two diets were fed alternately and in the last two weeks of each period the animals were weighed on 5 consecutive days at 10.00 am. At the end of the experiment the animals were slaughtered, and the gut contents and empty gastrointestinal tracts weighed. The extra gut fill due to the by-product based diets, compared to the cereal diet, was estimated by regression analysis. An extra 40 g of crude fibre/kg DM resulted in an extra gut fill of between 1.0 and 1.4 kg. The empty wet weight of the gastrointestinal tract was hardly influenced by the diet.

The crude fibre contents of the two diets fed in this trial were 51.9 and 62.7 g/kg DM for the diets containing 100 and 300 g wheatfeed/kg, a difference of approximately 11 g/kg DM. Using the data of Jongbloed and Hoekstra (1985) an increase in CF content of this magnitude would produce an increase in gut fill in the range 0.25-0.35 kg which is probably too small to be detected by the methods used in this trial. However, the situation is likely to be more complicated and gut fill will almost certainly be dependent on diet composition and the source of fibre, as well as level. Secondly, the results of the trial suggested that there was some response of the small and large intestines to the ingestion of a diet i.e. containing a higher proportion of wheatfeed the total weight of the tract was higher, although increases in the weights and lengths of individual segments could not be identified. This is most likely to be due to a wide between pig variation and the relatively small number of tracts which were examined. Pekas (1986) found similar results in a trial with 10 pigs of each of two genotypes (obese v lean) which were fed on one of two diets; a conventional maize-soya bean diet and a diet containing 500 g alfalfa meal/kg formulated by replacing 0.5 units of ground limestone and 49.5 units of maize in the maize-soya bean diet with 50 units of alfalfa meal. The feed was available *ad libitum* until the pigs obtained 100 kg liveweight. The pigs were fasted for 24 to 30 hours, slaughtered and the viscera removed immediately. Although the average weight of virtually every organ measured (stomach, small intestine, large intestine (caecum, colon, rectum), pancreas, liver, heart, kidney and spleen) was heavier in the pigs of each genotype fed the alfalfa diet, only the weight of the colon-rectum and total gastrointestinal tract were significantly heavier. The most notable responses to dietary fibre were observed for the small intestine, colon-rectum and liver of the lean genotype pigs. The conclusion drawn from this work was that the gastrointestinal tract is responsive to the indigestible or poorly digestible components of the diet. Other workers have shown similar trends and have suggested morphological changes which may occur as a result of the ingestion of fibre. Stanogias and Pearce (1985) reported the tendency for an increased weight of gastrointestinal organs, particularly that of the colon in response to increased intakes of NDF by pigs. This report is consistent with the earlier work of Kass *et al.* (1980) and Pond *et al.* (1981), although Cunningham *et al.* (1961) and Gargallo and Zimmerman (1980) showed little or no change occurred in the gastrointestinal tract of pigs given diets containing increased levels of cellulose or sunflower hulls. The differences recorded could be due to a number of factors including the genotype of the pig (Pond *et al*, 1981), the individual variation among pigs in their ability to utilise fibre (King and Taverner, 1975), and also differences in the source and amount of fibre ingested.

The previous Chapters have shown that the pig is able to digest and utilise the products of fermentation of some sources of fibre to an appreciable extent. It is likely that if a pig could adapt to a form of digestion which would enable it to make more use of the energy from dietary fibre, then the segments of its gastrointestinal tract would increase in size and also weight.

Brown, Kelleher and Losowsky (1979) and Sakata (1988) have investigated the physical and chemical effects of dietary fibre on the intestines of rats. Brown *et al.* (1979) reported that the weight and length of the small intestine, caecum and colon were significantly greater in rats fed on a high fibre (pectin diet) than in those given the pelleted or fibre-free basal diet. Histiological examinations of the small intestine revealed that muscle layer thickness was greater in the pectin-fed rats, leading to increased weights of the small intestine, and probably caecum and colon.

Sakata (1988) reported that poorly fermented fibre (eg cellulose) tended to increase the weight of the non-mucosal part of the intestine, whereas readily fermentable fibre (eg. pectin) increased the mucosal mass. These effects might be due to a number of mechanisms including the physical effect of fibres such as mass or abrasion, and also the chemical effects of the products of hind gut fermentation. Consequently, trials were performed to try and separate the physical and chemical influences of dietary fibre using model experiments and observing the effects of a nonfermentable mass (kaolin) and short-chain fatty acids (SCFA; acetic, propionic and butryic acids) on the intestines of rats. Kaolin had little effect on the epithelial cell proliferation, with a slight increase in muscle tissue mass. In contrast to this, SCFA infused into the hind gut recovered the proliferative activity of the epithelium depressed by the absence of bacteria or dietary substrate. SCFA also stimulated the proliferation of the jejunal epithelium, a situation which is very similar to that found in the development of the rumen. The effect was seen to occur fairly rapidly, within 1-2 days of administration, and was dose dependent, in order of increasing activity acetic < propionic < butyric acid. From this it can be concluded that dietary fibre has at least two possible trophic effects on the intestinal tissue a) a physical effect on the muscle layers and b) an effect as a fermentation substrate to stimulate cell proliferation. It would seem likely that the increase in weight of the small and large intestines observed in this trial could reflect hypertrophy of the muscle layers in response to an increased amount of work of these particular segments in moving and expelling larger amounts of undigested residues. However, in the current trial the daily liveweight gain of the pigs on the diet with the higher wheatfeed inclusion level was only lowered slightly indicating that the energy yield from this diet was only slightly less than that from the diet where wheatfeed was included at a level of 100 g/kg. The undigested dietary residues from the diet containing 300 g wheatfeed/kg were, therefore, probably not much higher than those from the 100 g wheatfeed/kg diet. An examination of the ingredient formulations of the two diets (Table 4.2.0) reveals that the energy level in the diet containing 300 g wheatfeed/kg was maintained by an increased inclusion level of fat, and it may therefore be reasonable to suppose that the diet higher in wheatfeed produced a higher level of dietary residues, which in turn produced an increase in weight of the intestines as described above. Since the lengths of the small intestine and colon were only slightly affected by the level of wheatfeed in the diet, the increase in weight of these segments is most likely to have resulted from hypertrophy of the wall and an increase in diameter.

The trend in backfat depth changes exhibited in this trial i.e. an increasing wheatfeed inclusion level significantly reduced the P2 measurement, contrasts with that found in a previous trial (Dalgety Agriculture Limited, unpublished). The crude fibre levels measured in the diets fed in the current trial were found to be higher than expected. This could account for a slight reduction in the digestible energy value of the diet containing 300 g wheatfeed/kg when compared to the formulated level of digestible energy, although the magnitude of the increase above the expected value was similar for both diets. The following prediction equation (Morgan, Whittemore, Phillips and Crooks, 1987) was used to estimate the DE content of the two diets fed from their chemical composition;

$$\text{DE (MJ/kg DM)} = 17.468 + 0.157\ \text{OIL} + 0.078\ \text{CP} - 0.325\ \text{ASH} - 0.141\ \text{NDF}$$

The values obtained for the diets containing 100 and 300 g/wheatfeed were 13.9 and 13.8 MJ/kg (values expected from the formulations were 13.82 and 13.81 MJ/kg). It can therefore be concluded fairly confidently that, since the diets were equivalent in their DE content, there was a reduction in the utilisation of the apparently digested energy when the diet containing 300 g wheatfeed/kg was fed. The results suggest that the apparently digested energy of wheatfeed is used less efficiently than that of wheat and barley which it replaced in the formulation.

To summarise, growing pigs given a diet containing 300 g wheatfeed/kg were able to maintain the same performance as those given a diet with wheatfeed included at a level of 100 g/kg, but their killing-out percentage was reduced. No significant difference in gut contents could be found between a small sample of pigs given the two dietary treatments but the total weight of the small and large intestines was significantly higher in the pigs given the diet higher in wheatfeed, which could help to explain, at least in part, the reduced killing-out percentage of these pigs. The reduction in P2 backfat depth with increasing wheatfeed usage indicates that the efficiency of utilisation of the apparently digested energy of wheatfeed is less than that of the cereal components of the diet, in agreement with the work of Taylor and Fisher (1980), and confirming the results of Experiment 31 (Chapter 3).

5.0 DISCUSSION: IMPLICATIONS FOR THE FEEDING OF FIBROUS FOODS TO GROWING PIGS

If producers and feed compounders are to make greater use of relatively cheap, readily available fibrous materials to replace a proportion of the cereals in growing pig diets then detailed information on the following nutritional aspects is required;

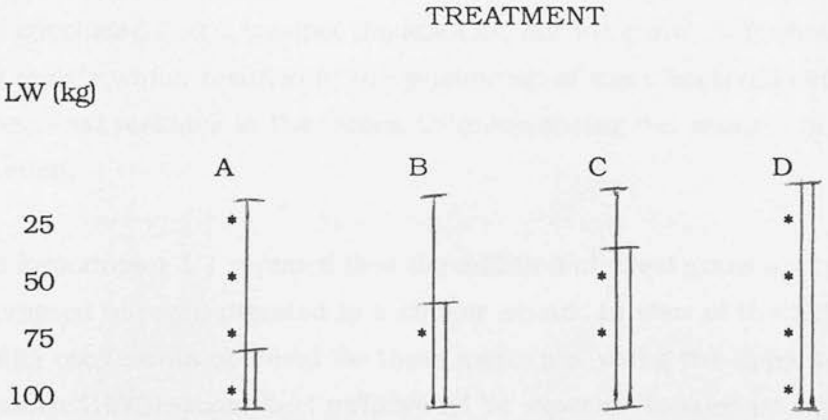
- the digestibility of various sources of fibre in pigs of different ages
- ways of minimising the depressing effect of fibre on the digestibility of other nutrients
- the effect of level of feeding of fibre on digestibility and methods of improving the digestibility of fibre
- the efficiency of utilisation of the products of fibre fermentation
- the suitability of readily available fibrous feedstuffs as dietary ingredients for growing pigs.

Measurements of nutrient digestibilities, growth rates and calorimetric studies have been used in a series of investigations, with different sources of fibre, which were designed to provide useful information for compounders to consider when including fibrous foods in rations for growing pigs. A discussion follows on the implications the results obtained have for the feeding of fibrous foods to growing pigs.

5.1 The digestibility of different sources of fibre in pigs of different ages

The adaptation of growing pigs in their ability to digest the ADF and NDF fractions of two different sources of fibre, unmolassed sugar-beet pulp and dried grass, over time was investigated in Chapter One. The magnitude of the improvement in fibre digestibility was largely dependent on the source of fibre: the ADF and NDF fractions of sugar-beet pulp were generally highly digestible and the improvement over time was proportionately less than that of the less degradable fractions of dried grass. At 92 kg liveweight the DE of sugar-beet pulp was 12.7 MJ/kg DM, and when compared to the potential DE of 14.1 MJ/kg DM (predicted from the ME value for ruminants), it can be concluded that there is only a small amount of scope for further improvement with liveweight. Conversely, the DE for dried grass was 7.14 MJ/kg DM compared to a potential DE of 13.0 MJ/kg DM, suggesting that there is the opportunity for further adaptation and that the ceiling was not reached in this investigation.

Whether the increase in digestibility was due to an increased period of feeding and/or increased liveweight is difficult to interpret from this trial since adaptation period and liveweight were not separated i.e. the diets were fed continuously between the liveweights of 37 and 92 kg. However, this is probably a fair representation of practical pig feeding since diets containing similar ingredients will be fed between the liveweights of 30 and 90 kg, and adaptation to these diets could therefore occur over this period. A further experiment which could be carried out to separate the effects of adaptation and liveweight, however, could be of advantage. Groups of pigs given a low-fibre basal diet could be progressively given a supplement of the fibre source as detailed below;



* digestibility measurement; basal diet; basal diet + fibre source.

In this way, digestibility measurements will be made in pigs of the same age that have been fed a fibre source for differing periods of time enabling conclusions to be drawn about the effects of bodyweight and adaptation time on the digestibility of fibre. An examination of the microbial population in the hind gut after different periods of feeding would also be useful in terms of observing the response of the microflora to the ingestion of diets containing fibrous materials.

5.2 Minimising the depressing effect of fibre on the digestibility of other nutrients

5.2.0 Depressing effect of fibre on nutrient digestibilities

The digestibility studies which formed an integral part of the investigations reported in Chapters One, Two and Three indicate an inverse relationship between the addition of fibre to a low-fibre basal diet and the digestibility of nitrogen and energy. The depressive effect of increased intakes of dietary fibre on the apparent digestibilities of nitrogen and energy are likely to be the result of a number of factors including 1) an increased rate of passage through the alimentary tract, 2) an increased excretion of metabolic and microbial nitrogen, 3) a low availability of nitrogen and other nutrients in the fibre and 4) the increased excretion of N and other nutrients bound or physically entrapped in the fibrous digesta. The source and amount of dietary fibre fed has been shown by Whiting and Bezeau (1957) to affect quite considerably metabolic nitrogen excretion. However, Mason and Palmer (1973) concluded that it was not the amount, but the extent of fermentation of dietary dry matter which resulted in the production of more bacterial cells and hence more bacterial residues in the faeces, thus increasing the amount of faecal nitrogen excretion.

The results of Experiment 1.1 revealed that the addition of dried grass and sugar-beet pulp depressed nitrogen digested to a similar extent. In view of the NDF and ADF digestibility coefficients obtained for these materials, using the hypothesis of Mason and Palmer (1973), sugar-beet pulp would be expected to support a greater microbial metabolism and would therefore be expected to cause a greater reduction in nitrogen, and energy digestibility. While the reduction in nitrogen digestibility brought about by the inclusion of soya-bean hulls, lupin hulls and wheat bran observed by Stanogias and Pearce (1985) supported the view of Mason and Palmer (1973), the reduction caused by the inclusion of less-digestible lucerne stems as compared to the other sources of fibre mentioned, and dried grass in Experiment 1.1 suggest that factors other than the digestibility of fibre e.g. the protein content of the fibre are also important. The crude protein contents (g/kg DM) of the dried grass and beet pulp fed in this trial were 178 and 91 respectively. The less-digestible lucerne stems fed by Stanogias and Pearce (1985) contained 149 g/kg DM crude protein compared to 100, 25 and 138 for soya-bean hulls, lupin hulls and wheat bran. The increase in bacterial nitrogen output relative to that of undigested feedstuff will determine the effect on the overall nitrogen digestibility. It appears that highly digestible fibre sources lead to an increased microbial nitrogen output and a low output of nitrogen from the fibre source. Conversely, it is conceivable that less degradable fibre sources produce a lower microbial output of nitrogen but a higher output of nitrogen from the fibre source. Therefore, it is possible that overall nitrogen digestibility can be similar for fibre sources with differing digestibilities.

5.2.1 Addition of fat

The DE values of fibrous materials tend to be lower than those of cereals which they may replace in a ration e.g. in Experiment 3.1 (Chapter 3) sugar-beet pulp was shown to have a DE of 12.4 MJ/kg DM as compared to 15.9 for maize. The inclusion of a fibrous food in a diet will therefore have the effect of diluting the energy concentration so that compensatory amounts of high energy materials, such as oil or fat will need to be added in order to maintain energy, and hence pig performance levels. The inverse relationship between fibre level and energy digestibility described above will reduce the availability of dietary energy to the pig still further, emphasising the need for supplementation with oil/fat.

Experiment 2.1 (Chapter Two) investigated the interactions of fat and fibre in the diet, and their effects on nutrient digestibilities, nitrogen retention and excretion. Wheat bran was added to the diet as a source of fibre, and maize oil and tallow as sources of unsaturated and saturated fatty-acids respectively.

Increasing the level of added wheat bran from 80 g/day to 320 g/day did not significantly depress the digestibility of the AHF fraction of the diet or the maize oil and tallow, but the addition of fat in particular, the unsaturated maize oil, caused a reduction in ADF digestibility at the highest fat:bran ratio. When the digestibilities measured for maize oil (0.921) and tallow (0.856) were compared to other values in the literature, there was, however, evidence to suggest that some depression in digestibility had occurred by adding wheat bran to the diet.

It seems that by maintaining the fat at a constant level, and increasing the level of fibre, the digestibility of the fibre will be maximised. However this will result in a lowering of the DE of the diet and will produce negative effects on the digestibility of nitrogen, AHF and energy, which will lead to a depression in animal performance. However, the inverse relationship established between the addition of food fibre to a diet and the digestibility of energy of the diet was not evident in Experiment 4.1 (Chapter 4), where fat (Frank Fehr 310; see Table 4.1.1) was added to the diet in increasing quantities as the level of the wheatfeed increased, in order to maintain the DE content of the diet. In this situation there does not appear to have been a significant adverse effect of fat/fibre interactions on the digestibility of energy and DE value of the diet, since pigs on the different diets showed similar performance. However, it is likely that the levels of wheatfeed included in the diet may have been low enough to prevent a significant depression of fat digestibility. In addition, the contribution the wheatfeed made to the total DE of the diet was probably insufficient to allow the detection of any changes.

5.3 Effect of level of feeding of fibre on digestibility and methods of improving the digestibility

5.3.0 Effect of level of feeding of fibre on fibre digestibility

In Chapters 2 and 3, where the digestibility of the NDF and ADF fractions of wheat bran and unmolassed sugar-beet pulp were measured by difference at different levels of addition to the diet, the amount added was unimportant in determining the digestibility of these fractions. No significant differences or linear relationships could be identified between NDF or ADF coefficients and their level of addition.

Some uncertainty exists on this subject. The work of Stanogias and Pearce (1985), with a wide range of fibrous materials, also failed to illustrate a consistent effect of the level of NDF intake on the apparent digestibility of NDF. This agrees with the findings of Keys, Van Soest and Young (1970) and Farrell (1973) who found that the digestibility of cellulose by pigs was constant irrespective of the level of inclusion. The extent of fibre digestibility therefore seems predominantly dependent on its source, and the amount of fibre in the diet seems relatively unimportant.

5.3.1 Effect of crude protein level on fibre digestibility

In the ruminant, the fermentation of fibre is dependent not only on a supply of fermentable carbohydrate but also on a supply of degradable protein. A similar situation might be expected when there is substantial fermentative digestion of carbohydrate in the hind gut of the pig. Experiment 2.2 (Chapter 2) investigated the digestion of the NDF and ADF fractions of sugar-beet pulp when fed with basal diets considered inadequate and over-adequate in crude protein.

The level of crude protein in the diet was important in determining the extent to which NDF was digested; when the beet pulp was fed with a diet containing 240 g crude protein/kg DM the digestibility of the NDF fraction was significantly higher than when fed with a diet containing 140 g crude protein/kg DM. The addition of a fibrous food to a low fibre diet has the effect of shifting the site of digestion so that a greater proportion occurs by fermentation in the large intestine. The digestion of protein and amino acids in the hind gut of the pig, appears to confer benefit to the microflora only; nitrogen absorbed from the large intestine has been shown to be rapidly and completely excreted in the urine, (Zebrowska *et al.*, 1978). This might be considered beneficial in terms of fibre degradation and energy supply, but the DE value of the diet and beet pulp was not in fact increased by the higher crude protein diet, probably due to an increased output of microbial matter in the faeces. The feeding of high protein diets in order to benefit only the gastrointestinal microflora, and hence fibre digestibility is therefore highly questionable.

Experiment 2.2 relied on the assumption that the extra crude protein fed resulted in a greater flow of undigested protein/amino acids into the hind gut, the main site of microbial digestion. To test whether crude protein level does influence microbial activity and hence fibre digestibility, an extra supply of nitrogen to the hind gut must be ensured. A further experiment could compare the digestibility of the fibrous fraction of sugar-beet pulp when fed with casein, which is almost entirely digested in the small intestine, or meat and bone meal, a portion of which is known to be degraded in the large intestine.

5.3.2 Processing of fibrous materials: Grinding and pelleting

The benefits of processing, by chopping, pelleting or various chemical treatments, fibrous roughages for ruminants have long been recognised with regard to feed intake, and a reduction in the work of digestion, although throughput can be increased with the result of depressed digestibility.

Pig rations are usually fed finely ground in the form of a meal or pellets. This may have the effect of reducing the amount of work needed to move fibrous digesta through the tract, but the digestibility of the fibre may be reduced. Fine grinding has been shown to adversely effect the water adsorbing properties of fibre and hence hydratability and fermentability (Van Soest, 1985).

Unmolassed sugar-beet pulp was fed in three different forms during the course of this work; dried, shredded (Experiment 1.1, Chapter 1; Experiment 2.2, Chapter 2); dried and ground (Experiment 3.2, Chapter 3); and dried, ground and pelleted in Experiment 3.1 (Chapter 3).

An examination of the digestibilities of the NDF fractions of these three forms and their energy values may reveal whether grinding and/or pelleting is detrimental or beneficial to the digestion of unmolassed beet pulp. The level of protein in the diet must also be considered as it has been shown to be an important factor in determining fibre digestibility.

Table 5.3.0 The effect of grinding, and grinding and pelleting on the digestibility of the NDF of sugar-beet pulp

Experiment	Form	Protein (g/kg DM)	NDF Digestibility
1.1; 2.2	Shredded	230	0.783
		140	0.697
		240	0.874
3.2	Ground	175	0.818
3.1	Ground and Pelleted into whole diet	220	0.735

Table 5.3.0 is difficult to interpret since these trials were not designed specifically to test the effects of grinding and/or pelleting on fibre digestibility and energy

values. However, grinding and/or pelleting does not appear to confer any particular benefit or adverse effect on fibre digestibility. The diet fed in Experiment 1.1 has a similar protein content to that of Experiment 3.1, yet digestibility of the NDF fraction of the shredded and ground and pelleted beet pulp was similar. Feeding the beet pulp ground but unpelleted (Experiment 3.2) gave a digestibility coefficient which was higher than that obtained with crude protein levels well above 175 g/kg.

5.4 Efficiency of utilisation of the products of fibre fermentation

5.4.0 Carcase growth promoting properties of fermented energy

The results of the growth trial and digestibility studies reported in Chapter 3 (Experiment 3.1) showed that the energy produced by the fermentation of sugar-beet pulp can be utilised for carcase growth by the growing pig with an efficiency of 0.72 relative to that produced by the enzymic digestion of maize. The apparently digested energy arising from the fermentation of polysaccharides, therefore, does not correspond directly, in terms of potential use to the animal, with that obtained from the enzymic digestion of maize starch. This is due in part to some of the apparently absorbed energy being lost as heat of fermentation, and a further amount as methane, and suggests that products of digestion have different metabolic values. Müller (1984), Hoffmann and Schiemann (1986), van der Honing (1986), and this current trial have all reported values which are higher than the results of ARC (1981). Two hypotheses were put forward by van der Honing (1986) which could result in an increased utilisation of fermented energy over that predicted by ARC (1981). It was suggested that the fermentation of carbohydrates to lactic acid rather than VFA could result in a better utilisation of fermented energy, but further work is needed to estimate the amounts of lactate produced and absorbed in growing pigs. The incorporation of VFA into body fat is a more efficient process than as a source of ATP, and this is an alternative suggestion which could explain this higher than predicted utilisation of fermented energy. Results of work carried out by Latymer and Low (1984) showed that substantial portion of acetate was retained in the carcase, mainly as subcutaneous fat and *in vitro* studies using tissues from various parts of the pig showed that the rate of incorporation was highest in adipose tissue. The carbon/nitrogen balance, the results of which were detailed in Chapter 3 (Experiment 3.2), also suggested that all of the extra energy retained, when beet pulp was fed in addition to the low-fibre basal diet, was as fat, and not as protein and fat. However, since the intake of nitrogen was limiting protein deposition, a further trial feeding different levels of protein, would provide further information on the fate of the energy from the fermentation of beet pulp.

5.4.1 Methane production by growing pigs fed fibrous foods

ARC (1981) reviewed work which estimated the loss of apparently digested energy as methane when fermentation occurs, and values ranging from 0.18 DE (Hungate, 1966) to 0.08-0.11 DE (Ørskov *et al.*, 1975) were reported for ruminants.

Methane production in the hind gut of growing pigs amounts to only a few litres daily and has been shown to represent a loss of 0.0055 (conventional diet) and 0.011 (for a sugar-beet pulp supplemented diet) of the gross energy intake of the whole diet (Chapter 3, Experiment 3.2, 3.2.4). Fuller and Boyne (1977) also showed losses as methane to be very small on conventional diets and values in the range 0.002-0.01 were reported by Verstegen (1971), Hoffmann *et al.* (1977), Jentsch and Hoffmann (1977) and van der Honing *et al* (1982). The proportion of the fermented DE of sugar-beet pulp lost as methane calculated in Chapter 3 (Experiment 3.2, Section 3.2.5) was 0.022, which suggests that the value reported by ARC (1981) of 0.10 grossly overestimates the fermented energy lost as methane by growing pigs.

Generally, methane production is not taken into consideration when estimating the feeding value of foods for pigs. It was considered conceivable that for pigs given diets containing relatively high proportions of fermentable carbohydrate, energy losses as methane could become significant. However, the results of Experiment 3.2 and those of other workers, show that this loss of energy is too small to influence significantly the accuracy of the measurement of feeding values of foods for pigs.

5.4.2 Metabolic efficiency of VFA

The values measured in Chapter 3 (Experiments 3.1 and 3.2) for the energy loss as methane (0.022) of DE and the utilisation of fermented DE relative to glucose (0.72) were combined with the value for energy loss as heat of fermentation (0.06, ARC (1981)) to calculate a value for the metabolic efficiency of VFA relative to glucose. The value obtained was 0.78, which compares well with the value of 0.80 suggested by the ARC (1981).

5.4.3 The concept of corrected digestible energy (DEc) and ration formulation

Existing energy systems imply that the sources of energy from a diet are carbohydrate, fat and protein, and that these are absorbed anterior to the terminal ileum. This ignores VFA production by fermentation in the hind gut. However, several workers have shown that VFA may contribute significantly to the energy economy of pigs given diets containing fibrous materials (Table 3.1.0, Chapter 3), or diets containing materials which are not digested conventionally in the duodenum and ileum (e.g. raw potato starch). While organic matter disappearing anywhere in the intestine will be recorded by balance trials as apparently digestible and metabolisable, the VFA will not be used as efficiently as the glucose end-products of conventional carbohydrate digestion and energy lost as heat and methane will not be recorded. This is not significant with conventional diets, but when diets containing fibrous materials were fed, substantial fermentative digestion can occur and a greater proportion of the energy supplied to the animal will be in the form of VFA. It may, therefore, be necessary to use a corrected digestible energy value (DE_C) to account for the lower metabolic efficiency of VFA, and improve the accuracy of formulating diets containing fibrous materials.

The Rowett Research Institute (1983) produced an equation for calculating the DE_C of a particular food;

$$DE_C = a\,(b + d\,(c-b))$$

where a = gross energy
b = coefficient of apparent digestibility of energy at terminal ileum
c = coefficient of apparent digestibility of energy over whole gut
d = efficiency of utilisation of fermented energy.

A DE_C value for unmolassed sugar-beet pulp can be calculated using values from Chapter 3. The gross energy intake of unmolassed sugar-beet pulp was 7.32 MJ. The only portion of unmolassed sugar-beet pulp assumed to be digested anterior to the terminal ileum was water-soluble carbohydrate, calculated to represent 0.42 MJ. The coefficient of apparent digestibility of energy at the terminal ileum is therefore 0.057. The mean coefficient of apparent digestibility of energy over whole gut in Experiment 3.2 was 0.670, and the efficiency of utilisation of fermented energy 0.72 (Experiment 3.1). The DE_C for unmolassed sugar-beet pulp is therefore;

$$DE_C = 16.31\ (0.057 + 0.72\ (0.670 - 0.057)\ )$$
$$= 7.77\ MJ/kg\ DM$$

The effectiveness of least-cost diet formulation is dependent on an accurate knowledge of the energy content and chemical composition of the ingredients available for inclusion. For fibrous feeds, such as sugar-beet pulp, the use of DE_C could improve the accuracy of diet formulation.

5.5 An evaluation of fibrous feeds as useful dietary ingredients for growing pigs

5.5.0 Use of fibrous foods in the diets of young pigs

From information in the literature reviewed in Chapter 4, it was apparent that different types of dietary fibre influence voluntary intake in different ways. Although pigs might be expected to increase their intake to compensate for a lowered DE content, caused by the presence of relatively indigestible fibre, the reverse effect was seen to occur in some instances. Compensation does not always appear complete and it has been suggested (Forbes, 1986), that eating to bulk may have superceded the physiological control of food intake, due to changes in genotype. In young animals, stomach distension could be the most important limit to food intake. This will produce adverse effects on growth rate during a period when the potential for rapid growth is high and should be exploited.

The inclusion of wheatfeed, a fibrous by-product of the milling industry, at levels of up to 150 g/kg in the diets of pigs aged 5-9 weeks had no significant adverse effect on food intake, growth rate or food conversion. However, there was a slight tendency for feed intake to increase and food conversion ratio to deteriorate at this rate of wheatfeed inclusion, particularly during the 7-9 week age period.

The conclusion which may be drawn from this feeding trial is that the bulking effect of wheatfeed is not sufficient to act as a limit for voluntary food intake in young pigs at inclusion levels up to 150 g/kg. Wheatfeed, might therefore be considered an acceptable ingredient for young pig diets when ground and fed in the form of a pellet. The use of wheatfeed, could result in a saving in the cost of production of diets for pigs of this age, because highly digestible, relatively expensive ingredients are usually included.

G.G. Partridge (personal communication) has examined the effects on performance of including wheat bran (150 and 300 g/kg) and unmolassed sugar-beet pulp (100 and 200 g/kg) in the diets of 3 week-old pigs. Feed intake remained unchanged while daily liveweight gain and food conversion ratio both deteriorated with the addition of both wheat bran and sugar-beet pulp.

Since the diets fed in Experiment 4.1, and those fed in Partridge's work were formulated to be equivalent in DE, the deterioration in FCR suggests that the energy produced by the fermentative digestion of wheatfeed, wheatbran and sugar-beet pulp was used with an efficiency lower than that from the digestion of the cereals they replaced in the diet.

5.5.1 The use of fibrous foods in the diets of growing/finishing pigs (30-90 kg)

Wheatfeed, was used in a growth trial (Experiment 4.2, Chapter 4), which examined the effect of level of inclusion on daily liveweight gain and feed conversion. The ability of a fibrous material to maintain rapid growth must also be concomitant with producing a carcass of acceptable quality. Hence, this trial also examined the effect of wheatfeed inclusion level on killing-out percentage, P2, shoulder and loin fat thickness.

Pigs given a diet containing 300 g wheatfeed/kg were able to maintain the same performance as those given a diet with 100 g/kg, but their killing-out percentage was adversely affected. It was concluded that losses on slaughter occurred as a result of the physicochemical effects of food fibre. The weight of the gut contents will be increased by the adsorption of water and as a result of an increased bulk there may be some hypertrophy of the intestines resulting in a higher total wet weight of the gastrointestinal tract. However, the gut contents of pigs given the diets with the two wheatfeed levels were similar, although there was some evidence of hypertrophy of the intestines in the pigs fed the diet with the higher wheatfeed inclusion level. This increase in weight will be due to increases in the mucosal and/or non-mucosal layers of the intestines, largely determined by the fermentability of the fibre. Poorly digested fibre eg. cellulose tends to increase the weight of the non-mucosal part of the intestine eg. muscle, while readily fermentable fibre increases mucosal mass (Sakata, 1988). The same author suggested that these effects might be due to a number of mechanisms including the physical effects of fibres such as mass and abrasion, and also the chemical effects of the products of hind-gut fermentation.

In terms of carcase quality, P2 backfat measurements (which act as good indicators of the energy supply to the pig) were reduced by increasing wheatfeed inclusion, thus indicating a reduction in the effective DE of the diet. This may be beneficial in the light of the current tight grading standards.

A factor, other than the fibre content of the diet, which will influence the performance of pigs given diets containing high levels of wheatfeed, is the availability of the nitrogen in the wheatfeed. Data from Lin *et al.* (1987) indicate that there are differences in the apparent digestibility of amino acids between wheat and wheatfeed, and that wheatfeed protein is not as readily degraded by the intestinal microflora as the non-protein fraction. This information implicates the use of ideal digestibilities of amino acids for the formulation of diets where a considerable amount of fermentative digestion occurs, to aid in the accuracy of formulations. However, the content of limiting amino acids in cereals and cereal by-products is low and therefore the degree of improvement in the formulation is only likely to be small, but they do contribute a significant amount to the diet. The digestibility studies of Chapters One, Two and Three have shown that the addition of fibre to a diet often reduces the digestibility of nitrogen i.e. it increases the nitrogen output in the faeces, but this may be countered by a reduced nitrogen output in the urine producing little overall effect on nitrogen balance. The results of Experiments 1.1, 2.1, 2.2, 3.1 and 3.2 show the relative responses of faecal and urinary nitrogen excretion to an increased intake of fibre to be variable. Malmlöf and Hakansson (1984) concluded that dietary fibre suppressed the liberation of ammonia into the colon by promoting the activity of the microflora, and reducing urinary nitrogen excretion. They also proposed that the increase in nitrogen retention of pigs given high-fibre diets was due to a greater effectiveness of internal nitrogen metabolism. It could be that the removal of nitrogen waste products via the faeces and a suppression of the flow of ammonia reduces the loading on nitrogen metabolism and increases retention through greater efficiency.

ileal

In cases where nitrogen retention is increased with the addition of fibre, the results of the measurements on the gastrointestinal tracts reveal that part or all of this increase could be due to deposition in the gut wall, leaving protein deposition in the carcase unchanged.

5.6 A consideration of non-nutritional aspects of feeding fibrous foods

As well as considering the nutritional aspects of feeding fibrous foods, there are also a number of non-nutritional factors which will influence the feeding of fibrous materials in practice.

5.6.1 Behaviour

Many of the effects of fibrous foods on the behaviour of pigs result from the greater intakes necessary to meet the animal's nutrient requirements for growth, development and reproduction. A greater food intake increases gut fill and can reduce retention time in the gastrointestinal tract. This may result in a more satiated, less excitable animal and have important implications for the welfare of the animal. With increasing public interest in welfare, any means of improving the general well-being of pigs is likely to be welcomed. Many behavioural studies have been carried out with sows, and generally activity has been reduced. If this were also true for growing pigs, a reduction in activity could result in a lower energy expenditure, and at similar levels of energy intake, may promote a higher rate of nutrient retention and body gain, assuming the rate of passage of digesta and heat increment are unchanged.

5.6.2 Health and disease in growing pigs and piglets

The prevalence of *E. coli* infections, gastric ulcers, and more recently non-specific colitis has increased dramatically over the past 20 years with the intensification of pig production systems, and the tendency towards increasing nutrient densities in the diet. The aetiology of these disorders is not clear, but two factors likely to be involved are nutrition and stress.

Gastric ulcers are found to occur frequently in pigs and are a cause for concern by virtue of the loss of production which results (Lawrence, 1984). One of the predisposing factors is thought to be the particle size of the diet, in particular the cereal component. Numerous reports implicate small particle size in the development of gastric ulcers (Mahan, Pickett, Perry, Curtin, Featherstone and Beeson, 1966; Reese, Muggenberg, Kowalcyk, Grummer and Hockstra, 1977; Kelly and Blackshaw, 1980). The addition of fibrous materials can help in this context through effects on the gut environment. Changes in the rate of passage, gastric pH, and dry matter content of the digesta obtained appear dependent upon the source of fibre and its physical form in the diet. Recent evidence from Rainbird and Low (1986) suggests that the soluble fraction of the fibre is important since this leads to a reduction in acid secretion in the stomach of pigs. This is likely to be just one of a number of factors involved in the formation of gastric ulcers.

The role of dietary fibre in the diet of young pigs has been little studied, but beneficial effects of fibrous diets on the health of young pigs has been clearly demonstrated in relation to bacterial activity and gastroenteritis. Smith and Halls (1968), following studies on the aetiology and occurrence of oedema disease in young pigs, caused by certain types of *E. coli*, suggested that as the fibre was largely indigestible, a possible mode of action in preventing the disease from occurring, was its ability to influence the secretory or absorptive function of the epithelium, both of which are implicated in bacterial adhesion. Drochner *et al.* (1978) also suggested that crude fibre (especially lignin) in the diet could depress bacterial activity in the gut of the young pig. More recently studies by Ball and Aherne (1982) showed that although there was little difference in the growth rate of animals fed diets differing only in their crude fibre content (28 g/kg cf. 43 g/kg), the number of animals affected, and the length and severity of attacks of diarrhoea were reduced in the pigs fed the higher fibre diet.

Lawrence (1970, 1972) suggested that certain bacteria may be depressed by feeding coarsely-ground or high-fibre diets, and that this could be associated with a decrease in gastric pH, a change in transit time and faecal dry matter, and also variations in both bile secretion and VFA production.

Manipulating the environment of the stomach and intestines therefore appears important in minimising infection and enhancing rapid growth in the young, weaned pig when it is susceptible to nutritional, environmental and husbandry practices.

Diets fed at this stage in the life of the young pig must combine such potential benefits of fibre with high digestibility, in order to exploit the young pig's capacity for rapid growth. Sources of highly digestible fibre, which could contribute significantly to the energy economy of the pig, may not produce the beneficial effects of relatively indigestible fibre reported by Smith and Halls (1968) and Drochner *et al.* (1978) although they may confer other benefits such as the maintenance of a normal gastrointestinal microflora and act as buffering agents through cation exchange (McBurney *et al.*, 1983; Van Soest *et al.*, 1984).

5.6.3 Climatic considerations

Fibrous foods are generally considered to have a higher heat increment as a result of the extra work required for their digestion and metabolism. The utilisation of fibrous foods may, therefore, produce important thermoregulatory effects. The additional heat produced may be used to substitute for some of the extra heat required by an animal in a cold environment. In this situation fibrous foods might be utilised more efficiently and promote a higher rate of gain. Stahly (1982), and Stahly and Cromwell (1979) demonstrated these effects with pigs fed diets to which either fibre or fat (which results in low thermal increments) were added, and fed under cold and hot conditions. The heat increment of the fibrous component was more efficiently utilised by the cold-stressed pigs, whereas the addition of fat was more beneficial under hot conditions.

It has not been established whether all fibrous ingredients behave similarly since they vary greatly in their digestibilities and heat increments. However, the results of the calorimetric studies reported in Chapter Three (Experiment 3.2) failed to show an increase in heat output when sugar-beet pulp was added to a low-fibre basal diet. Longland *et al.* (1988) obtained similar results when feeding similar diets.

5.6.4 Other considerations

A number of factors, other than those described above will also influence the usage of fibrous materials, including their cost and availability. Throughout the course of this work changes in the consistency of the faeces of pigs given high fibre diets have been noted. For example, the pigs given the control diet in Experiment 3.2

(Chapter 3) produced faeces with a dry matter of 314 g/kg, as compared to 239 g/kg when this diet was supplemented with sugar-beet pulp. This kind of change can be alarming to farmers and determine their choice of feed. Thus feed compounders should be aware of such effects. It seems, therefore, that producer preference will be important in determining the extent of the use of fibrous feedstuffs. Despite frequent demands for cheaper foods, UK producers are very anxious about what goes into their diets.

Wheatfeed and sugar-beet pulp may be useful dietary ingredients for growing pigs. The inclusion of these materials in the diets of young weaned and growing pigs has shown that rapid growth can be achieved, and that a substantial part of the energy is supplied in the form of VFA produced by the fermentation of the non-starch polysaccharide in the beet pulp and wheatfeed. Growth rates may be slightly depressed by the inclusion of fibrous materials such as these and this could lead to on farm problems associated with a decreased throughput eg overstocking. The reduction in carcase value due to a reduction in killing-out percentage was however outweighed by the increase resulting from a lower P2 backfat thickness, important with the current tight grading standards. The use of a corrected digestible energy value and ileal digestibilities of amino acids for fibrous materials when formulating diets could lead to an improvement in the prediction of performance.

5.6.5 Limitations of the techniques used and their implications for future work.

Definition of dietary fibre and its determination

The acid and neutral detergent fibre methods used together for the analysis of dietary fibre in this work had the advantage of being simple and rapid, and the main problem of starch retention was solved by employing a method which involved the addition of an α-amylase. However, their disadvantage was the loss of soluble components such as pectin, of particular significance in the estimation of the dietary fibre content of unmolassed sugar beet pulp where losses amounted to approximately 200 g/kg DM. The use of NDF to describe the fibre of dried grass and wheat bran did not result in such a serious underestimation of the total dietary fibre, since soluble components contribute a relatively low proportion to the dietary fibre of these materials.

Despite the fact that the detergent methods continue to have value in practical pig nutrition for the prediction of DE it seems that in future work the use of a more detailed method of dietary fibre determination would be of value to obtain a more accurate estimation and description of total dietary fibre. The method of Englyst *et al* (1982) is in wide usage by several groups of workers but it is extremely time consuming and costly. It would appear that efforts are currently being made by Englyst and his co-workers (A.G. Low, personal communication) to develop a rapid method for the accurate determination of dietary fibre.

Digestibility measurements

The digestibility measurements made throughout the course of this work were overall, or faecal, digestibilities which provide information on the total effect of enzymic and microbial digestion. In Section 1.0 (Chapter One) the way in which many types of dietary fibre may influence the digestion, absorption and metabolism of all nutrient types in the various gut segments were discussed. The shift in digestion which occurs in response to the ingestion of high-fibre diets, so that a greater proportion of digestion occurs in the hind gut by microbial activity, has implications for the measurement of faecal digestibility. Micro-organisms are both catabolic and anabolic, and only the net effect of their activity will be recorded in the faeces. To obtain a clearer picture of the extent of breakdown of fibre, and the effect of fibre on the digestibility of other nutrients in different gut segments, it would be necessary to use animals cannulated at the terminal ileum for the measurement of actual digestibilities. If such animals had been available during the course of this work, measurements of the flow of total lipid and nitrogen into the hind gut would have enabled firmer conclusions to be drawn about the interaction between fibre and both lipid and protein at the end of Experiments 2.1 and 2.2 respectively. The measurement of ileal digestibilities in any future work would therefore be of prime importance. In Chapter Four it was also suggested that the use of ileal digestibilities when formulating diets containing high levels of fibrous materials would lead to a more accurate prediction of pig performance, which should also be considered in future work.

Use of metabolism crates

The housing of animals in metabolism crates allows for the accurate collection of faeces and urine, and enables the calculation of digestibility and nitrogen retention data. However, movement is severely restricted and the pig is unable to exhibit its normal behaviour. It is conceivable that stressing an animal in this way could interfere with the digestive processes and confound digestibility measurements. Where the calculation of digestibility is required in future, it might be interesting to study the feasibility of using a suitable marker, eg. chromic oxide, thus enabling the pigs to be housed in a larger, less restrictive environment. The main disadvantage of using this method is that urinary losses of nitrogen and energy cannot be quantified, and as a consequence, nitrogen retention and the metabolisable energy of the diet cannot be calculated.

REFERENCES

ADOLPH, E.F. (1947) Urges to eat and drink in rats. American Journal of Physiology, **151**: 110-125.

AGRICULTURAL DEVELOPMENT AND ADVISORY SERVICE (1986) Feeding stuffs for pigs. MAFF Publications. P3060 HMSO, Alnwick.

AGRICULTURAL RESEARCH COUNCIL (1967) In 'The Nutrient Requirements of Farm Livestock'. Agricultural Research Council, London: 56-63.

AGRICULTURAL RESEARCH COUNCIL (1981). In 'The Nutrient Requirements of Pigs'. Commonwealth Agricultural Bureaux, Farnham Royal: 41-44.

ALBERS, N. & HENKEL, H. (1979) Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde, 42: 113-121, cited from Low, A.G. (1985).

ALLISON, M.J., ROBINSON, I.M., BUCKLIN, J.A. & BOOTH, G.D. (1979) Comparison of bacterial populations of the pig cecum and colon based upon enumeration with specific energy sources. Applied & Environmental Microbiology **37**: 1142-1151.

ANDERSON, D.M. & NORTHROP, A.J. (1973) The dirunal variation in volatile fatty acid concentration in portal and atrial plasma in pigs. Proceedings of the Nutrition Society, **32**: 37A.

ANDREWS, R.J. (1966) The utilization of dietary fats by ruminants. PhD Thesis, University of Nottingham.

ARGENZIO, R.A. & SOUTHWORTH, M. (1975) Sites of organic acid production and absorption in gastrointestinal tract of the pig. American Journal of Physiology, **228**: 454-460.

ARGENZIO, R.A. (1982) Volatile fatty acid production and absorption from the large intestine of the pig. Les Colloques de l'INRA, **12**: 207-215.

ARMSTRONG, D.G., BLAXTER, K.L., GRAHAM, N. McC., & WAINMAN, F.W. (1958) The utilisation of the energy of two mixtures of steam-volatile fatty acids by fattening sheep. British Journal of Nutrition **12**: 177-188.

ASP, N-G., JOHANNSON, C-G., HALLMER, H., & SILJESTROM, M. (1983) A rapid enzymatic assay of insoluble and soluble dietary fibre. Journal of Agricultural and Food Chemistry, **31**: 476-482.

ASP, N.G. & JOHANSSON, C-G (1984) Dietary fibre analysis. Nutrition Abstracts and Reviews. Reviews in Clinical Nutrition, **54**(9): 735-752.

ASPINALL, G.O. & FERRIER, R.J. (1957) J. chem. Soc. **840**: 4188, cited from Eastwood, M.A. (1973).

AXELSSON, J. & ERIKSSON, S. (1950) The availability of the method of determination by difference of the effect of individual feeds. Annals of Royal Agricultural College of Sweden **17**: 161-203.

BAILEY, R.W. (1973) In: Chemistry and Biochemistry of Herbage. **1**: 157. Edited by G.W. Butler and R.W. Bailey. Academic Press; London.

BAILEY, R.W., MILLS, S.E. & HOVE, E.L. (1974) Composition of sweet and bitter lupin seed hulls with observations on the apparent digestibility of sweet lupin seed hulls by young rats. Journal of the Science of Food and Agriculture, **25**: 955-961.

BAIRD, D.M., McCAMPBELL, H.C. & ALLISON, J.R. (1970) Levels of crude fiber with constant energy levels for growing-finishing swine using computerized rations. Journal of Animal Science, **31**: 518-525.

BAKER, D.H., BECKER, D.E., JENSEN, A.H. & HARMON, B.G. (1968) Effect of dietary dilution on performance of finishing swine. Journal of Animal Science, **27**: 1332-1335.

BALL, R.O. & AHERNE, F.X. (1982) Effect of diet complexity and feed restriction on the incidence and severity of diarrhoea in early-weaned pigs. Canadian Journal of Animal Science, **62**: 907-913.

BARCROFT, J., McANNALY, R.A. & PHILLIPSON, A.T. (1944) Absorption of volatile acids from the alimentary tract of sheep and other animals. Journal of Experimental Biology, **20**: 120-129.

BARDON, T. & FIORAMONTI, J. (1983) Nature of the effects of bran on digestive transit time in pigs. British Journal of Nutrition, **50**: 685-690.

BARROW, P.A. (1978) PhD Thesis. University of Reading, cited from Ratcliffe, B. (1985).

BAYLEY, H.S. & LEWIS, D. (1965) The use of fats in pig feeding 1. Pig faecal fat not of immediate dietary origin. Journal of Agricultural Science, **64**: 367-372.

BELL, J.M., SHIRES, A. & KEITH, M.O. (1983) Effect of hull and protein contents of barley on protein and energy digestibility and feeding value for pigs. Canadian Journal of Animal Science, **63**: 201-212.

BERGNER, H., SIMON, O. & BERGNER, U. (1980) In Protein Metabolism and Nutrition: 198-204. Ed. H.J. Oslage and K. Rohr. European Association of Animal Production, Braunschweig.

BERGNER, H. (1981) Chemically treated straw meal as a new source of fibre in the nutrition of pigs. Pig News and Information **2**: 135-140.

BERGNER, H. (1982) Fibre and nitrogen digestion. Les Colloques de l'INRA, **12**: 237-245.

BLACKSHAW, J.K. & KELLY, W.R. (1980) Effects of gastric ulceration on growth rate of intensively reared pigs. Veterinary Record, **106**: 52-57.

BLAXTER, K.L. (1962) The Energy Metabolism of Ruminants. Hutchinson, London.

BLOOMFIELD, D.K. (1963) Proc. Natn. Acad. Sci. USA, **50**: 117, cited from Eastwood, M.A. (1973).

BOHMANN, V.R., HUNTER, J.E. & McCORMICK, J. (1955) The effect of graded levels of alfalfa and aureomycin upon growing-fattening swine. Journal of Animal Science, **14**: 499-506.

BOWLAND, J.P., YOUNG, B.A. & MILLIGAN (1971) Influence of dietary VFA mixtures on performance and on fat composition of growing pigs. Canadian Journal of Animal Science **51**: 89-94.

BREIREM, E. (1935) National Institute of Animal Science Report, **162**: 0-269. Copenhagen: Landhusholdrungsselskabers Forlag.

BROOKS, C.C., GARNER, G.B., GEHRKE, C.W., MUHRER, M.E. & PFANDER, W.H. (1954) The effect of added fat on the digestion of cellulose and protein by ovine microorganisms. Journal of Animal Science, **13**: 758-764.

BROUWER, E. (1965) In Energy Metabolism. Ed. K.L. Blaxter. Academic Press: 441.

BROWN, R.C., KELLEHER, J. & LOSOWSKY, H.S. (1979) The effect of pectin on the structure and function of the rat small intestine. British Journal of Nutrition, **42**: 357-365.

CAMPBELL, R.G., TAVERNER, M.R. & CURIC, D.M. (1983) The influence of feeding level from 20 to 45 kg liveweight on the performance and body composition of female and entire male pigs. Animal Production, **36**: 193-199.

CANGUILHEM, R. & LABIE, C. (1977) Variation de la duree du transit intestinal chez le porc selon la teneur de la ration cellulose. Revue de Medecine Veterinaire, **128**: 1669-1681.

CHESSON, A., RICHARDSON, A.J. & ROBERTSON, J.A. (1985) Fibre digestion and bacteriology of the digestive tract of pigs fed cereal and vegetable fibre. Beretning fra Statens Husdyrbrugsforsøg, **580**. Digestive Physiology in the Pig. Ed. A. Just, H. Jørgensen and J.A. Fernandez: 272-275.

CHRISTENSEN, K. & THORBEK, G. (1987) Methane excretion in the growing pig. British Journal of Nutrition, **57**: 355-361.

CHUNG, I.Ch., KIM, Y.S., SCHADCHER, A., GARRIDO, A., MacGREGOR, I.L. & SLEISENGER, M.H. (1979) Protein digestion and absorption in human small intestine. Gastroenterology, **76**: 1415-1421.

CLAPPERTON, J.L & STEELE, W. (1983) Fat supplementation in animal production - ruminants. Proceedings of the Nutrition Society, **42**: 343-350.

CLEMENS, E.T., STEVENS, C.E. & SOUTHWORTH, M. (1975) Sites of organic acid production and pattern of digesta movement in the gastrointestinal tract of swine. Journal of Nutrition, **105**: 759-768.

COEY, W.E. & ROBINSON, K.L. (1954) Some effects of dietary crude fibre on liveweight gains and carcass conformation of pigs. Journal of Agricultural Science, Cambridge, **45**: 41-47.

COLE, D.J.A., DUCKWORTH, J.E. & HOLMES, W. (1967) Factors affecting voluntary feed intake in pigs. II The effect of two levels of crude fibre in the diet on the intake and performance of fattening pigs. Animal Production, **9**: 149-154.

CRANWELL, P.D. (1968) Microbial fermentation in the alimentary tract of the pig. Nutrition Abstracts and Reviews, **38**(3): 721-730.

CUMMINGS, J.H. (1978) Nutritional implications of dietary fibre. American Journal of Clinical Nutrition, **31**: S21-S29.

CUMMINGS, J.H., SOUTHGATE, D.A.T., BRANCH, W.J., WIGGINS, H.S., HOUSTON, H., JENKINS, D.J.A., JIVRAJ, T. & HILL, M.J. (1979) The digestion of pectin in the human gut and its effect on calcium absorption and large bowel function. British Journal of Nutrition, **41**: 477-485.

CUMMINGS, J.H., SOUTHGATE, D.A.T., BRANCH, W.J., HOUSTON, H., JENKINS, D.J.A. & JAMES, W.P.T. (1978) Colonic response to dietary fibre from carrot, cabbage, apple, bran and guar gum. Lancet, **1**: 5-8.

CUMMINGS, J.H., HILL, M.J., & JIVRAJ, T., HOUSTON, H., BRANCH, W.J. & JENKINS, D.J.A. (1979) The effect of meat protein and dietary fibre on colonic function and metabolism. 1. Changes in bowel habit, bile acid excretion, and calcium absorption. American Journal of Clinical Nutrition, **32**: 2086-2093.

CUNNINGHAM, H.M., FRIEND, D.W., & NICHOLSON, J.W.G. (1961) The effect of a purified source of cellulose on the growth and body composition of growing pigs. Canadian Journal of Animal Science, **41**: 120-125.

CUNNINGHAM, H.M., FRIEND, D.W. & NICHOLSON, J.W.G. (1962) The effect of age, bodyweight, feed intake and adaptability of pigs on the digestibility and nutritive value of cellulose. Canadian Journal of Animal Science **42**: 167-175.

CZERKAWSKI, J.W. & CLAPPERTON, J.L. (1983) Fats as energy-yielding compounds in the ruminant diet. In: Fats in Animal Nutrition. Ed. J. Wiseman. Butterworths, London: 249-263.

DECUYPERE, J. & DER HELYDE, H. (1972) Zbl. Bakt. Hyg. I. Abt. Orig. **A221**: 492-510, cited from Ratcliffe, B. (1985).

DE GOEY, L.W. & EWAN, R.D. (1975) Effect of level of intake and diet dilution on energy metabolism in the young pig. Journal of Animal Science **40**: 1045-1051.

DEMIGNE, C. & REMSEY, C. (1979) Annals de Biologie Animale Biochemie Biophysique, **19**(38): 929-935, cited from Ratcliffe, B. (1985).

DEVENDRA, C. & LEWIS, D. (1974) The interaction between dietary lipids and fibre in the sheep. Animal Production, **19**: 67-76.

DIERICK, N., VERVAEKE, I., DECUYPERE, J. & HENDERICKX, H.K. (1983) Revue de l'"Agriculture (Brussels), **36**: 1691-1712, cited from Low, A.G. (1985)

EASTWOOD, M.A. & HAMILTON, O. (1968) Studies on the adsorption of bile salts to non-absorbed components of the diet. Biochimica et Biophysica Acta, **152**: 165-173.

EASTWOOD, M.A. (1973) Vegetable fibre: its physical properties. Proceedings of the Nutrition Society, **32**: 137-143.

EASTWOOD, M.A. & BOYD, G.S. (1967) Biochim. biophys. Acta, **137**, 393, cited from Eastwood, M.A. (1973).

EASTWOOD, M.A. & KAY, R.M. (1979) An hypothesis for the action of dietary fibre along the gastrointestinal tract. American Journal of Clinical Nutrition, **32**: 364-367.

EASTWOOD, M.A., ROBERTSON, J.A., BRYDON, W.G. & MACDONALD, D. (1983) Measurement of water-holding properties of fibre and their faecal bulking ability in man. British Journal of Nutrition **50**: 539-547.

EHLE, F.R., JERACI, J.L., ROBERTSON, J.B. & VAN SOEST, P.J. (1982) The influence of dietary fibre on digestibility, rate of passage and gastrointestinal fermentation in pigs. Journal of Animal Science **55** (No 5): 1071-1081.

ENGLYST, H., WIGGINS, H.S. & CUMMINGS, J.H. (1982) Determination of the non-starch polysaccharides in plant foods by gas-liquid chromatography of constituent sugars as alditol acetates. Analyst, **107**: 307-318.

ENGLYST, H.N. & CUMMINGS, J.H. (1985) Measurement of starch and non-starch polysaccharides and their breakdown in the small intestine of man. Beretning fra Statens Husdyrbrugsforsøg, **580**. Digestive physiology in the pig. Ed A. Just, H. Jørgensen and J.A. Fernandez. Copenhagen: 188-191.

EWAN, R.C. (1976) Distill. Feed Res. C. Conf. Proc. **31**: 16-21, cited from Taylor, A.J. and Fisher, C. (1980).

FARRELL, D.J. & JOHNSON, K.A. (1972) Utilization of cellulose by pigs and its effects on caecal function. Animal Production **14**: 209-217.

FARRELL, D.J. (1973) Digestibility by pigs of the major chemical components of diets high in plant cell-wall components. Animal Production, **16**: 43-47.

FERNANDEZ, J.A., JØRGENSEN, H. & JUST, A. (1986) Comparative digestibility experiments with growing pigs and adult sows. Animal Production **43**: 127-132.

FERNENDEZ, J.A. & JØRGENSEN, J.N. (1986) Digestibility and absorption of nutrients as affected by fibre content in the diet of the pig. Quantitative aspects. Livestock Production Science **15**: 53-71.

FERNANDEZ, J.A., JUST, A. & JØRGENSEN, H. (1979) Comparison of the ability of growing pigs and sows to digest different feedstuffs. Commission on Pig Production. 30th Annual Meeting of the European Association for Animal Production. Harrogate: 1-4.

THE FERTILISERS AND FEEDINGSTUFFS (AMENDMENT) REGULATIONS (1976) Statutory Instruments No. 840: 31-32. HMSO, London.

FIORAMONTI, J. & BUENO, L. (1980) Motor activity in the large intestine of the pig related to dietary fibre and retention time. British Journal of Nutrition **43**: 155-161.

FLEMING, S.E. & WASILEWSKI, M.M. (1984) Using the pig as a tool for studying fermentation in the human gut. Nutrition Reports International, **30**: 825-834.

FORBES, R.M. & HAMILTON, T.S. (1952) The utilization of certain cellulosic materials by swine. Journal of Animal Science, **11**: 480-490.

FORBES, J.M. (1986) In: The Voluntary Food Intake of Farm Animals: 86-113. Butterworths, London.

FRIEND, D.W., CUNNINGHAM, H.M. & NICHOLSON, J.W.G. (1963) Volatile fatty acids and lactic acids in the alimentary tract of the young pig. Canadian Journal of Animal Science, **43**: 174-181.

FRIEND, D.W., CUNNINGHAM, H.M. & NICHOLSON, J.W.G. (1963) II. The effect of diet on the levels of volatile fatty acids and lactic acid in sections of the alimentary tract. Canadian Journal of Animal Science, **43**: 156-168.

FRIEND, D.W., NICHOLSON, J.W.G., & CUNNINGHAM, H.M. (1964) Volatile fatty acid and lactic acid content of pig blood. Canadian Journal of Animal Science. **44**: 303-308.

FRANK, G.R., AHERNE, F.X. & JENSEN, A.H. (1983) A study of the relationship between performance and dietary component digestibilities by swine fed different levels of dietary fibre. Journal of Animal Science, **57**: 645-654.

FULLER, R. (1962) PhD Thesis, University of Reading, cited from Ratcliffe, B. (1985).

FULLER, M.F. & BOYNE, A.W. (1971) The effects of environmental temperature on the growth and metabolism of pigs given different amounts of food. 1. Nitrogen metabolism, growth and body composition. British Journal of Nutrition, **25**: 259-272.

FULLER, M.F. & CROFTS, R.M.J. (1977) The protein sparing effect of carbohydrate. 1. Nitrogen retention of growing pigs in relation to diet. British Journal of Nutrition, **38**: 479-488.

GAILLARD, B.D.E. (1962) The relationship between the cell-wall constituents of roughages and the digestibility of the organic matter. Journal of Agricultural Science (Cambridge), **59**: 369-373.

GALBRAITH, H., MILLER, T.B., PATON, A.M., & THOMPSON, J.K. (1971) Antibacterial activity of long chain fatty acids and the reversal with calcium, magnesium, ergocalciferol and cholesterol. Journal of Applied Bacteriology, **34**: 803-813.

GARGALLO, J. & ZIMMERMAN, D.R. (1980) Effects of dietary cellulose and neomycin on function of the caecum of pigs. Journal of Animal Science, **51**: 121-126.

GARGALLO, J. & ZIMMERMAN, D.R. (1981) Effect of sunflower hulls on large intestine function in finishing swine. Journal of Animal Science, **53**(5): 1286-1291.

GENELL, S., GUSTAFFSON, B.E. & OHLSSON, K. (1976) Quantitation of active pancreatic endopeptidases in the intestinal contents of germfree and conventional rats. Scandinavian Journal of Gastroenterology, **11**: 757-762.

GRAHAM, H., HESSELMAN, K., AMAN, P. (1985) The effect of wheat bran, whole crop peas, and beet pulp on the digestibility of dietary components in a cereal-based pig feed. Beretning fra Statens Husdyrbrugsforsøg, **580**. Digestive Physiology in the pig. Ed. A. Just, H. Jørgensen and J.A. Fernandez, Copenhagen: 195-198.

GRAHAM, H., HESSELMAN, K. & AMAN, P. (1986) The influence of wheat bran and sugar-beet pulp on the digestibility of dietary components in a cereal-based pig diet. Journal of Nutrition, **116**: 242-251.

GUSTAFSSON, B.E. & NORMAN, A. (1968) Scandinavian Journal of Gastroenterology, **3**: 625, cited from Eastwood, M.A. (1973).

HAKANSSON, J. & MALMLOF, K. (1984) The nutritive value of grass-, clover- and pea crop meals for growing pigs. Swedish Journal Agricultural Research, **14**: 45-51

HARFOOT, C.G., CROUCHMAN, M.L., NOBLE, R.C. & MOORE, J.H. (1974) Competition between food particles and rumen bacteria in the uptake of long chain fatty acids and triglycerides. Journal of Applied Bacteriology, **37**: 633-641.

HARFOOT, C.G. (1978) Lipid metabolism in the rumen. Progress in Lipid Research, **17**: 21-54.

HARRIS, D.L. & KINYON, J.M. (1974) Significance of anaerobic spirochetes in the intestines of animals. American Journal of Clinical Nutrition, **27**: 1297-1304.

HARTLEY, R.D. (1972) p-coumaric and ferulic acid components of cell walls of ryegrass and their relationships with lignin and digestibility. Journal of Science of Food and Agriculture, **23**: 1347-1354.

HARTLEY, R.D. (1983) Degradation of cell walls of forages by sequential treatment with sodium hydroxide and a commercial cellulase preparation. Journal of the Science of Food and Agriculture, **34**: 29-36.

HARTOG, den L.A., BOON, P.J., HUISMAN, J., LEEUWEN, P. VAN AND WEERDEN, E.J. VAN (1985) The effect of crude fibre content on the digestibility and the rate of passage in the small and large intestines of pigs. Beretning fra Statens Husdyrbrugsforsøg, **580**. Digestive Physiology in the Pig. Ed. A. Just, H. Jørgensen, J.A. Fernandez, Copenhagen: 199-202.

HENDERSON, C. (1973) The effects of fatty acids on pure cultures of rumen bacteria. Journal of Agricultural Science, Cambridge, **81**: 107-112.

HILL, M.J. (1981) In Colon and Nutrition. Falk Symposium **32**: 37-45. Eds. Kasper, H. and Gaebell, H. MTP Press Ltd. The Hague.

HOCHSTETLER, L.N., HOEFER, J.A., PEARSON, A.M. & LUECKE, R.W. (1959) Effect of varying levels of fiber of different sources upon growth and carcass characteristics of swine. Journal of Animal Science, **18**: 1397-1404.

HOFFMANN, L., JEYNTSCH, W., KLEIN, M. & SCHIEMANN, R. (1977) Archiv für Tierernährung, **27**: 421-438, cited from Christensen, K. and Thorbek, G. (1987).

HOLMES, J.H.G., BAYLEY, H.S. & LEADBEATER, P.A. (1974) Digestion of Protein in the small and large intestine of the pig. British Journal of Nutrition, **32**: 479-489.

HONING, Y van der, JONGBLOED, A.W., SMITS, B. & WIEMAN, B.J. (1982) Effect of substitution of cereals by carbohydrates from different by-products or by animal fat on energy utilization by growing boars. In Proceedings of the 9th Symposium on Energy Metabolism. Ed. Ekern, A. and Sundstol, F. European Association of Animal Production Publication, **29**: 202-205. Ski, Norway.

HORSZCUZARUK & SLJIVOVACKI (1962; 1966; 1971) cited from Digestion in the Pig. Ed. D.E. Kidder and M.J. Manners. Scientechnica, Bristol: 141.

HORWITZ, W. (Ed.) (1980) Official methods of analysis of the association of official analytical chemists, Washington D.C.

HOUPT, T.R. (1968) Heat production of bovine ruminal ingesta. American Journal of Veterinary Research, **29**: 411-419.

HOVE, E.L., & KING, Susan (1979) Effects of pectin and cellulose on growth, feed efficiency, and protein utilization, and their contribution to energy requirement and caecal VFA in rats. Journal of Nutrition, **109**(2): 1274-1278.

HOVELL, F.D. De B., GREENHALGH, J.F.D. & WAINMAN, F.W. (1976) The utilization of diets containing acetate salts by growing lambs as measured by comparative slaughter and respiration calorimetry, together with rumen fermentation. British Journal of Nutrition, **35:** 343-363.

HUANG, W.Y. & KUMEROW, F.A. (1976) Cholesterol and fatty acid synthesis in swine. Lipids, **11**, No 1: 34-41.

HUISMAN, J., DEN HARTOG, L.A., BOER, H., VAN WEERDEN, E.J. & THIELEN, W.J.G. (1985) The effect of various carbohydrate sources on the ileal and faecal digestibility of protein and amino acids in pigs. Beretning fra Statens Husdyrbrugsforsøg, **580**. Digestive Physiology in the Pig. Ed. Just, A., Jørgensen, H. and Fernandez, J.A.: 207-210.

HUNGATE, R.E. (1968) In 'Handbook of Physiology' Ed. C.F. Code. Washington D.C.: American Physiological Society, **5**: 2725-2745.

IMOTO, S. & NAMIOKA, S. (1978) VFA Production in the large intestine. Journal of Animal Science, **47**(2): 467-478.

IMOTO, S. & NAMIOKA, S. (1983) Nutritive value of acetate in growing pigs. Journal of Animal Science, **56**(4): 858-866.

JAMES, P.S. & SMITH, M.W. (1976) Methionine transport by pig colonic mucosa measured during early post-natal development. Journal of Physiology, **262**: 151-168.

JENKINS, D.J.A., WOLEVER, T.M.S., LEEDS, A.R., GASSULL, M.A., HAISMAN, P., DILAWARI, J., GOFF, D.V., METZ, G.L. & ALBERTI, K.G.M.M. (1978) Dietary fibres, fibre analogues, and glucose tolerance: importance of viscosity. British Medical Journal, **1**: 1392-1394.

JENTSCH, W., SCHIEMANN, R. & HOFFMANN, L. (1968) Model versuche mit schweinen zur bestimmung der energetischen verwertung von alkohol, essig- und michsaure. Archives für Tierernährung, **18**: 352-357.

JENTSCH, W. & HOFFMANN, L. (1977) Archiv für Tierernährung, **27**: 491-507, cited from Christensen, K. and Thorbek, G. (1987).

JOHNSON, I.T., GEE, J.M. & MAHONEY, R.R. (1984) Effect of dietary supplements of guar gum and cellulose on intestinal cell proliferation, enzyme levels and sugar transport in the rat. British Journal of Nutrition, **52**: 477-487.

JONGBLOED, A.W. & HOEKSTRA, J.A. (1985) Effect of type and amount of diet on the gutfill in pigs growing from 30 to 110 kg. Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde, **54**: 84-85.

JØRGENSEN, H., JUST, A. & FERNANDEZ, J.A. (1985) The influence of diet composition on the amount of gut fill, energy disappearing in caecum-colon and utilisation of ME in growing pigs. 10th Symposium on Energy Metabolism, Airlie, VA, USA. E.A.A.P. Publications.

JUST, A. (1980) Influence of dietary composition on site of absorption and efficiency of utilization of metabolizable energy in growing pigs. In: Energy Metabolism. Ed. Mount, L.E. Butterworths, London: 27-30.

JUST, A. (1982) The net value of crude fat for growing pigs. Livestock Production Science, **9**: 501-509.

JUST, A., ANDERSEN, J.O. & JØRGENSEN, H. (1980) Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde, **44**: 82-90, cited from Low (1985).

JUST, A., JØRGENSEN, H. & FERNANDEZ, J.A. (1981) The digestive capacity of the caecum-colon and the value of the nitrogen absorbed from the hind gut for protein synthesis in the pig. British Journal of Nutrition, **46**: 209-219.

JUST, A., FERNANDEZ, J.A. & JØRGENSEN, H. (1983) The net energy value of diets for growth in pigs in relation to the fermentative processes in the digestive tract and the site of absorption of the nutrients. Livestock Production Science, **10**: 171-186.

KASS, MARIA L., VAN SOEST, P.J., POND, W.G., LEWIS, BERTHA & McDOWELL, R.E. (1980) Utilization of dietary fibre from alfalfa by growing swine. 1. Apparent Digestibility of Diet Components in specific segments of the gastrointestinal tract. Journal of Animal Science **50**(1): 175-191.

KENNELLY, J.J. & AHERNE, F.X. (1980) The effect of fibre in diets formulated to contain different levels of energy and protein on digestibility coefficients in swine. Canadian Journal of Animal Science, **60**: 717-726.

KENNELLY, J.J., AHERNE, F.X. & SAUER, W.C. (1981) Volatile fatty acid production in the hindgut of swine. Canadian Journal of Animal Science, **61**: 349-361.

KEYS, J.E. Jr., VAN SOEST, P.J. & YOUNG, F.P. (1970). Effect of increasing dietary cell wall content on the digestibility of hemicellulose and cellulose in swine and rats. Journal of Animal Science, **31**: 1172-1177.

KEYS, J.E. & DeBARTHE, J.V. (1974) Cellulose and hemicellulose digestibility in the stomach, small intestine and large intestine of swine. Journal of Animal Science, **39**: 53-57.

KIDDER, D.E. & MANNERS, M.J. (1978) Digestion in the pig. Scientechnica, Bristol.

KING, R.H. & TAVERNER, M.R. (1975) Prediction of the digestible energy in pig diets from analyses of fibre contents. Animal Production, **21**: 275-284.

KIRCHGESSNER, M., ROTH-MAIER, D.A. & ROTH, F. (1975) Zuchtungskunde, **47**: 96-103, cited from Low, A.G. (1985)

KOMAI, M. & KIMURA, S. (1980) Journal of Nutritional Science and Vitaminology, **26**: 389-399, cited from Stanogias, G. and Pearce, G.R. (1985b).

KORNEGAY, E.T. (1981) Soybean hull digestibility by sows and feeding value for growing-finishing swine. Journal of Animal Science, **53**: No. 1: 138-145.

KOWALCYZK, J., ØRSKOV, E.R., ROBINSON, J.J. & STEWART, C.S. (1977) Effect of fat supplementation on voluntary feed intake and rumen metabolism in sheep. British Journal of Nutrition, **37**: 251-257.

KUAN, K.K., STANOGIAS, G. & DUNKIN, A.C. (1983) The effect of proportion of cell-wall material from lucerne leaf meal on apparent digestibility, rate of passage and gut characteristics in pigs. Animal Production, **36**: 201-209.

KUPKF, B. & HENKEL, H. (1977) Der einfluss einer holz-bzw. Strohcellulosezulage auf die bilanz der rohnährstoffe und der energieansatz beim mastschwein. Zeitschrift für Tierphysiologie Tierernährung und Futtermittelkunde, **38**: 330-331.

LANGBORG, HANSEN, H., JUST, A. & KJELDSEN RASMUSSEN, O. (1976) Fodermidlernes vaerdi til svin. Statens Husdyrbrugsforsøg, 1958 København V. Meddelelse **126**, 1-4.

LATYMER, E.A. & WOODLEY, S.C. (1984) In vivo incorporation of ^{14}C into plasma fractions of pigs after injection of [U-^{14}C] sodium acetate into the caecum. Proceedings of the Nutrition Society, **43**: 22A.

LATYMER, E.A. & LOW, A.G. (1984) Tissue incorporation and excretion of ^{14}C in pigs after injection of [U-^{14}C] sodium acetate into the caecum. Proceedings of the Nutrition Society, **43**: 12A.

LATYMER, E.A., LOW, A.G. & WOODLEY, S.C. (1985) The effect of dietary fibre on the rate of passage through different sections of the gut in pigs. Beretning fra Statens Husdrybrugsforsøg **580**. In: Digestive Physiology in the Pig. Ed. A. Just, H. Jørgensen and J.A. Fernandez Copenhagen: 215-218.

LAU, M.M. & VAN SOEST, P.J. (1981) Titratable groups and soluble phenolic compounds as indicators of the digestibility of chemically treated roughages. Animal Feed Science and Technology, **6**: 123-131.

LAWES AGRICULTURAL TRUST (1982) Genstat V, Mark 4.01. Rothamsted Experimental Station, Harpenden.

LAWRENCE, T.L.J. (1970) Some effects of including differently processed barley in the diet of the growing pig. s. *In vivo* gastric pH change. Animal Production, **12**: 151-163.

LAWRENCE, T.L.J. (1972) The effect of certain dietary factors on *in vivo* pH changes and pepsin activity in the stomach of the growing pig. British Veterinary Journal, **128**: 402-411.

LAWRENCE, T.L.J. (1984) Manipulation of the gut environment of pigs. In Recent Advances in Animal Nutrition. Ed. W. Haresign and D.J.A. Cole. Butterworths, London: 97-109.

LAWRENCE, P. (1980) Macro-determination of carbon in agricultural materials by oxygen-bomb combustion and titrimetry. Analyst, **105**: 922-924.

LEEDS, A.R., KANG, S.S., LOW, A.G. & SAMBROOK, I.E. (1980) The pig as a model for studies on the mode of action of guar gum in normal and diabetic man. Proceedings of the Nutrition Society, **39**: 44A.

LIN, F.D., KNABE, D.A. & TANKSLEY, T.D. (1987) Apparent digestibility of amino acids, gross energy and starch in corn, sorghum, wheat, barley, oat groats and wheat middlings for growing pigs. Journal of Animal Science, **64**: 1655-1663.

LIU, Y.F., FADDEN, K., LATYMER, E., LOW, A.G. & HILL, M.J. (1985) The use of the cannulated pig to study the effect of dietary fibre supplements on the bacterial flora of the porcine hindgut. Beretning fra Statens Husdyrbrugsforsøg, **580**. Digestive Physiology in the Pig. Ed. A. Just, H. Jørgensen and J.A. Fernandez: 300-303.

LOCKHART, H.B., LEE, H.S., O'MAHONY, S.P., HENSLEY, G.W. & HOULIHAN, E.J. (1980) Caloric value of fibre-containing cereal fractions and breakfast cereals. Journal of Food Science, **45**: 372-374.

LONGLAND, A.C. & LOW, A.G. (1987) The digestion of three sources of dietary fibre by growing pigs. Proceedings of the Nutrition Society (in press.)

LONGLAND, A.C., LOW, A.G., KEAL, H.D. & HARLAND, J.I. (1987) The digestibility of growing-pig diets containing dried molassed or plain sugar-beet pulp. Proceedings of the Nutrition Society.(in press).

LONGLAND, A.C., LOW, A.G., KEAL, H.D. & HARLAND, J.I. (1987) Dried molassed and plain sugar-beet pulp in diets for growing pigs. Proceedings of the Nutrition Society (in press).

LONGLAND, A.C., CLOSE, W.H. & LOW, A.G. (1988) Digestion of carbohydrates from sugar-beet pulp in pigs with ileo-rectal anastomoses and energy balance measured by calorimetry. In: Proceedings of 4th International Seminar on Digestive Physiology in the Pig (in press). Institute of Animal Physiology and Nutrition, Jabłonna.

LOW, A.G. & RAINBIRD, A.L. (1984) Effect of guar gum on nitrogen secretion into isolated loops of the jejunum in concious growing pigs. British Journal of Nutrition, **52**: 499-505.

LOW, A.G. (1985) Role of dietary fibre in pigs diets. In: Recent Advances in Animal Nutrition. Ed. W. Haresign and D.J.A. Cole: 87-112. Butterworths, London.

LOW, A.G. & KEAL, H.D. (1981) 12th International Congress of Nutrition, San Diego: 56, cited from Low, A.G. (1985).

LY, J. (1974) Caecal function in the pig: VFA content and utilisation by the caecal wall. Cuban Journal of Agricultural Science, **8**: 247-254.

LY, J. (1975) Caecal function in the pig: daily variation of caecal parameters in pigs fed on molasses diets. Cuban Journal of Agricultural Science, **9**: 39-47.

MacLEOD, G.K. & BUCHANAN-SMITH, J.G. (1972) Digestibility of hydrogenated tallow, saturated fatty acids and soya bean oil-supplemented diets by sheep. Journal of Animal Science, **35**: 890-895.

MADSEN, A. (1963) Fordøjelighedsforsøg med suin. 337 beretn. forsøgslab. København: 191 cited from Fernandez, J.A., Just, A. & Jørgensen, H. (1979).

MAHAN, D.C., PICKETT, R.A., PERRY, T.W., CURTIN, T.M., FEATHERSTONE, W.R. & BEESON, W.M. (1966) Influence of various nutritional factors and physical form of feed on esophagogastric ulcers in swine. Journal of Animal Science, **25**: 1019-1023.

MALMLÖF, K. & HAKANSSON, J. (1984) The effect of dietary fibre level on the diurnal pattern of urinary nitrogen excretion in swine. Swedish Journal of Agricultural Research, **14**: 53-57.

MALMLÖF, K. (1985) Effects of wheat straw metal on some blood plasma variables in the growing pig. In: Pig Research at the Department of Animal Nutrition and Management 1974-84. Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management Report **152**, Uppsala: 16-17.

MANNERS, M.J. (1976) The development of digestive function in the pig. Proceedings of the Nutrition Society, **35**: 49-55.

MARSHALL, K.C. (1980). In: Microbial Adhesion to Surfaces, Chapter 9; 187. Society of Chemists in Industry; London.

MARSTON, H.R. (1948) The fermentation of cellulose *in vitro* by organisms from the rumen of sheep. Biochemical Journal, **42**: 564-574.

MASON, V.C. & PALMER, R. (1971) Studies on the digestibility and utilisation of the nitrogen of irradiated rumen bacteria by rats. Journal of Agricultural Science, **76**: 567-572.

MASON, V.C. & PALMER, R. (1973) The influence of bacterial activity in the alimentary canal of rats on faecal nitrogen excretion. Acta Agriculturae Scandinavica, **23**: 141-150.

MASON, V.C., JUST, A & BECH-ANDERSEN, S. (1976) Bacterial activity in the hindgut of pigs. 2. Its influence on the apparent digestibility of nitrogen and amino acids. Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde, **36**: 310-324.

MASON, V.C. (1979) Role of the large intestine in the processes of digestion and absorption in the pig. In: Current Concepts of Digestion and Absorption in Pigs. NIRD Technical Bulletin 3. Ed. A.G. Low and I.G. Partridge: 112-129.

MASON, V.C., KRAGELUND, Z. & EGGUM, B.O. (1982) Influence of fibre and nebacitin on microbial activity and amino acid digestibility in the pig and rat. Zeitschrift für Tierphysiologie, Tierernährung and Futtermittelkunde, **21**: 138-146.

MASON, V.C. (1984) Metabolism of nitrogenous compounds in the large gut. Proceedings of the Nutrition Society, **43**: 45-53.

MERKEL, R.A., BRAY, R.W., GRUMMER, R.H., PHILLIPS, P.H. & BOHSTEDT, G. (1958) The influence of limited feeding, using high fibre rations, upon growth and carcass characteristics of swine. II Effects upon carcass characteristics. Journal of Animal Science, **17**: 13-19.

MICHEL, F., THIBAULT, J.F. & BARRY, J.L. & de BAYNAST, R. (1988) Preparation and characterisation of dietary fibre from sugar-beet pulp. Journal of the Science of Food and Agriculture, **42**(1): 77-85.

MICHEL, M.C. (1966) Annals de Biologie Animale Biochemie Biophysique, **6**: 33, cited from Ratcliffe, B. (1985).

MIDTVEDT, T. & NORMAN, A. (1972) Acta path. microbiol. scand. **808**: 202, cited from Eastwood, M.A. (1973).

MILLARD, P. & CHESSON, A. (1984) Modification to swede (Brassica napus) anterior to the terminal ileum of pigs: some implications for the analysis of dietary fibre. British Journal of Nutrition, **52**: 583-594.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1986) Standing committee on tables of feed composition. Feed composition: UK Tables of Feed Composition and Nutritive value for ruminants. Chalcombe Publications.

MISIR, R. & SAUER, W.G. (1980) Infusion of starch at the terminal ileum on amino and digestibility in pigs. Canadian Journal of Animal Science, **60**(4): 1035.

MÖHME, V.H., MOLNAR, S. & LENKEIT (1970) Untersuchungen zur ^{14}C-ausscheidung nach oraler verabreichung von 1-^{14}C-acetat beim ferkel in der neugeborenenphase. Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde, **21**: 138-146.

MORGAN, D.J., COLE, D.J.A. & LEWIS, D. (1975) Energy values in pig nutrition. Journal of Agricultural Science, Cambridge, **84**: 7-17.

MORGAN, C.A., WHITTEMORE, C.T. & COCKBURN, J.H.S. (1984) The effect of level and source of protein, fibre and fat in the diet on the energy value of compounded pig feeds. Animal Feed Science and Technology, **11**: 11-34.

MORGAN, C.A., WHITTEMORE, C.T., PHILLIPS, P. & CROOKS, P. (1987) The prediction of the energy value of compounded pig foods from chemical analysis. Animal Feed Science and Technology, 17: 81-107.

MORGAN, C.A. & WHITTEMORE, C.T. (1988) Dietary fibre and nitrogen excretion and retention by pigs. Animal Feed Science and Technology, **19**: 185-189.

MOSENTHIN, R. & HENKEL, H. (1983) Les Colloques de l'INRA, **16**: 447-450, cited from Low, A.G. (1985).

MULLER, H.L. & KIRCHGESSNER, M. (1983) Energetische verwertung von zellulose beim schwein. Zeitschrift für Tiererphysiologie, Tierernährung und Futtermittelkunde, **49**: 127-133.

MULLER, H.L. (1984) Wirkung von Gerüstsubstanzen auf die energiebilanz bei sauen. Zeitschrift für Tierernährung, Tierphysiologie und Futtermittelkunde, **52**: 57.

MURRAY, A.G., FULLER, M.F. & PIRIE, A.R. (1977) The effect of fibre in the form of various polysaccharides on the apparent digestibility of protein in the pig. Animal Production **24**: 139.

McBURNEY, M.I., VAN SOEST, P.J. & CHASE, L.E. (1983) Cation exchange capacity and buffering capacity of neutral-detergent fibres. Journal of the Science of Food and Agriculture, **34**: 910-916.

NIELSEN, H.E. (1962) Avlens og fodringens indflydelse på tarmkanalens udvikling hos svinet. Ugeskr. Landmaend, **107**(16): 235-240, cited from Fernandez, J.A. and Jørgensen, J.N. (1986).

NIEMAN, C. (1954) Influence of trace amounts of fatty acids on the growth of microorganisms. Bacteriological Reviews **18-19:** 147-163.

NORDFELT, S. (1946) The ability of brood sows to digest the feed as compared to that of young pigs. Annals of the Royal Agricultural College of Sweden **13**: 136-152.

NOTTLE, M.C. & ROOK, J.A.F. (1963) The effect of dietary fat on the production of volatile fatty acids in the rumen of the cow. Proceedings of the Nutrition Society, **22**: 7.

NYMAN, M. & ASP, NILS-GEORG (1985) Dietary fibre fermentation in the rat intestinal tract: effect of adaptation period, protein and fibre levels, and particle size. British Journal of Nutrition, **54**: 635-643.

ØRSKOV, E.R., GRUBB, D.A., SMITH, J.S., WEBSTER, A.J.F. & CORRIGALL, W. (1979) Efficiency of utilisation of volatile fatty acids for maintenance and energy retention by sheep. British Journal of Nutrition, **41**: 541-551.

OWEN, J.B. & RIDGMAN, W.J. (1967) The effect of dietary energy content on the voluntary intake of pigs. Animal Production, **9**: 107-113.

OWEN, J.B. & RIDGMAN, W.J. (1968) Further studies of the effect of dietary energy content on the voluntary intake of pigs. Animal Production, **10**: 85-91.

PALS, O.A. & EWAN, R.C. (1978) Utilization of the energy of dried whey and wheat middlings by young swine. Journal of Animal Science, **46**(2): 402-408.

PARTRIDGE, I.G., LOW, A.G., SAMBROOK, I.E. & CORRING, T. (1982) The influence of diet on the exocrine pancreatic secretion of growing pigs. British Journal of Nutrition, **48**: 137-145.

PARTRIDGE, I.G., MITCHELL, K.G. & KEAL, H.S. (1982) The utilization of dietary cellulose by growing pigs. Animal Production, **35**: 209-214.

PEARSON, P.B. & PANZER, F. (1949) The effect of fat in the diet of rats on their growth and their excretion of amino acids. Journal of Nutrition, **38**: 257-265.

PEERS, S.G., TAYLOR, A.G. & WHITTEMORE, C.T. (1977) The influence of feeding level and level of dietary inclusion on the digestibility of barley meal in the pig. Animal Feed Science and Technology, **2**: 41-47.

PEKAS, J.C. (1986) Gastrointestinal responses of swine to feed intake and dietary fibre. Swine in Biomedical Research Vol. 2. Ed. M.E. Tumbleson. Plenum Press. New York and London.

PETERSSON, H., HAKANSSON, J. & ERIKSSON, S. (1979) A preliminary study of the length, area and dry weight of the small intestine in slaughter pigs. Swedish Journal of Agricultural Research, **9**: 75-82.

POND, W.G., YEN, J.T., LINDVALL, R.N. & HILL, D. (1981) Dietary alfalfa meal for genetically obese and lean growing pigs: effect on bodyweight gain and carcass and gastrointestinal tract measurements and blood metabolites. Journal of Animal Science, **51**: 367-373.

POND, W.G. (1984) Feeding for efficient Pork Production: The role of visceral organ metabolism in response to diet. In: Proceedings of the 1984 Maryland Nutrition Conference for Feed Manufacturers, USA, University of Maryland; 47-53.

POTKINS, ZOE, V., LAWRENCE, T.L.J. & THOMLINSON, J.R. (1985) Effects of dietary substitution of complex polysaccharides on gastric emptying, digesta transit time to terminal ileum and rectum, and nutrient utilization in the growing period. Beretning fra Statens Husdrybrugsforsøg, **580**. Digestive Physiology in the Pig. Ed. A. Just, H. Jørgensen and J.A. Fernandez: 231-234.

RAINBIRD, A.L., LOW, A.G. & ZEBROWSKA, T. (1984) Effect of guar gum on glucose and water absorption from isolated loops of jejunum in concious growing pigs. British Journal of Nutrition, **52**: 489-498.

RAINBIRD, A.J. & LOW, A.G. (1986) Effect of various types of dietary fibre on gastric emptying in growing pigs. British Journal of Nutrition, **55**: 87-98.

RATCLIFFE, B. (1985) The influence of the gut microflora on the digestive processes. Beretning fra Statens Husdyrbrugsforsøg, **580**. Ed. A. Just, H. Jørgensen and J.A. Fernandez: 245-267, Copenhagen.

REESE, N.A., MUGGENBERG, B.A., KOWALCZYK, T., GRUMMER, R.H. & HOCKSTRA, W.G. (1966) Nutritional and environmental factors influencing gastric ulcers in swine. Journal of Animal Science, **25**: 14-20.

RERAT, A., VAISSADE, P. & VAUGELADE, P. (1979) Annals de Biologie Animale Biochimie Biophysique, **19**; 739-747, cited from Low, A.G. (1985).

RERAT, A. (1978) Digestion and absorption of carbohydrates and nitrogenous matters in the hindgut of the omnivorous non-ruminant animal. Journal of Animal Science, **46**(6): 1808-1837.

ROBERTSON, J.B. & VAN SOEST, P.J. (1977) Dietary fibre estimation in concentrate animal feed-stuffs. 69th Meeting of the American Society of Animal Science. Journal of Animal Science, **45** (Supplement 1): 254-255.

ROBINSON, I.M., ALLISON, M.J. & BUCKLIN, J.A. (1981) Characterisation of the caecal bacteria of normal pigs. Applied and Environmental Microbiology, **41**: 950-955.

ROTH, F.X. & KIRCHGESSNER, M. (1984) Verdaulichkeit der energie und Rohnährstoppe beim schwein in abhängigkeit von fütterungsniveau und lebendgewicht. Zeitschrift für Tiererphysiologie, Tierernährung und Futtermittelkunde, **36**: 301-310.

ROWETT RESEARCH INSTITUTE (1983) Annual Report of studies in animal nutrition and allied sciences, **39**: 92.

SAKATA, T. (1988) Physical and chemical trophic effects of dietary fibre on the intestine of monogastric animals. In: Digestive Physiology in the Pig. Jabłonna. In Proceedings of the 4th International Seminar on Digestive Physiology in the Pig (in press). Institute of Animal Physiology and Nutrition, Jabłonna.

SALTER, D.N. (1973) The influence of gut micro-organisms on utilization of dietary protein. Proceedings of the Nutrition Society, **32**: 65-71.

SAMBROOK, I.E. (1979) Studies on digestion and absorption in intestines of growing pigs 8. Measurements of the flow of total lipid, acid detergent fibre and volatile fatty acids. British Journal of Nutrition, **42**: 279-287.

SAMBROOK, I.E. (1980) In: Current Concepts of Digestion and Absorption in Pigs. (Eds. A.G. Low and I.G. Partridge.) N.I.R.D. Reading Technical Bulletin 3: 78-93.

SAMBROOK, I.E. (1981) Studies on the flow and composition of bile in growing pigs. Journal of the Science of Food and Agriculture, **32**: 781-791.

SAMBROOK, I.E., RAINBIRD, A.L.& LOW, A.G. (1982) In: Fibre in Human and Animal Nutrition (Abstract). Royal Society of New Zealand; Wellington.

SAUER, W.C., STOTHERS, C.S. & PARKER, R.J. (1977) Apparent and true availabilities of amino acids in wheat and milling products for pigs. Canadian Journal of Animal Science, **57**: 775-784.

SAUER, W.C., JUST, A., JØRGENSEN, H.H., MAKONNEN FEKADU & EGGUM, B.O. (1980) The influence of diet composition on the apparent digestibility of crude protein and amino acids at the terminal ileum and overall in pigs. Acta Agriculturae Scandinavica, **30**: 449-459.

SAVAGE, D.C. (1977) Microbial ecology of the gastrointestinal tract. Annual Review of Microbiology, **31**: 107-133.

SISSONS, J.W., RAINBIRD, A.L. & THURSTON, S.M. (1984) Regulation of gastric motility. Gut, **25**: A1318-A1319.

SMITH, W.W. (1944) In: Pork Production 2nd Edition. New York.

SMITH, H.W. & HALLS, S. (1968) The production of oedema disease and diarrhoea in weaned pigs by the oral administration of *Escherichia coli* factors that influence the course of the experimental disease. Journal of Medical Microbiology, **1**: 45-49.

SNEDECOR, G.W. & COCHRAN, W.G. (1973) Statistical methods, 6th Ed. Ames, Iowa. Iowa State University Press.

SOUTHGATE, D.A.T. (1969) Determination of carbohydrates in foods II unavailable carbohydrates. Journal of the Science of Food & Agriculture, 20: 331-335.

SOUTHGATE, D.A.T. (1973) Fibre and other unavailable carbohydrates and their effects on the energy value of the diet. Proceedings of the Nutrition Society, **32**: 131-136.

SOUTHGATE, D.A.T. (1976) Determination of food carbohydrates. London: Applied Science Publishers 107-112.

SOUTHGATE, D.A.T. (1982) Definitions and terminology of dietary fibre. In: Dietary Fibre in health and disease. Vahouny, G.V., Kritchevsky, D. (Eds) . New York: Plenum Press, 1-7.

SOUTHON, S., LIVESEY, G., GEE, J.M. & JOHNSON, I.T. (1985) Differences in intestinal protein synthesis and cellular proliferation in well nourished rats consuming conventional laboratory diets. British Journal of Nutrition, **53**: 87-95.

STAHLY, T.S. & CROMWELL, G.L. (1979) Effect of environmental temperature and dietary fat supplementation on the performance and carcase characteristics of finishing swine. Journal of Animal Science, **49**: 1478-1486.

STAHLY, T.S. (1982) The energetics of growth in pigs as influenced by environmental temperature and diet composition. Proceedings of the Maryland Nutrition Conference for Feed Manufacturers: 58-64.

STANOGIAS, G. & PEARCE, G.R. (1985a) The digestion of fibre by pigs. 1. The Effects of Amount and Type of Fibre on Apparent Digestibility, N balance and Rate of Passage. British Journal of Nutrition, **53**: 513-530.

STANOGIAS, G. & PEARCE, G. (1985b) The digestion of fibre by pigs. 3. Effects of the amount and type of fibre on physical characteristics of segments of the gastrointestinal tract. British Journal of Nutrition, **53**: 537-548.

STEELE, W. & MOORE, J.H. (1968) The digestibility coefficients of myristic, palmitic and stearic acids in the diet of sheep. Journal of Dairy Science, **35**: 371-376.

STEPHEN, A.M. & CUMMINGS, J.H. (1979) The influence of faecal nitrogen excretion in man. Proceedings of the Nutrition Society, **38**: 141A.

STOTZKY, G. (1980) Surface interactions between clay minerals and microbes, viruses and soluble organics, and the probable importance of these interactions to the ecology of microbes in soil. In: Microbial Adhesion to Surfaces: 231-247. Society of Chemists in Industry; London.

SZABO, J. (1979) In 'Clinical and Experimental Gnotobiotics'. T. Fliedner, H. Heit, D. Niethammer and H. Pflieger Zbl. Bakt. Supplement 7. Gustav Fischer Verlag, Stuttgart: 125-128.

TAVERNER, M.R., CAMPBELL, R.G. & BIDEN, S. (1984) The effects of dietary energy concentration on the voluntary intake of grower pigs fed a high fibre diet. Proceedings of the Australian Society of Animal Production, **15**: 757.

TAVERNER, M.R., HUME, I.D. & FARRELL, D.J. (1981) Availability to pigs of amino acids in cereal grains. 1. Endogenous levels of amino acids in ileal digesta and faeces of pigs given cereal diets. British Journal of Nutrition, **46**: 149-158.

TAYLOR, A.J. & FISHER, C. (1980) Thermogenic effect in pigs of diets containing wheat or wheatfeed. In Energy Metabolism Ed. L.E. Mount: 31-35.

TROWELL, H., SOUTHGATE, D.A.T., WOLEVER, T.M.S., LEEDS, A.R., GASSULL, M.A. & JENKINS, D.J.A. (1976) Dietary fibre redefined. Lancet, **1**: 967.

VAN DER HONING, Y., METZ, S.H.M. & JONGBLOED, A.W. (1986) The effect of fibre on the utilisation of metabolisable energy by fast-growing pigs. Summary of a paper presented at the meeting of the European Feed Team, May 1st 1986 at Kerkrade organised by Koudys-Wouda B.V.

VAN SOEST, P.J. (1963) Use of detergents in the analysis of fibrous feeds. II A Rapid Method for the Determination of Fibre and Lignin. Journal of the Association of Official Analytical Chemists, **46**: 829-835.

VAN SOEST, P.J. & McQUEEN, R.W. (1973) The chemistry and estimation of fibre. Proceedings of the Nutrition Society, **32**: 123-130.

VAN SOEST, P.J. (1981) In: Banbury Report 7: Gastrointestinal Cancer: Endogenous Factors: 61 Cold Spring Harbor Laboratory.

VAN SOEST, P.J. (1984) Some physical characteristics of dietary fibres and their influence on the microbial ecology of the human colon. Proceedings of the Nutrition Society, **43**: 25-33.

VAN SOEST, P.J. , McBURNEY, M.I. & RUSSELL, J. (1984) Proceedings of California Animal Nutrition Conference **53**. Pomona, California.

VAN SOEST, P.J. (1985) Definition of fibre in animal feeds: 55-70. In: Recent Advances in Animal Nutrition. Ed. Haresign, W. and Cole, D.J.A., Butterworths, London.

VAREL, V.H., JUNG, H.G. & POND, W.G. (1988) Effects of dietary fibre on young adult genetically lean, obese and contemporary pigs: rate of passage, digestibility and microbiological data. Journal of Animal Science, **66**: 707-712.

VAREL, V.H., POND, W.G., PEKAS, J.C. & YEN, J.T. (1982) Influence of high-fibre diet on bacterial populations in gastrointestinal tracts of obese- and lean-genotype pigs. Applied and Environmental Microbiology, **44**(1): 107-112.

VERSTEGEN, M.V.A. (1971) Mededelingen van de Landbouwhoegeschool te Wageningen, **71-2**: 0-115, cited from Christensen, K. and Thorbek, G. (1987).

WALKER, D.M. & HEPBURN, W.R. (1955) Normal acid fiber: a proposed analysis for the evaluation of roughages. 1. The analysis of roughages by the normal acid fiber method and its use for predicting the digestibility of roughages by sheep. Agricultural Progress, **30**: 118-119.

WARD, J.K., TEFFT, C.W., SIRNY, R.J., EDWARDS, H.N. & TILLMAN, A.D. (1957) Further studies concerning the effect of alfalfa ash upon the utilization of low-quality roughages by ruminant animals. Journal of Animal Science, **16**: 633-641.

WEBSTER, A.J.F., OSUJI, P.O., WHITE, F. & INGRAM, J.F. (1975) The influence of food intake on portal blood flow and heat production in the digestive tract of sheep. British Journal of Nutrition, **34**: 125-139.

WEBSTER, A.J.F. (1978) World Review of Nutrition and Dietics, **30**: 189, cited from Van Soest, P. J. (1985).

WHITING, F. & BEZEAU, L.M. (1957) The metabolic faecal nitrogen excretion of the pig as influenced by the amount of the fibre in the ration and by bodyweight. Canadian Journal of Animal Science, **57**: 5-105.

WHITTEMORE, C.T. & ELSLEY, F.W.H. (1976) In: Practical Pig Nutrition: 146-147. Farming Press Limited, Ipswich.

WIEBUL, X. (1919) Staatsbled No. 581 (See Official Standardised and Recommended Methods of Analysis S.A.C. 1973, 2nd.,: 160).

WISEMAN, J. (1986) Assessment of the digestible and metabolizable energy of fats for non-ruminants. In: Fats in Animal Nutrition. Ed J. Wiseman. Butterworths, London: 277-297.

WISEMAN, J. & COLE, D.J.A. (1979) Energy evaluation of cereals for pig diets. In: Recent Advances in Animal Nutrition. Ed. Haresign, W. and Lewis, D. Butterworths, London.

WRICK, K.L., ROBERTSON, J.B., VAN SOEST, P.J., LEWIS, B.A., RIVERS, J.M., ROE, D.A. & HACKLER, L.R. (1983) The influence of dietary fibre source on human intestinal transit and stool output. Journal of Nutrition, 113: 1464-1479.

WUSSOW, W. & WENIGER, J.H. (1954) Archiv für Tierernährung, **4**: 151-181, cited from Stanogias, G. and Pearce, G.R. (1985).

YOUNG, R.J., GARRETT, R.L. & GRIFFITHS, M. (1963) Factors affecting the absorbability of fatty acid mixtures high in saturated fatty acids. Poultry Science, **42**: 1146-1154.

ZEBROWSKA, T. (1973) Digestion and absorption of nitrogenous compounds in the large intestines of pigs. Roczniki Nauk Rolniczych, **95B3**: 85-90.

ZEBROWSKA, T. (1973) Roczniki Nauk Rolniczych, **95B1**: 115-123, cited from Zebrowska, T. (1982).

ZEBROWSKA, T. (1975) The apparent digestibility of nitrogen and individual amino acids in the large intestines of pigs. Roczniki Nauk Rolniczych, **97-B-1**: 117-123.

ZEBROWSKA, T. & BURACZEWSKI, S. (1977) Proceedings of the 2nd Symposium on Protein Metabolism: 82. Lelystad, Holland, cited from Zebrowska, T. (1982).

ZEBROWSKA, T. , BURACKEWSKA, L. & BURACZEWSKI, S. (1977) Roczniki Naukrol Niczych, **B99**: 87-98, cited from Mason, V.C. (1984).

ZEBROWSKA, T. , BURACZEWSKA, L. & ZEBROWSKA, H. (1981) VI International Symposium on Amino Acids, Serock, Poland, cited from Zebrowska, T. (1982).

ZEBROWSKA, T. , LOW, A.G. & ZEBROWSKA, H. (1983) Studies on gastric digestion of protein and carbohydrate, gastric secretion and exocrine pancreatic secretion in the growing pig. British Journal of Nutrition, 49: 401-410.

ZEBROWSKA, T. (1985) The influence of the level and source of fibre in the diet on the endocrine pancreatic secretion in growing pigs. (Beretning fra Statens Husdrybrugsforsøg, 580). Digestive Physiology in the Pig. Ed. A. Just, H. Jørgensen, and J.A. Fernandez.

ZEBROWSKA, T. (1982) Nitrogen digestion in the large intestine. Digestive Physiology in the Pig. Les Colloques de l'INRA, No. 12: 225-236.

ZHU, J.Q. & FOWLER, V.R. (1987) Digestion of sugar-beet pulp in young growing pigs and implications for the value of fermented energy. Animal Production, **44**(Part 3): 487.

ZOIOPOULOS, P.E., ENGLISH, P.R. & TOPPS, J.H. (1983a) Fibrous agro-industrial by-products as protein sources for bacon pigs 1. Assessment of performance, digestibility and carcass quality. Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde **49**: 210-218.

ZOIOPOULOS, P.E., TOPPS, J.H. & ENGLISH, P.R. (1983b). Fibrous agro-industrial by-products as protein sources for bacon pigs. 2. Study of digestion with pigs cannulated at the ileum. Zeitschrift fur Tierphysiologie, Tierernährung und Futtermittelkunde, **49**: 219-228.

ZOIOPOULOS, P.E., ENGLISH, P.R. & TOPPS, J.H. (1982) High-fibre diets for *ad libitum* feeding of sows during lactation. Animal Production, **35**: 25-33.

APPENDIX ONE

THE DETERMINATION OF NEUTRAL DETERGENT FIBRE

This method is based on that of Robertson and Van Soest (1977) with modifications as specified by MAFF (1985).

PRINCIPLE

Cell soluble material is extracted by boiling with a neutral solution of sodium lauryl sulphate containing disodium ethylene diamine tetra-acetate (EDTA), 2-ethoxyethanol, sodium borate and disodium phosphate. Starch, which may give enhanced results is removed by conversion to soluble sugars by the action of α-amylase. The insoluble material remaining is neutral detergent fibre.

DETERMINATION

Apparatus

600 ml tall beakers without a spout
50 ml sintered glass crucibles, porosity no. 1

Reagents

Neutral Detergent Solution

1. 93 g of EDTA and 34 g of sodium borate were dissolved in distilled water with heating.
2. 150 g of sodium lauryl sulphate and 50 ml of 2-ethoxyethanol were added.
3. 22.8 g of disodium hydrogen phosphate (anhydrous) were dissolved in distilled water with heating. This solution was added to the first, and the final solution diluted to 5 litres and mixed well.
4. The pH was measured to check that it was in the range 6.9 - 7.1

α-amylase solution

2 g of α-amylase (ex. *Bacillus subtilis* BDH product No. 39004) were dissolved in 90 ml of distilled water. The solution was filtered and 10 ml of 2-ethoxyethanol were added to the filtrate. This solution was prepared fresh.

Acetone

PROCEDURE

Immediately prior to use, the requisite number of crucibles were placed into a muffle furnace and the temperature raised to 500°C. The temperature was maintained for 30 minutes and the crucibles then allowed to cool.

Removal of the Oil

1. 0.500 g of the dried material (ground to pass a 1 mm screen) were placed onto a 9 cm No. 54 Whatman filter paper.
2. The filter paper was folded a number of times to enclose the sample and the folded paper placed in a soxhlet thimble.
3. The thimble was placed into the extractor and the sample extracted with petroleum spirit boiling point range 40-60°C for 2 hours.
4. The filter paper was removed and allowed to dry completely.
5. The filter paper was unfolded and the sample transferred into a 600 ml beaker using a fine brush.

Extraction with Neutral Detergent Solution

1. 50 ml of neutral detergent solution were added to the defatted sample and heated to boiling. The solution was kept under reflux for 30 minutes.
2. The beaker was removed from the hot plate and 50 ml of cold neutral detergent solution and 2 ml of α-amylase solution added. The beaker was allowed to stand for 15 minutes.
3. The contents were then reheated to boiling and maintained for a further 30 minutes.
4. The solution was filtered with vacuum immediately through a sintered glass crucible, porosity no. 1 and the residue washed twice with boiling water.
5. The crucible was removed. 30 ml of hot water (80°C) and 2 ml of α-amylase were added. The crucible was allowed to stand for 15 minutes.
6. The crucible was replaced and filtered. The residue was washed twice with hot water and twice with acetone.
7. The crucible was placed in an oven overnight at 102°C. It was cooled, weighed (W1) and ashed at 500°C for 3 hours.
8. The crucible was cooled in a desiccator and reweighed (W2).

CALCULATION

$$\% \mathrm{NDF} = (W1 - W2) * 200$$

APPENDIX TWO

PIG FINISHER SUPPLEMENT PT12C

Specification/kg supplement

Vitamin A	miu	2.0
Vitamin D3	miu	0.4
Vitamin E	iu	3 200
Vitamin K	mg	200
Vitamin B2	mg	1 200
Pantothenic Acid	mg	4 000
Nicotinic Acid	mg	4 800
Vitamin B12	mg	4.0
Thiamin B1	mg	200
Vitamin B6	mg	200
Manganese	mg	20 000
Zinc	mg	40 000
Iron	mg	40 000
Copper	mg	40 000
Cobalt	mg	40
Iodine	mg	200
Selenium	mg	40
Base	Limestone Flour	
Calcium	g	197

Calculation of energy retention and heat production of the pigs in the calorimetric studies. Experiment 3.2

Pig Number : One

Diet : Basal

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	452.7	31.35	19.87
Excretion in faeces	67.9	6.63	2.86
Excretion in urine	14.9	14.49	0.66
Excretion as methane	1.82	–	0.13
Excretion as CO_2	328.82	–	
Balance	39.26	10.23	–
Intake of metabolisable energy	–	–	16.22
Protein and Fat Storage			
Protein stored	(10.23 x 6.25)		63.9 g
Carbon stored as protein	(63.9 x 0.512)		32.7 g
Carbon stored as fat	(39.26 - 32.7)		6.6 g
Fat stored	(6.6 ÷ 0.746)		8.9 g
Energy retention and heat production			
Energy stored as protein	(6.39 x 23.6)		1.51 MJ
Energy stored as fat	(8.9 x 39.3)		0.35 MJ
Total energy retention	(1.51 + 0.35)		1.86 MJ
Heat production	(16.22 - 1.86)		14.36 MJ

Pig Number : Two
Diet : Basal + Beet pulp

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	643.3	37.57	27.20
Excretion in faeces	115.9	12.23	4.77
Excretion in urine	16.3	11.26	0.68
Excretion as methane	3.29	–	0.24
Excretion as CO_2	321.40	–	–
Balance	186.41	14.08	–
Intake of metabolisable energy	–	–	21.51

Protein and Fat Storage

Protein stored	(14.08 x 6.25)	88.0 g
Carbon stored as protein	(88.0 x 0.512)	45.1 g
Carbon stored as fat	(186.41 - 45.1)	141.31 g
Fat stored	(141.31 ÷ 0.746)	189.42 g

Energy retention and heat production

Energy stored as protein	(88.0 x 23.6)	2.08 MJ
Energy stored as fat	(189.42 x 39.3)	7.44MJ
Total energy retention	(2.08 + 7.44)	9.52 MJ
Heat production	(21.51 - 9.52)	11.99 MJ

Pig Number : Three
Diet : Basal diet

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	452.7	31.3	19.87
Excretion in faeces	65.6	6.7	2.75
Excretion in urine	13.3	12.7	0.61
Excretion as methane	1.31	—	0.097
Excretion as CO_2	356.93	—	—
Balance	15.6	11.9	—
Intake of metabolisable energy	—	—	16.41

Protein and Fat Storage

Protein stored	(11.9 x 6.25)	74.4 g
Carbon stored as protein	(74.4 x 0.512)	38.1 g
Carbon stored as fat	(15.6 - 38.1)	-22.5 g
Fat stored	(-22.5 ÷ 0.746)	-30.16 g

Energy retention and heat production

Energy stored as protein	(74.4 x 23.6)	1.76 MJ
Energy stored as fat	(-30.16 x 39.3)	-1.19 MJ
Total energy retention	(1.76 - 1.19)	0.57 MJ
Heat production	(16.41 - 0.57)	15.84 MJ

Pig Number : Four

Diet : Basal + Beet pulp

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	643.3	37.57	27.19
Excretion in faeces	113.5	11.98	6.37
Excretion in urine	20.5	13.45	0.75
Excretion as methane	3.61	–	0.266
Excretion as CO_2	352.16	–	–
Balance	153.53	12.14	–
Intake of metabolisable energy	–	–	19.80

Protein and Fat Storage

Protein stored	(12.14 x 6.25)	75.9 g
Carbon stored as protein	(75.9 x 0.512)	38.9 g
Carbon stored as fat	(153.53 - 38.9)	114.6 g
Fat stored	(114.63 ÷ 0.746)	153.7 g

Energy retention and heat production

Energy stored as protein	(75.9 x 23.6)	1.79 MJ
Energy stored as fat	(153.7 x 39.3)	6.04 MJ
Total energy retention	(1.79 + 6.04)	7.83 MJ
Heat production	(19.80 - 7.83)	11.97 MJ

Pig Number : Five

Diet : Basal diet

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	452.7	31.35	19.87
Excretion in faeces	69.7	6.53	2.89
Excretion in urine	11.5	10.63	0.49
Excretion as methane	1.29	–	0.095
Excretion as CO_2	329.0	–	–
Balance	41.21	14.19	–
Intake of metabolisable energy	–	–	16.40

Protein and Fat Storage

Protein stored	(14.19 x 6.25)	88.7 g
Carbon stored as protein	(88.7 x 0.512)	45.4 g
Carbon stored as fat	(41.21 - 45.40)	-4.19 g
Fat stored	(-4.19 ÷ 0.746)	-5.62 g

Energy retention and heat production

Energy stored as protein	(88.7 x 23.6)	2.09 MJ
Energy stored as fat	(-5.62 x 39.3)	-0.22 MJ
Total energy retention	(2.09 - 0.22)	1.87 MJ
Heat production	(16.40 - 1.87)	14.53 MJ

Pig Number : Six

Diet : Basal diet

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	452.7	31.35	19.87
Excretion in faeces	55.4	4.93	2.32
Excretion in urine	14.4	13.95	0.65
Excretion as methane	1.60	–	0.12
Excretion as CO_2	332.0	–	–
Balance	49.3	12.47	–
Intake of metabolisable energy	–	–	16.78
Protein and Fat Storage			
Protein stored	(12.47 x 6.25)		77.9 g
Carbon stored as protein	(77.9 x 0.512)		39.9 g
Carbon stored as fat	(49.3 - 39.9)		9.4 g
Fat stored	(9.4 ÷ 0.746)		12.6 g
Energy retention and heat production			
Energy stored as protein	(77.9 x 23.6)		1.84 MJ
Energy stored as fat	(12.6 x 39.3)		0.50 MJ
Total energy retention	(1.84 + 0.50)		2.34 MJ
Heat production	(16.78 - 2.34)		14.44 MJ

Pig Number : Seven

Diet : Basal + Beet pulp

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	643.3	37.57	27.20
Excretion in faeces	132.0	14.75	5.54
Excretion in urine	18.5	13.00	0.81
Excretion as methane	3.15	–	0.23
Excretion as CO_2	368.6	–	–
Balance	121.1	9.82	–
Intake of metabolisable energy	–	–	20.62
Protein and Fat Storage			
Protein stored	(9.82 x 6.25)		61.4 g
Carbon stored as protein	(61.4 x 0.512)		31.4 g
Carbon stored as fat	(121.1 - 31.4)		89.7 g
Fat stored	(89.7 ÷ 0.746)		120.2 g
Energy retention and heat production			
Energy stored as protein	(61.4 x 23.6)		1.45 MJ
Energy stored as fat	(120.2 x 39.3)		4.72 MJ
Total energy retention	(1.45 + 4.72)		6.17 MJ
Heat production	(20.62 - 6.17)		14.45 MJ

Pig Number : Eight

Diet : Basal + Beet pulp

Results of experiment (per 24 h)	Carbon (g)	Nitrogen (g)	Energy (MJ)
Intake	643.3	37.57	27.20
Excretion in faeces	131.0	13.85	5.46
Excretion in urine	15.1	10.70	0.64
Excretion as methane	2.22	–	0.16
Excretion as CO_2	362.23	–	–
Balance	132.75	13.02	–
Intake of metabolisable energy	–	–	20.94

Protein and Fat Storage

Protein stored	(13.02 x 6.25)	81.4 g
Carbon stored as protein	(81.4 x 0.512)	41.7 g
Carbon stored as fat	(132.75 - 41.7)	91.1 g
Fat stored	(91.1 ÷ 0.746)	122.1 g

Energy retention and heat production

Energy stored as protein	(81.4 x 23.6)	1.92 MJ
Energy stored as fat	(122.1 x 39.3)	4.80 MJ
Total energy retention	(1.92 + 4.80)	6.72 MJ
Heat production	(20.94 - 6.72)	14.22 MJ