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Statens Husdyrbrugsforsøg

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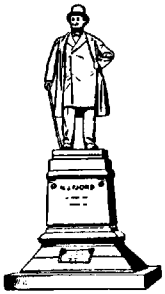
Determination of Linoleic acid requirements in slaughter pigs

Daily gain, feed conversion efficiency, digestibility of nutrients, and nitrogen and energy metabolism as response factors

Bestemmelse af linolsyrebehov til slagtesvin

Daglig tilvækst, foderudnyttelse, fordøjelighed af næringsstoffer samt kvælstof- og energiomsætning som behovskriterier



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Foreword

Linoleic acid is an essential fatty acid to pigs. However, the requirement for dietary linoleate to meaty pigs under modern rearing conditions is not known.

The present investigations were undertaken to establish the requirement for dietary linoleate in slaughter pigs using both important performance and production criteria as well as physiological and biochemical parameters as response factors.

This report describes the results obtained during the growth period on daily gain and feed conversion efficiency, the digestibility of feed components and gross energy, and nitrogen and energy metabolism, factors which greatly influence the slaughter value of the body and the economic output of the production.

The chemical analyses of feed, faeces and urine were performed by the staff of the department of animal physiology, biochemistry and analytical chemistry under the direction of Dr.h.c. Grete Thorbek and cand. polyt. Kirsten Weidner.

The manuscript was typed by Mr. E. W. Karlsen and Mr. C. Cramer.

Copenhagen, August 1984

Arnold Just

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I. Introduction

1.1 Background of own investigations

The great economic stress which is put on present-day production of animal products highly necessitate the supply of energy and essential nutrients in optimum amounts. One group of essential nutrients is the essential fatty acids (EFAs) of which linoleic acid is the most common in the feed of swine. Our knowledge about the requirement for EFAs in the production of slaughter pigs producing a large amount of meat is scarce and incomplete. As a matter of fact the dietary requirement of EFAs of pigs has never been studied with Danish breeds under Danish rearing conditions.

Numerous Danish experiments have been concerned with the effect of the dietary fat composition on the fatty acid composition of the depot fat and organ lipids in relation to the quality of the carcass. Only a brief summary of the investigations will be presented here, as they have recently been summarized by *Madsen et al. (1977)*. These experiments establish in general that the more unsaturated fatty acids pigs receive in their feed, the more soft is the backfat. Other undesirable quality characteristics such as reduced storage stability, rancidity, off flavours, and discolouring of the carcass fat are also encountered. In the production of bacon the presence of unsaturated acids is further critical, because both saline and smoke contain oxidative reagents which may enhance the degradation of the lipids. Consequently, the amount of unsaturated fat in the diets of pigs has been reduced to a minimum.

A conventional feed to pigs consisting of barley and a fat poor protein source such as skim milk powder or soya bean meal contains mainly fat from barley. Barley contains 1.5–2.5% crude fat with approximately 65% of the fatty acids as polyunsaturated fatty acids (PUFAs). Of these both linoleic acid (55%) and linolenic acid (10%) are EFAs, but with different biological functions.

The present author's interest in EFA nutrition of pigs stems from my Ph.D. work: Synthesis and deposition of intramuscular lipids in relation to the quality of pork *(Christensen, 1969)*. In order to obtain a variable fat synthesis the pigs were fed a fat free diet supplemented with sunflower oil to provide 1 energy% linoleate or diets containing 20% linseed oil or coconut oil. The pigs receiving the fat free diet for 60–70 days refused to eat and developed dermal lesions on the back, the nose and the feet. A supply of 20 ml sunflower oil daily restored appetite and appearance to normal within 3 weeks. The pigs receiving the fat free diet and the coconut oil diet showed pale, soft, and exudative meat (PSE)

when slaughtered at 90 kg live weight. One pig of each group died and showed enlarged hearts and PSE at post mortem examination. This observation was discussed in relation to the meat quality of pigs receiving different amounts of fat from skim milk, fish meal and grains, and it was postulated that the amount of linoleate in the diet might be related to the meat quality of pigs *(Christensen, 1970)*. Shortly afterwards, studies in our institute showed that cocks fed an ordinary diet produced less meat than cocks receiving 12% soya bean oil in the diet *(Petersen et al., 1970)*, and EFA deficient rats had a greater catabolism of protein compared with rats supplemented with linoleate, possibly due to impaired oxidative phosphorylation *(Jakobsen, 1972)*.

To obtain further information about the possible role of linoleic acid in the meat quality of pigs a pilot study was performed with two groups of pigs (6 pigs per group) receiving 0.4 and 6.4 energy% linoleate, respectively, supplied as soya bean oil. The fatty acid composition of total lipids of blood plasma and skeletal muscle during the growth period showed that the group receiving 0.4 energy% linoleate was EFA deficient as judged from the 20:3,n-9/20:4,n-6 ratio *(Christensen, 1973)*. Similar findings were obtained in phospholipids of mitochondria isolated from the liver, the heart and the *longissimus dorsi* muscle of the same pigs *(Christensen, 1974a)*.

These mitochondria also showed impaired ATP formation *(Christensen, 1974a)*. There was no significant difference in the anatomical and chemical composition of the carcasses from the two groups except for the fatty acid composition *(Christensen, 1974b)*. The meat quality of the EFA deficient pigs was inferior to that of the supplemented pigs, and apparently the function of the heart and skeletal muscle was inadequate *(Christensen, 1974b)*.

1.2 Purpose of own investigations

In view of the findings in own preliminary experiments reviewed in section 1.1 and the relatively scarce information on the significance of EFAs in intensive production and performance of slaughter pigs, which can be deduced from the following chapter, it was decided to determine the requirement of linoleate both from a physiological and productional point of view. In other words: *How much linoleic acid (linoleate) must be supplied in the diet to secure a satisfactory health, performance and production from weaning to slaughter?*

When determining the requirement of a nutrient it is common to feed increasing amounts of the nutrient from deficient to maximum levels and to measure the effect of the supply of the nutrient on sensitive response parameters. Similarly, in the present investigations linoleate was supplied in various levels ranging from zero to maximum levels. Soya bean oil was chosen as the source of linoleate. It was decided to include both important performance and produc-

tion criteria as well as physiological and biochemical parameters as response factors.

The present report describes the results obtained during the growth period on daily gain and feed conversion efficiency, the digestibility of feed components and gross energy, and nitrogen and energy metabolism, factors which greatly influence the slaughter value of the body and the economic output of the production.

II. Literature review on the role of EFAs in nutrition

The following sections review the present knowledge about the metabolism and functions of EFAs with special attention to the studies performed with pigs.

2.1 Metabolism and functions of EFAs

Burr and Burr (1929; 1930) first established that the rat does not thrive on diets rigidly devoid of fat, but develops a characteristic deficiency disease. The most important fat deficiency symptoms are a scaly condition of the skin, retardation and eventual complete cessation of growth, renal lesions often manifesting themselves in the appearance of blood in the urine, abnormally high water consumption and irregularities in ovulation, gestation and lactation. Male reproductive functions are also considerably impaired. Death may occur at last as a consequence of the renal damages. The same rats were cured by linoleic acid (either isolated in pure state, or in olive oil, lard, corn oil, puppy-seed oil, linseed oil, or egg lecithin). On this basis *Burr and Burr (1930)* put forward the hypothesis that warm blooded animals in general cannot synthesize appreciable quantities of linoleic acid and possibly also other unsaturated acids, and the term »essential fatty acid« was coined for linoleic acid.

2.1.1 The linoleic acid family (n-6 family)

Linoleic acid (cis,cis-9, 12-octadecadienoic acid or 18:2, n-6 or 18:2, ω-6 cf. Fig. 2.1) is the most common PUFA, and as is also the case with the much less well studied linolenic acid (18:3,n-3) can be synthesized only by the plant kingdom. Mammals lack the enzymes which introduce double bonds at carbon atoms beyond C-9 in the fatty acid chain. This makes the double bond at the 12th carbon atom (counted from the carboxyl group) of linoleic acid »essential«. *Ellis and Zeller (1930)* and *Hilditch et al. (1939)* demonstrated that pigs do not synthesize linoleic acid, but accumulate it from the dietary lipids. In the body of most mammals, however, linoleic acid can be used as starting point for the synthesis of longer chain fatty acids some of which have also been found to possess biological activity. These PUFAs are formed by alternating chain elongation (addition of 2 C-units) and dehydrogenation reactions in the microsomes. The pattern of conversions are described in detail e.g. by *Mead (1968), Brenner (1971)* and *Sprecher (1977)*.

The major metabolic pathway of conversion of linoleic acid to PUFAs of the n-6 family is as follows:

(2.1) 18:2,n-6 (linoleic acid) → 18:3,n-6 (γ-linolenic acid) → 20:3,n-6 (dihomo-γ linolenic acid) → 20:4,n-6 (arachidonic acid) → 22:4,n-6 → 22:5,n-6

It is essential for this series of reactions that the first double bond is positioned at the 6th carbon atom counted from the carbon atom of the methyl group called n-6 or ω-6 in older nomenclature. This series of PUFAs is called the linoleic acid family or the n-6 family and has the general formula: CH_3-$(CH_2)_4$-CH = CH-R (cf. Fig. 2.1). It can only be derived from linoleic acid of dietary origin. Of these fatty acids linoleic acid *(Burr and Burr, 1929;1930)*, arachidonic acid *(Turpeinen, 1938)*, γ-linolenic acid *(Thomasson, 1953)* and dihomo-γ-linolenic acid *(Hassam and Crawford, 1978)* are known to possess EFA activity in reversing EFA deficiency symptoms, the latter three being even more effective than linoleic acid. The pig is able to form arachidonic acid from linoleic acid as shown by the studies of *Ellis and Isbell (1926b)* and *Hilditch et al., (1939)*. This is apparently not the case with the cat, which is lacking *(Rivers et al. 1975)* or has a reduced ability *(Sinclair et al., 1981)* to convert linoleic acid into arachidonic acid.

The only essential fatty acid of the n-6 family which must be supplied through the diet is linoleic acid. It is essential in the sense that it cannot be synthesized in the body, or at least not in sufficient amounts. Thus, recent studies have indicated that som synthesis may take place as reported by *Kass et al. (1975)*. Their observations on pigs are, however, not conclusive, and it is not stated whether the synthesis takes place in the body tissues or in the intestinal tract. It has been found that the microflora apparently is able to synthesize octadecadienoic acid, which can be utilized by the organism *(Girard, 1974)*. Arachidonic acid and γ-linolenic acid are also found in the lower flora and fauna, for instance, in protozoa *(Nichols and Appleby, 1969)*, and thus may contribute to the EFA status of the body.

After absorption linoleic acid is partly oxidized or accumulated in the adipose tissue, or, preferably, converted to PUFAs and incorporated into structural lipids. In pigs, 60–70% of the total serum linoleate was found in the sterol esters, and 70–75% of the total serum arachidonate in the phospholipids *(Leat, 1963)*, preferentially in the β-position *(Leat, 1964b)*. In the tissues n-6 PUFAs have structural as well as other functions. Structurally they are important because of the physical properties which they impart to membranes. They may also maintain various enzymes in these membranes in such a state that the enzymic active sites are exposed.

Furthermore, dihomo-γ-linolenic acid and arachidonic acid may be released from the phospholipids of the membranes of virtually all cells by phospholipases and react with molecular oxygen to form a variety of newly dis-

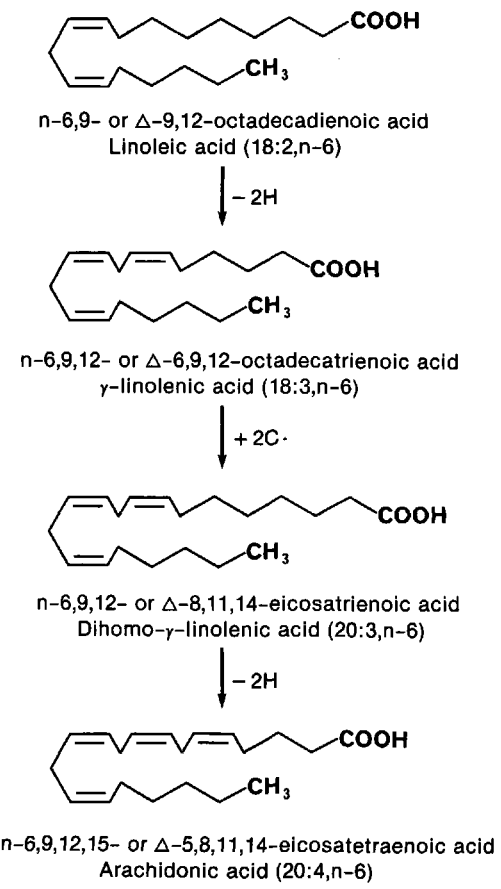

Figure 2.1. The linoleic acid family also called the n-6 or ω-6 family
Linolsyrefamilien også kaldt n-6 eller ω-6 familien

covered derivatives many of which possess biological activity. The multiple metabolic pathways that arachidonic acid may follow by reaction with oxygen and either cyclo-oxygenase and/or lipoxygenase depending on the tissue or organ in question are schematically shown in Figure 2.2.

Arachidonic acid (20:4,n-6) is the precursor of the cyclic endoperoxides, which are termed prostaglandin G_2 (PGG_2) and prostaglandin H_2 (PGH_2) *(Hamberg et al., 1974; Hamberg and Samuelsson, 1974)*. The formation of PGG_2 from arachidonic acid is catalyzed by an enzyme called fatty acid cyclo-oxygenase or prostaglandin synthetase. PGH_2 can decompose both spontaneously and enzymatically into the classical prostaglandins PGE_2, $PGF_{2\alpha}$ and

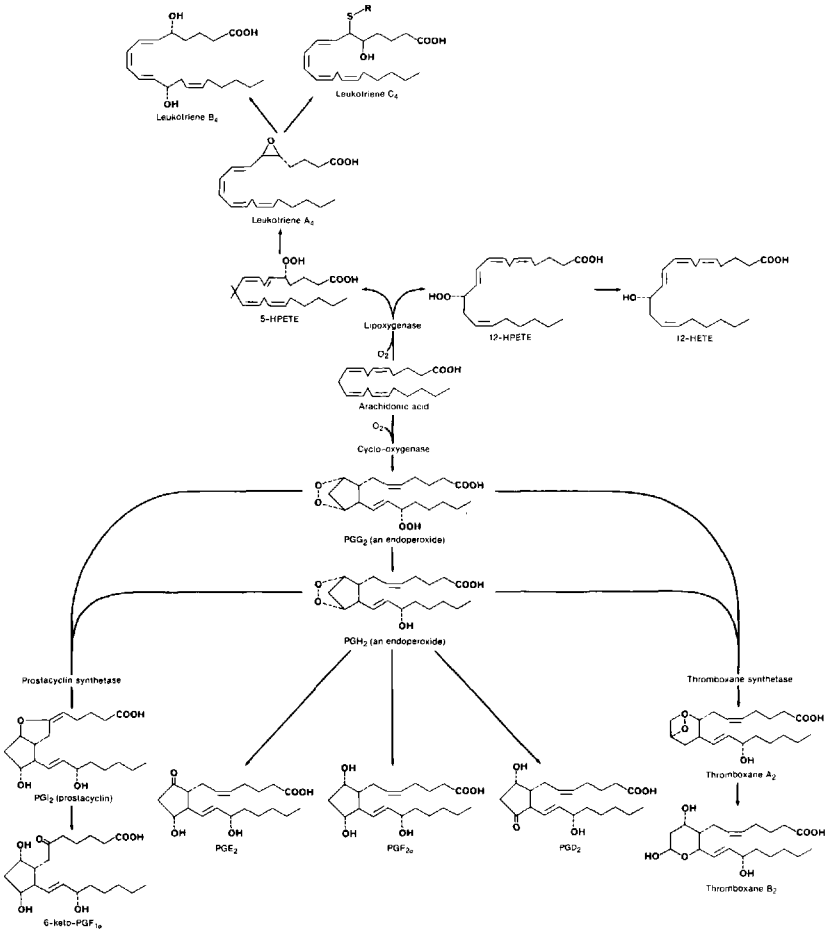

Figure 2.2. Metabolism of arachidonic acid by reaction with molecular oxygen in different tissues. See text

Arakidonsyrens omsætning ved reaktion med molekylær ilt i forskellige væv. Se tekst

PGD_2 *(van Dorp et al., 1978),* which are found in virtually all cells *(Karim et al., 1967).* The endoperoxides were found to be much more potent than PGE_2 in producing aggregation of human platelets and contraction of the rabbit aorta *(Hamberg et al., 1974).* The endoperoxides are not only the precursors of the classical prostaglandins, but also of the nonprostaglandin derivatives called the thromboxanes (TX) *(Hamberg et al., 1975).* An enzyme called thromboxane synthetase converts PGH_2 into the shortlived ($t_{½}$ = 32 sec at 37°C) thromboxane

A_2 (TXA_2), which is finally converted into the more stable thromboxane B_2 (TXB_2). Thromboxanes have been found in blood platelets, leukocytes, lung tissue, spleen, kidney, umbilical artery and brain *(Samuelsson, 1977)*. TXA_2 is much more potent than the endoperoxides as a vasoconstrictor and platelet aggregation stimulator *(Samuelsson, 1977)*, but their mode of action has not yet been clarified. In the vascular wall of man and different species including the pig an enzyme called prostacyclin synthetase converts the endoperoxides into a compound first called prostaglandin X and subsequently referred to as prostacyclin or prostaglandin I_2 (PGI_2), which is a powerful vasodilator and an inhibitor of platelet aggregation thus opposing the effects of the endoperoxides and thromboxane A_2 *(Moncada et al., 1976; Gryglewski et al., 1976; Moncada and Vane, 1977)*.

The balance between the rates of production of TXA_2 and PGI_2 has been proposed to be a mechanism responsible for the maintenance of vascular homeostasis *(Korbut and Moncada, 1978)*. It has recently been shown that the ratio between the two (TXA_2/PGI_2) increases with age indicating a greater tendency for thrombi formation in old than in young age *(Jørgensen, 1982)*. Prostacyclin decomposes to 6-keto-$PGF_{1\alpha}$ *(Johnson et al., 1976)*.

Arachidonic acid was found to follow another pathway in platelets catalyzed by a lipoxygenase, whereby the hydroperoxide 12-HPETE (12-hydroperoxy-5, 8, 10, 14-eicosatetraenoic acid) and the hydroxy derivative 12-HETE (12-hydroxy-5, 8, 10, 14-eicosatetraenoic acid) were formed as shown in Figure 2.2 *(Hamberg and Samuelsson, 1974)*. 12-HPETE but not 12-HETE was found to be a possible regulator of thromboxane synthesis *(Hammerström and Falardeau, 1977)*.

On reaction with molecular oxygen arachidonic acid may be converted by a lipoxygenase to noncyclized C_{20} carboxylic acids with one or two oxygen substituents and three conjugated double bonds, the so-called leukotrienes (LT), which were first identified in leukocytes *(Murphy et al., 1979; Samuelsson et al., 1979)*.

As shown in Figure 2.2 the unstable leukotriene A_4 (LTA_4) is converted into leukotriene B_4 (LTB_4) and leukotriene C_4 (LTC_4), the latter being known as the slow reacting substance of anaphylaxis (SRS). Leukotriene C_4 may be converted into other cysteinyl containing derivatives of the leukotriene-4 (LT_4) family *(Samuelsson and Hammarström, 1980; Hammarström, 1981)*. The principal physiological function so far reported for leukotrienes is their capacity to cause contraction of smooth muscle, although LTC_4 has also been reported to cause an increase in the permeability of capillaries *(Hedqvist et al., 1980)*. LTE_4 and LTD_4 may play a physiological role in the immune system *(Webb et al., 1982)*.

Dihomo-γ-linolenic acid (20:3,n-6) is transformed to metabolites analogous

to those formed from arachidonic acid, i.e. endoperoxides (PGG_1 and PGH_1) *(Falardeau et al., 1976; Needleman et al., 1976)*, prostaglandins (PGE_1, $PGF_{1\alpha}$, PGD_1) (the prostaglandin-1-family) *(Bergström et al., 1964; Falardeau et al., 1976)*, thromboxanes (TXB_1, but not TXA_1) *(Falardeau et al., 1976; Needleman et al., 1976)*, and hydroperoxy and hydroxy acids through the lipoxygenase pathway *(Falardeau et al., 1976)*. Prostaglandin I (PGI_1) and leukotrienes are apparently not formed from dihomo-γ-linolenic acid *(Moncada and Vane, 1977; Samuelsson and Hammarström, 1980)*.

While arachidonic acid produces platelet aggregation through the formation of endoperoxides (PGG_2 and PGH_2) and especially thromboxane A_2, dihomo-γ-linolenic acid and PGE_1 inhibits platelet aggregation, and although its endoperoxides (PGG_1 and PGH_1) are proaggregatory, their effect is much less than those produced from arachidonic acid *(Needleman et al., 1976)*. PGE_1 has also been found to be a potent peripheral vasodilator resulting in a decrease of arterial pressure and an inhibitor of catecholamine stimulated lipolysis in adipose tissue and heart, thus being a factor in the control of thrombus formation and myocardial infarct (reviewed by *Mjøs et al., 1976)*.

Prostaglandins, endoperoxides and thromboxanes have important physiological and pathophysiological roles e.g. in the cardiovascular, gastrointestinal and reproductive systems, the skin, the central nervous system, as well as in imflammatory, immunological and metabolic reactions. Although these areas have common interest in animals and man, the interest in swine production for these compounds has mainly been concerned with the reproductive system. In sows prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) or its synthetic analogues are being used for induction of parturition (e.g. *Einarsson, 1981)* and may be used for abortion *(Schultz and Copeland, 1981)*.

The biochemistry of prostaglandins and their functions have recently been reviewed by *Vapaatalo and Parantainen (1978), Galli (1980)* and *Hansen* (1983). The role of prostaglandins in reproduction is discussed in a series of papers in *Acta Veterinaria Scandinavica, suppl. 77 (1981)* to which reviews the reader is referred for further information.

Metabolic disorders by lack of n-6 fatty acids occur if linoleic acid or n-6 family acids are lacking in the diet. The tissue concentrations of linoleic and arachidonic acid decrease, and a trienoic acid (20:3,n-9) mainly derived from oleic acid (18:3,n-9) accumulates (see Fig. 2.3) *(Nunn and Smedley-MacLean, 1938; Mead and Slaton, 1956; Fulco and Mead, 1959). Holman (1960)* used this metabolic lesion as an estimate for the degree of EFA deficiency and suggested that the ratio between eicosatrienoic and eicosatetraenoic acid (20:3,n-9/ 20:4,n-6) could be used as an index of EFA requirements in rats. He related the PUFA content of heart, erythrocytes and plasma lipids of the rat to the dietary linoleic acid content, expressed as percentage of feed energy, and showed that

a ratio of triene/tetraene in blood or heart lipids of more than approximately 0.4 indicates EFA deficiency, and a ratio of 0.2 or less that the minimum requirement of linoleate has been met. This ratio has been widely accepted as a criterion for EFA status and EFA requirement in many other species including the pig.

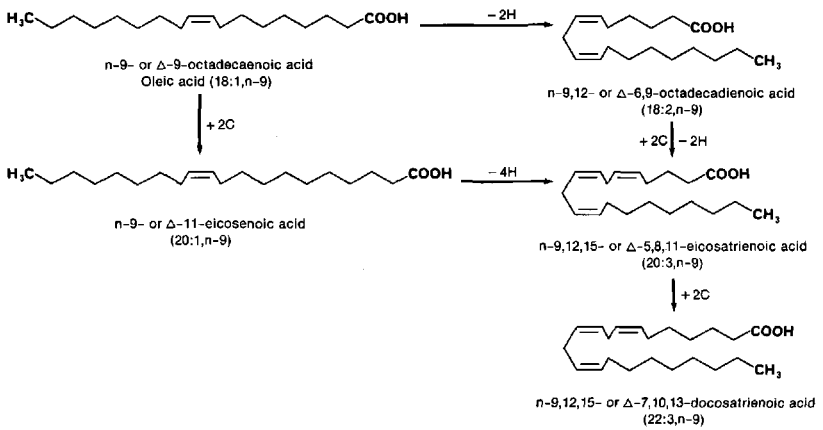

Figure 2.3. The oleic acid family also called the n-9 or ω-9 family
Oliesyrefamilien også kaldt n-9 eller ω-9 familien

20:3,n-9 is not a substrate for prostaglandin synthesis *(Struijk et al., 1966; Ziboh et al., 1974)* and may inhibit the conversion of endoperoxides into prostaglandins *(van Evert et al., 1978)*. However, it may be converted into leukotrienes (LTC_3 and LTD_3) with similar functions as the leukotrienes derived from arachidonic acid (LTC_4 and LTD_4) *(Hammarström, 1981)*.

The list of symptoms ascribed to EFA deficiency ranges from classical signs such as reduced growth rate, dermal lesions, increased water permeability of the skin, increased susceptibility to bacteria, male and female sterility, and elevated 20:3,n-9/20:4,n-6 ratios of plasma and tissue lipids *(see Review by Holman, 1970)* to recently recognized symptoms such as decreased prostaglandin biosynthesis *(van Dorp, 1971)*, reduced myocardial contractility *(ten Hoor et al., 1973)*, abnormal thrombocyte aggregation *(Hornstra, 1974)*, swelling of rat liver mitochondria *(Houtsmuller et al., 1969)*, and increased heat production *(Müller, 1975)*. These and other defects in EFA deficiency in insects, birds, various mammals and man have been described and commented upon in many excellent reviews (see e.g. *Aaes-Jørgensen, 1961; Holman, 1968; Mead, 1968; Guarnieri and Johnson, 1970; Vergroesen, 1976)*.

Some of the deficiency symptoms may be caused by the lack of PG's as for example the dermal changes *(Privett et al., 1972; Ziboh and Hsia, 1972)* or by the lack of PG's or thromboxanes as for instance the alterations in platelet function *(Hornstra and Haddeman, 1975; Bult and Bonta, 1976)*, but many consequences of dietary EFA deficiency cannot be prevented by supplementation with PG's even over a long period of treatment *(Kupiecki et al., 1968)*. The fact that the total production of prostaglandin metabolites is about 1 mg/24 h *(Nugteren, 1975)* and the dietary intake of linoleate by human beings about 10 g/day, a factor of at least 10,000 between the linoleic acid intake and excretion of prostaglandin metabolites, makes it probably for arachidonic acid and dihomo-γ-linolenic acid to fulfill a multiple function: That of precursors of the prostaglandin-2- and the prostaglandin-1-family, respectively, and that of essential building units of the membranes *(van Dorp, 1976)*.

2.1.2 The linolenic acid family (n-3 family)

Linolenic acid (α-linolenic acid, all-cis-9,12,15-octadecatrienoic acid or 18:3,n-3 or 18:3,ω-3) is also an essential fatty acid, as it cannot be synthesized in the mammalian organism.

The major metabolic pathway of the conversion of linolenic acid to long chain polyunsaturated fatty acids is as follows:

(2.2) 18:3,n-3 → 18:4,n-3 → 20:4,n-3 → 20:5,n-3 → 22:5,n-3 → 22:6,n-3

This series of fatty acids is called the linolenic acid family or the n-3 family (older nomenclatureω-3). It is essential that they all have the first double bond at the third carbon atom counted from the carbon atom of the methyl group, and thus they all have the general formula: CH_3-CH_2-CH=CH-R (cf. Fig. 2.4).

There are no interconversions between the n-6 and the n-3 families, but the presence of one of them may suppress the conversion of the other *(Mohrhauer and Holman, 1963; Holman, 1964)*.

Linolenic acid is present in relatively small amounts in almost all seeds and oils, but in relatively great amounts in grass and linseed. The other PUFAs of the n-3 series are naturally abundant in fish and fish oils.

The PUFAs of the n-3 series are very actively incorporated into tissue phospholipids, and their concentrations, especially that of 22:6,n-3, are particularly high in the brain or cerebral cortex, retina, spermatozoa and testis (rev. by *Tinoco et al., 1979)*. 20:5,n-3 (all-cis-eicosa-5, 8, 11, 14, 17-pentaenoic acid) is furthermore the precursor of the n-3 series' endoperoxides PGG_3 and PGH_3 *(Needleman et al., 1976)*, prostaglandins PGE_3, $PGF_{3\alpha}$ etc. *(Bergström et al., 1964; van Dorp et al., 1964)*, thromboxanes TXA_3, TXB_3 *(Needleman et al., 1976)*, prostaglandin I_3 (PGI_3) *(Needleman et al., 1979)* through the cyclooxygenase pathway, and to leukotrienes LTA_5, LTB_5, LTC_5 etc. *(Samuelsson*

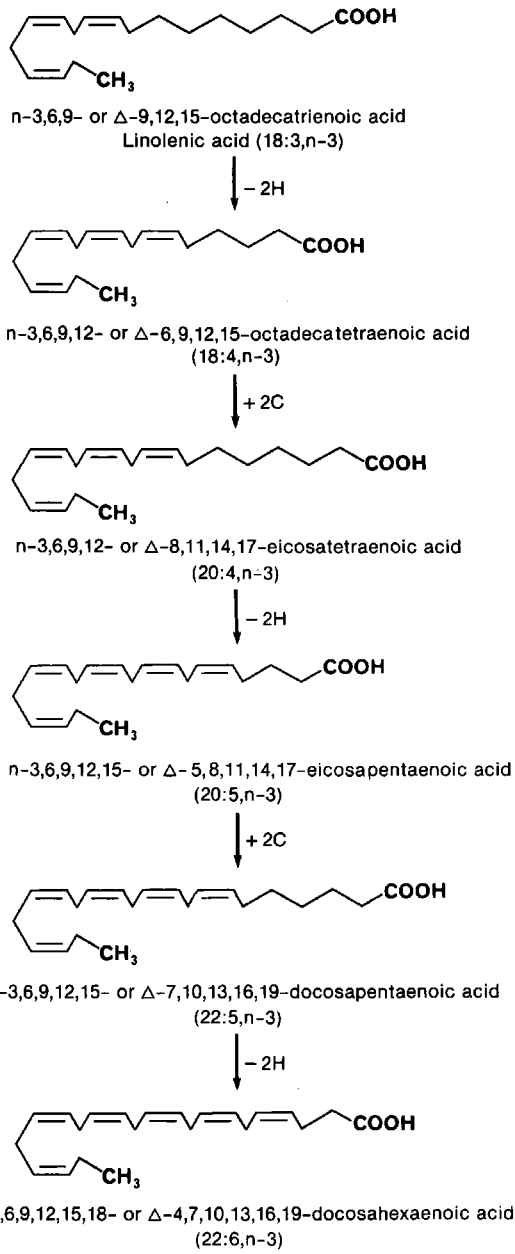

Figure 2.4. The linolenic acid family also called the n-3 og ω-3 family
Linolensyrefamilien også kaldt n-3 eller ω-3 familien

and Hammarström, 1980) and HEPE *(Needleman et al., 1979)* through the lipoxygenase pathway in a similar manner as shown for arachidonic acid in Figure 2.2.

Metabolic disorders by lack of n-3 fatty acids

Linolenic acid has been found to permit growth, but is unable to prevent the skin lesions of EFA deficiency and to support reproduction in EFA deficient rats *(Quackenbush et al., 1942; Leat and Northrop, 1979; 1980).* Differences in physical activity and ability to learn have been related to a low concentration of 22:6,n-3 in the brain of rats fed low linolenic acid levels *(Lamptey and Walker, 1976).* 20:5,n-3 causes a diminution in platelet aggregation and extension of the bleeding time *(Dyerberg and Bang, 1979; Sanders et al., 1980),* the mechanism of action still being unsettled. In some fish and shellfish linolenic acid is the only or main EFA required for growth and reproduction *(Tinoco et al., 1979; Yu et al., 1979).* Because of the discovery of its metabolic products, the interest in the linolenic acid family is increasing, and it might be expected that the use of fish meal for sows, boars and piglets would also embrace the beneficial effects of the n-3 polyunsaturated fatty acids.

2.1.3 Other essential fatty acids

According to *Holman (1958)* the term »essential fatty acids« should be limited to those polyunsaturated fatty acids which promote growth and prevent skin lesions, a definition which would limit the group to the n-6 family acids. The findings, however, that PUFAs with 20 carbon atoms derived from linoleic and linolenic acid, are the natural substrates in tissues for the formation of prostaglandins, thromboxanes and leukotrienes, certainly prove the essentiallity of both linoleic and linolenic acid.

The situation about the term »essential fatty acid« is still not too clear, because also other fatty acids with different chain lenghts (C17-C19-C20-C21-C22) and different number of double bonds can be converted into prostaglandins and possess biological activity *(Gurr and James, 1975).*

In the present report, the term »essential fatty acid« will be attributed to the members of the linoleic acid family, unless otherwise indicated. The importance of dietary linolenic acid has not been studied in pigs, and is not treated separately in the present studies.

Linoleic acid and linolenic acid do not occur as free acids in plants or animal tissues, but in esterified form as glycosyl glycerides in plants and as triglycerides or phospholipids in animal tissues. Free fatty acids may occur in waste fats or oils and may constitute as much as 4.5% of the feed without any deleterious effect on performance and production traits except for the softness of the fat depots which unsaturated fatty acids insert *(Mortensen et al., 1983).* In the present

report *the terms linoleic acid and linolenic acid will be used synonymously with linoleate and linolenate, respectively.*

2.2 The EFA deficiency syndrome in pigs

EFA deficiency symptoms are not readily produced in swine. *Ellis and Isbell (1926a)* and *Ellis and Zeller (1930)* reared pigs on diets containing only 0.5% ether extractable fat, but observed no signs of EFA deficiency. However, *Shrewsbury and Vestal (1945)* observed that rations containing 0.5% fat did not influence the rate of gain, but slightly lowered the utilization of feed compared to diets containing 2.0, 3.5 and 5.0% fat added as soya bean oil. In studies by the same authors diets containing 0.5, 5 and 20% fat included as soya bean oil were compared, and here pigs receiving 0.5% fat had a slightly slower rate of gain and a slightly reduced feed utilization *(Shrewsbury and Vestal, 1946)*.

Beeson and Kennelly (1947) first produced pronounced fat deficiency symptoms in growing pigs. This deficiency disease was characterized by dissatisfaction with the diet, scaliness of the skin, poor hair growth, increased amounts of hyalin-like materials in the kidneys, and low red and white blood cell counts. No detailed information about animals and diets is, however, available. By feeding highly purified diets based on glucose and casein containing 0.06 or 0.12% ether extractable fat to pigs from a weaning weight of 16–22 kg, *Witz and Beeson (1951)* observed the following fat deficiency symptoms after 42 days: A scaly dandruff-like dermatitis on the tail, back and shoulders. Loss of hair, the remaining hair being dull and dry. A gummy exudate on the belly and sides. Necrotic areas on the skin about the neck and shoulders. An unthrifty appearance. After 63 days on the diets the symptoms became quite severe, and after 77 days two pigs of a total of 4 receiving 0.06% ether extractable fat died. The latter pigs further showed the following fat deficiency symptoms: Slower growth rate and reduced efficiency of feed utilization; underdeveloped digestive system; a very small gall bladder with little or no bile; enlarged thyroid gland and retarded sexual maturity. Adding 1.5% con oil to the diets of the remaining pigs caused an immediate increase in growth rate and some recovery of other deficiency symptoms. No attempt was made to study the involvement of specific fatty acids, bud clearly such a purified diet contains very small concentrations of EFAs presumably of the order of 0.01% to about 0.05% of gross energy.

These early studies do not specifically investigate the need of swine for EFAs. Studies of EFA deficiency in pigs have been particularly difficult because of inability to deplete the weanling piglet of its stores of EFAs within a reasonable length of time. The availability of baby pigs obtained by hysterectomy and raised without colostrum and sow's milk on a purified diet made further studies on the development of the EFA deficiency symptoms in pigs

possible *(Hill et al., 1957)*. Attempts were also made to accelerate EFA deficiency by feeding cholesterol *(Hill et al., 1957)*.

Hill et al. (1957) used 15 miniature swine and 7 chester whites taken by hysterectomy for their studies on EFA deficiency symptoms. Dermal lesions were observed in only one pig, but some of the pigs developed a very rough hair coat. The deficient diet (0.14% dienoic acid) caused poor growth and listlessness, and only 8 pigs survived beyond the weaning age of 56 days. Of these, 5 pigs showed aortic lesions at or before 98 days on experiment. Later, however, *Hill et al. (1961)* attributed the aortic lesions to a magnesium deficiency. The longer the pigs were on the low EFA diet, the lower was the concentration of dienoic and tetraenoic acids in heart and liver lipids *(Hill et al., 1957)*.

The concentration of eicosatrienoic acid (20:3,n-9) in heart and liver lipids *(Hill et al., 1961)* and plasma lipids *(Leat, 1961a; b; 1963)* increased in *EFA deficient pigs. The ratio between eicosatrienoic acid (n-9) and eicosatetraenoic acid (n-6) as used previously by Holman (1960)* as an index of EFA status in rats was confirmed to be valid in pigs *(Hill et al., 1961; Caster et al., 1962; Leat, 1962)*, and this ratio has been used extensively to describe the EFA status in pigs. *Mason and Sewell (1966)* analyzed tissue samples from 15 sites of the carcass of pigs fed fat free diets for 13 weeks and found that except for the brain lipids, the fat free diets resulted in signigicantly lower levels of linoleic and arachidonic acid and significantly higher levels of oleic and eicosatrienoic acid compared to samples from pigs receiving either 10% corn oil or 10% beef tallow.

The described changes in the fatty acid pattern of almost all tissues and organs and in blood lipids of pigs receiving deficient amounts of EFAs have been found to be more reliable indices of EFA status than any other observed deficiency symptoms *(Hill et al., 1961; Caster et al., 1962; Leat, 1962; Sewell and Miller, 1966)*. As a matter of fact contradictory findings have been observed concerning all other parameters, as reviewed shortly in the following.

High mortality as observed in the early studies of EFA deficiency defects in pigs by *Witz and Beeson (1951)* and *Hill et al., (1957)* has not been observed by other authors.

Dermal lesions and loss of hair as described by *Witz and Beeson (1951)* have more or less been confirmed in the studies by *Leat (1959; 1961b; 1962), Sewell and Miller (1966), Babatunde et al. (1967)* and *Allt et al. (1969)*. Dermal lesions were only observed in one pig receiving 0.14% dienoic acid in the diet by *Hill et al. (1957)*, but in later studies including 25 pigs on semi synthetic diets no pigs showed any dermal changes *(Hill et al., 1961)*. This was also not the case with pigs receiving semi synthetic diets based on sucrose and casein from 5 to 90 kg live weight *(Gresham et al., 1964)* or in pigs reared on low fat diets containing 0.4% of the dietary energy as linoleate from a live weight of 20 to 90 kg *(Christensen, 1973)*. Even if skin lesions may occur as a consequence of EFA defi-

ciency in pigs, the validity of this parameter as a criterion of EFA status, is disputable. Such factors as temperature and humidity *(Brown and Burr, 1936)*, physical contact *(Leat, 1962)*, and the fat source *(Babatunde, 1967)* are known to affect the appearance of the skin. Also it is a well known fact that the well-being of the animal is of great importance for the development of the hair coat, and any changes from optimum environmental conditions (e.g. changes in feed composition, energy and protein level, supply of essential nutrients, rearing conditions, hygiene, physical and psychical stress) may affect the appearance of the skin and the hair coat.

Growth rate depression of pigs fed fat free diets or diets low in EFAs was observed by *Witz and Beeson (1951)* in pigs receiving 0.06% fat, but not in pigs receiving 0.12% fat in the diet. *Hill et al. (1957; 1961)* using pigs obtained by hysterectomy and fed an EFA deficient diet confirmed the need for EFAs for normal growth. However, early weaned piglets (approx. 3 weeks old) reared on semi purified diets until 90 kg live weight containing 0.03% of the dietary energy as linoleate did not show any reduced weight gain *(Leat, 1959; 1962)*, and later studies with EFA deficient diets have also failed to confirm a reduction in weight gain *(Howard et al., 1965; Sewell and Miller, 1966; Sewell and McDowell, 1966; Babatunde et al., 1967; Christensen, 1973)*. As concluded by *Sewell and Miller (1966)* growth rate does not appear to be a reliable criterion in ascertaining EFA adequacy in pigs.

Reduced feed utilization as a consequence of EFA deficiency in pigs was observed by *Shrewsbury and Vestal (1945; 1946), Witz and Beeson (1951), Hill et al. (1957), Leat (1959), Sewell and McDowell (1966) and Allt et al. (1969)*, but not by *Leat (1962), Howard et al. (1965)* and *Sewell and Miller (1966)*. A reduced feed utilization has been attributed to an increased metabolic rate or heat production in rats *(Wesson and Burr, 1931; Müller, 1975)* possibly caused by an uncoupling of oxidative phosphorylation *(Levin et al., 1957; Hayashida and Portman, 1960)*. A reduced phosphorylation capacity was noted in liver, heart and skeletal muscle mitochondria of EFA deficient pigs, but in these studies the effect on the feed utilization could not be tested as the pigs were group fed *(Christensen, 1973; 1974a)*.

Organ changes as found by *Witz and Beeson (1951)* have not been confirmed by other authors. *Leat (1961b)* found no abnormality at slaughter (90 kg live weight) in any organs of pigs fed 0.07% of the dietary energy as linoleate from weaning at about 3 weeks of age. *Gresham et al. (1964)* raised pigs from about 5 to 90 kg live weight on semi synthetic diets based on sucrose and casein to study the pathological changes in pigs receiving no fat, 10% beef tallow, 10% maize oil or a commercial ration. They observed no pathological changes produced by the no fat diet except a centrilobular fatty change in the livers. Here the phospholipid content was decreased, and cholesterol esters had accumu-

lated. Muscular dystrophy was claimed to develop in EFA deficiency (Siedler et al., 1964), but this was later rejected by *Holman et al. (1965)*. Muscular dystrophy was found to be related to vitamin E deficiency, rather than to linoleate intake by swine *(Tanhuanpää, 1965)*. Histological examination of the longissimus dorsi muscles of swine receiving 0.4% of the dietary energy as linoleate from 20 to 90 kg live weight, showed some changes in the connective tissue and myofibrils *(Christensen, 1974b)*. These studies also showed that the pigs receiving deficient amounts of dietary linoleate had blue lungs at slaughter, probably caused by an insufficient function of the heart. The hearts were dilated, and the wall of the left ventricle thin and pale. *Babatunde (1967)* did not observe any effects of EFA deficient diets on the weights of the liver or heart of swine. Changes in the lipid content of various organs have been observed as a consequence of feeding various levels of EFAs. Elevated levels of total lipids were found in liver and heart of EFA deficient pigs *(Babatunde et al., 1967)*, whereas decreased levels of total lipids were found in skeletal muscle and back fat of EFA deficient pigs compared to pigs receiving 6.4% of the dietary energy as linoleate *(Christensen, 1973)*. Total lipid concentrations were smaller in the mitochondria of skeletal muscle, heart and liver of EFA deficient pigs, but the phospholipid concentrations were not affected *(Christensen, 1974a)*. Total liver cholesterol was increased by EFA deficient diets, whereas heart cholesterol levels were not affected *(Babatunde et al., 1967)*.

Carcass composition. The proportions of meat, fat and bone was not influenced by EFA deficiency *(Witz and Beeson, 1951; Leat, 1962; Leat et al., 1964; Babatunde, 1967; Christensen, 1974b)*. However, the relative distribution of depot fat in the carcass appears to be affected. Thus, the feeding of fat free diets resulted in proportionately more intermuscular fat and less subcutaneous fat when pigs were fed 10% beef tallow or 10% corn oil *(Leat et al., 1964)*. Smaller subcutaneous fat layers were also found in pigs on fat free diets or diets containing 1% safflower oil, but the differences were not significant *(Babatunde, 1967)*.

Meat quality was found to be adversely affected in EFA deficient pigs, the pigs showing pale, soft and exudative meat *(Christensen, 1969; 1974b)*.

Blood parameters. Low red and white blood cell counts as observed by *Beeson and Kennelly (1947)* were not found by *Witz and Beeson (1951)* or other investigators. Erythrocyte fragility did not seem to be a reliable criterion for measuring EFA deficiency in pigs *(Babatunde, 1967)*. The blood hemoglobin and hematocrit concentrations were not adversely affected by semi synthetic diets containing no fat or 1–3% hydrogenated coconut oil *(Babatunde, 1967)*. Elevated blood plasma lipid levels were found in EFA deficient pigs *(Witz and Beeson, 1951; Babatunde et al., 1967)*. Levels of total fatty acids of blood serum *(Leat, 1961b; 1962)*, total cholesterol, free cholesterol and total phospholipids

(Howard et al., 1965) were unaffected of the dietary levels of linoleate. However, changes in the relative distribution of various phospholipids occured as a consequence of the dietary linoleate level. When the dietary linoleate level decreased to less than 1% of the energy intake, the percentage of lecithin in serum phospholipids increased at the expense of lysolecithin and sphingomyelin *(Leat, 1964a)*. A similar trend was found in pigs receiving a semi synthetic diet containing no fat or 10% beef tallow compared to pigs receiving 10% maize oil or a commercial ration *(Howard et al., 1965)*. Total serum protein concentrations were unaffected in pigs receiving a semi synthetic no fat diet, 10% beef tallow, 10% maize oil or a commercial diet *(Howard et al., 1965)*, but significantly depressed in pigs receiving a semi synthetic diet with no fat or 3% hydrogenated coconut oil compared to pigs receiving graded levels of safflower oil *(Babatunde et al., 1967)*. The levels of corticosteroids in plasma of EFA deficient pigs were significantly lower than in pigs supplied with linoleic acid, indicating that EFA deficiency may lead to stress susceptibility *(Christensen, 1974b)*.

The source of carbohydrate and protein may affect the severity of the deficiency symptoms. Thus, *Campbell and Sewell (1966)* observed dermal lesions characteristic of EFA deficiency in pigs fed glucose or sucrose as the only source of dietary carbohydrate, but not in pigs receiving corn starch. The triene/tetraene ratio of testicular lipids was significantly greater for pigs on the sucrose diet compared to pigs receiving glucose, the latter having a higher ratio than pigs receiving corn starch. *Campbell and Sewell (1966)* also found a significant increase in the arachidonate content of testicular tissue from pigs fed 36% protein as compared to pigs receiving either 18% or 9% protein.

2.3 Studies on EFA requirements in pigs

Classically, the minimum requirement of a nutrient is defined as that amount which will prevent the development of any of the signs of dietary deficiency. Conversely, an intake that does not allow a maximum growth rate, or results in metabolic changes indicative of the deficiency conditions, is defined as an intake below the minimal requirement, i.e. a deficient intake or a deficient diet. The determination of the minimum requirement requires groups of animals which are fed experimental diets containing increasing levels of the nutrient in question from zero or deficient amounts to above maximum levels. The smallest significant change in response that can be measured is dependent upon the precision and sensitivity of the experimental method and the variation between animals.

As for the determination of minimum requirements of EFAs in pigs, the various deficiency symptoms described in section 2.2 have been used as criteria for an adequate or inadequate supply. Most studies only imply two or three distinct

levels of dietary EFAs, which in all cases is linoleate, provided as the methyl ester or usually as an oil (olive oil, safflower oil, soya bean oil, corn oil). Only few studies involve more levels from which the minimum requirement may be derived.

In the studies of *Hill et al. (1961)* the minimum requirement for dietary linoleate was determined with sixty-six miniature swine fed purified diets based on glucose and casein varying in lonoleate level from 0.02 to 12.9% of energy intake. Thirteen different levels of linoleate were implied. Basal diets were supplemented with ethyl linoleate or corn oil. The linoleate requirement was deduced from the plot of triene/tetraene ratio of heart and liver lipids versus dietary linoleate concentration. From these curves and the weight gains, the dietary requirement was stated to be near 2 energy%. The pigs were taken by hysterectomy and deprived of sow's colostrum and milk. They were reared on the experimental diets from one to three weeks of age until an age of 56 to 77 days for most of the pigs.

Leat (1961a;b) raised 6 cross-bred pigs from weaning at 3 days of age for 21 weeks (90 kg live weight) on diets based on cassava, dried skim milk, extracted palm kernel cake and dried brewer's yeast supplemented with olive oil providing from 0.03 to 3.5% of the total dietary energy as linoleate (one pig per group). The relationship between dietary linoleate intake and the trienoic/tetraenoic acid ratio in the fatty acids of plasma, liver and heart lipids indicated a minimum linoleate requirement of 0.95% of the total dietary energy.

From the studies of *Leat (1962),* however, it appears that the requirement of the pig for EFAs is not constant throughout the growth period, but is maximal in the first 16 weeks of life. During this period the minimum requirement for EFAs was found to be between 1 and 2% of dietary energy estimated from the relationship between linoleate intake and the trienoic/tetraenoic acid ratio of serum lipids. When the first 24 weeks of life were examined in entity, however, 1% of the dietary energy was sufficient to prevent the metabolic lesion from developing. Animals and diets were similar to those used previously *(Leat, 1961a).* All dietary levels were sufficient to secure normal growth rate. The minimum requirement for linoleate to prevent a normal skin development appeared to lie between 0.07 and 0.28% of dietary energy intake.

Sewell and McDowell (1966) fed three weeks old cross-bred uncastrated male pigs six various levels of linoleate ranging from 0.02 to 4% of the dietary energy for 10 weeks (4 pigs per group). The diets were based on glucose and casein and linoleate was supplied as corn oil. Weight gain was not significantly influenced by the dietary linoleate level. The efficiency of feed utilization was increased as the linoleic acid content of the diet was increased, but the requirement of linoleate using this parameter as an estimate cannot be evaluated since the pigs were group fed and the diets were not iso-energetic. The requirement for

linoleate to prevent dermal lesions was found to be 1% of dietary energy intake. A plot of the triene/tetraene ratio of testes lipids versus the dietary linoleate level showed that the linoleate requirement was no more than 2% of the dietary energy intake. As indicated by *Sewell and McDowell (1966)* no statistical significance was found between the groups receiving 2% or more of the energy intake as linoleate, but as pointed out by *Riis (1970)* an increase in weight gain and a decrease in feed utilization in the studies of *Sewell and McDowell (1966)* is actually seen until a linoleate intake of 4% of the dietary energy. The discrepancy in interpretation of the results of the studies by *Sewell and McDowell (1966)* is apparently due to a different attitude to determination of requirements. Surely, the interpretation of the results by *Sewell and McDowell (1966)* is that of determination of minimum requirements, whereas that of *Riis (1970)* is an evaluation of recommended requirements or allowances. In the latter case the individual differences in sensitivity to deficiency should be encountered. The various interpretations of the term requirement has been discussed extensively *(Christensen, 1980; 1983)*.

The studies of *Nørby et al. (1967)* show that young boars of the Danish Landrace breed (8 months of age) fed 10,20 or 40% of the dietary energy as butter for 26 weeks corresponding to a dietary linoleate intake of less than 1.8% of the amount of feed had triene/tetraene ratios of plasma lipids between 0.25 and 0.85 indicating a marginal intake of linoleate. At slaughter after about 400 days on the respective diets, however, the triene/tetraene ratios of plasma lipids were about 0.2. These results indicate that the requirement for linoleate is greater for young animals than for adult animals.

2.4 Conclusion

The above mentioned experiments on determination of EFA requirements in pigs show that the magnitude of minimum requirement depends on age and EFA status of the tissues before the experimental period, which again depends on the piglet's supply of EFAs before and after birth, its sex and the criterion chosen for assessing deficiency symptoms. Thus, the minimum linoleate requirement of pigs seems to lie between zero and 2% of the dietary energy intake.

The criteria used for assessment of EFA status in pigs are summarized in Table 2.1.

Table 2.1 Effects (+) or no (−) effects of EFA deficieny in experiments with pigs
Tabel 2.1 Effekter (+) eller ingen (−) effekter af EFA mangel i forsøg med grise

Daily gain	±
Feed conversion efficiency	±
High mortality	±
Dermal lesions	±
Loss of hair	±
Organ weights	±
Histological changes in organs	±
Chemical composition of organs	±
Carcass composition	±
Meat quality	(+)
Blood parameters	±
20:3,n-9/20:4,n-6 in plasma and tissue lipids	+

(+) only measured by one author (Christensen, 1974b)

III. Materials and methods

3.1 General outline of experiments

The present investigations were carried out in 6 series (B-C-D-E-G-H) with a total of 56 Danish Landrace pigs, 24 females (sows:s) and 32 castrated males (barrows:b) distributed as shown in Table 3.1. During the growth period from 10 to 100 kg live weight the pigs received different proportions of the dietary gross energy as linoleic acid ranging from 0.04 to 9.5% (energy%).

Table 3.1 Allocation of barrows (b) and sows (s) in the different series, their initial and final age and live weights

Tabel 3.1 Fordeling af galte (b) og sogrise (s) på de forskellige serier samt deres alder og legemsvægte ved forsøgets begyndelse og afslutning

Ser.	Linoleate	No. of pigs		No. of balances		Mean of age, days		Mean of weight, kg	
No.	energy%	b	s	b	s	Initial	Final	Initial	Final
B	0.4	4	0	28	0	84	182	23.1	93.5
	9.5	4	0	22	0	86	184	23.6	103.8
C	0.04	2	2	6	6	108	150	25.0	50.6
	0.2	2	2	5	5	110	152	26.0	49.6
D	0.3	1	1	4	4	40	96	11.3	39.3
	1.0	1	1	4	4	42	98	10.9	39.2
	2.0	1	1	4	4	47	103	11.2	39.6
	2.7	1	1	4	4	49	105	10.7	40.5
E	0.1	1	1	8	3	53	165	14.6	88.3
	0.8	1	1	8	8	55	167	14.3	88.8
	1.5	1	1	7	6	60	172	13.8	88.6
	2.2	1	1	6	6	62	174	13.6	88.5
G	0.2	2	2	10	10	56	161	16.6	85.4
	1.1	2	2	6	10	59	164	16.6	87.0
	2.1	2	2	10	10	63	168	16.8	87.3
H	0.7	2	2	10	10	54	152	14.5	77.5
	1.6	2	2	10	10	57	155	14.2	75.8
	2.3	2	2	10	10	60	158	14.0	76.5
Total or Mean		32	24	162	110	64	150	16.2	72.2

Each pig was submitted to a minimum of three and a maximum of eight balance periods including the determination of digestibility of energy and feed components, nitrogen and carbon balances, and gas exchanges. Thus a total of 272 balance periods have been performed comprising 162 trials with barrows and 110 with sows (cf. Table 3.1).

For specific studies on the fatty acid composition of bile lipids three pigs from another series of experiments (Series K) were included.

The first part of the following is a description of the general treatment of the animals, whereas the second part is a more detailed description of the animals and their treatment in the individual series.

3.1.1 Description of animals

All pigs were bought from a production herd with sows and piglets. The piglets were selected from litters with 12–16 pigs and were always from the third to the fifth litter of the mother sow. They were weaned at 5 to 8 weeks, preferably at 6 weeks of age. After weaning they were transported by car to the National Institute of Animal Science (NIAS), Copenhagen, a distance of about 35 km. This transportation and the sudden change from one environment to another gave some problems with diarrhoea. To minimize the risk for diarrhoea the piglets were kept in the same pen on the day of arrival and had free access to a solution of glucose, NaCl and $NaHCO_3$ (50, 5 and 2.5 g per litre of water, respectively). No feed was offered. They were gradually given a mixture of barley, skim milk powder (spray), minerals and vitamins. Water was supplied ad libitum. If no troubles occurred, the piglets were penned individually. All piglets were dewormed for 7 days receiving 1 g pipirazinphosphate daily in their feed. The piglets were tested for stress susceptibility by means of a halothane test *(Sybesma and Eikelenboom, 1969)*. They were anaesthetized with 5% halothane solution (Halothanum NFN (2-Brom-2-chlor-1,1,1-trifluorethan) stabilized with 0.01% w/w tymol) aerated with oxygen (1.5 litre per min.). If they did not react within 3 min. of narcosis, they were termed halothane negative. All pigs used for the present investigations were halothane negative.

While the pigs were still in narcosis the extremities and the belly were washed with 2% Neguvon® vet. metrifonat solution against scabies. At the same time they received an intramuscular injection of 60 mg retinol (Avimin® Ido aquosum vet., Ferrosan Ltd., Copenhagen, Denmark), 0.5 mg cholecalciferol (Ultranol® aquosum vet., Ferrosan) and 200 mg α-tocopherol (α-tocopherylacetate, Ido-E aquosum vet., Ferrosan). A similar injection of vitamins was repeated when the pigs weighed about 40 kg. A blood sample was taken from *vena cava* for determination of the acid/base status of the blood and the fatty acid composition of plasma total lipids. The results from these analyses will be presented in subsequent papers. The pigs were weighed, numbered and distributed on the various groups of the series in question according to litter, sex and live weight. Gradually they received the experimental diet. When they had received full ration for at least two days, they were ready to enter the experimental period.

3.1.2 The experimental period

The experimental period during which the pigs solely received the experimental diet was divided into a number of balance periods of 2 or 3 weeks each. The preliminary periods were of 1 or 2 weeks' duration, whereas the collection periods always lasted 7 days. In the preliminary period the pigs were kept individually in pens (160 × 160 cm) on concrete floor with wooden-gratings in the beddings and without straw. During the collection period the pigs were placed in metabolic cages (140 × 70 cm) on steel wire bottom (mesh size 2 × 2.5 cm; wire diameter 0.5 cm) allowing a quantitative collection of faeces and urine *(Thorbek, 1975)*. In the middle of the collection period the pigs were placed for 24h in respiration chambers to measure their gas exchange. The pigs were weighed in the afternoon before entering the metabolic cages and again at the end of the collection period, in both cases before receiving their feed. The average live weight during the collection period coincides with the day of respiration trial. The average live weights and the age of the pigs at the beginning and end of the experimental period are shown in Table 3.1. The number of days on experimental diets and the average live weights of the pigs during the collection periods in the individual series are apparent from Tables 3.8–3.13. After having finished the experimental period the pigs were used for several other investigations. The results from these experiments will not be presented here.

3.1.3 Feed composition

Source of energy and linoleate. The principle for feeding the experimental animals was to supply all of them with the same daily amounts of energy, protein, minerals and vitamins, but with different amounts of linoleic acid ranging from 0 to 10% of the daily gross energy intake (energy%).

For reasons which will be discussed in section 3.2 it was found impossible to compose a fat free diet or a fat enriched diet which *1.* contained no linoleic acid, *2.* was physiologically optimal, and *3.* palatable.

Different feed compounds were used in the various series as shown in Table 3.2. Trace minerals and vitamins were added to provide the amount per kg mixture shown in Table 3.3.

As shown in Table 3.2 the basal diets contained from less than 0.05 to 0.4 energy% linoleic acid. Soya bean oil (Manchu extra, Danish Soyacake-factory Ltd., Copenhagen, Denmark) was added to the basal diets as a source of linoleic acid substituting an iso-energetic weight of either glucose or potato meal. Soya bean oil was chosen because its concentrations of linoleic and linolenic acids resemble those of barley as shown in Table 3.4. *In the following linoleic acid will be used synonymously with linoleate.*

When substituting glucose or starch with oil on iso-energetic basis, a difference in weight occurs. This difference may be levelled out in two ways, either

Table 3.2 Composition of the basal diets used in the different series of experiments (%)
Tabel 3.2 Sammensætning af basalfoderet i de forskellige forsøgsserier (%)

Compounds	B	C	D	E	G+H
Glucose[a)]	6.5	69.0	69.0	29.0	–
Sucrose	6.5	–	–	–	–
Maize starch	29.2	–	–	–	20.0
Potato meal	–	–	–	–	20.0
Tapioca meal	18.5	–	–	20.0	30.0
Maltodextrin[b)]	–	–	–	20.0	–
Casein	8.0	20.0	20.0	20.0	20.0
Skim milk powder (spray)	16.0	–	–	–	–
Soya bean meal	8.0	–	–	–	–
Cellulose	3.3	5.0	–	–	–
Beech sawdust	–	–	5.0	6.0	5.0
Mineral mixture[c)]	3.0	5.0	5.0	4.0	4.0
Trace mineral-vitamin mixture[d)]	1.0	1.0	1.0	1.0	1.0
Linoleate, energy%	0.4	<0.05	<0.05	0.1	0.2
App. dig. of DM, %[e)]	93	96	93	91	88

[a)] Cerelose dextrose monohydrate. [b)] Partly hydrolyzed maize starch.
[c)] 60% $CaHPO_4$, 20% K_2HPO_4, 14% NaCl, 6% $CaCO_3$. [d)] see Table 3.3.
[e)] see Table 5.1.

by adding the weight difference as an indigestible compound or by reducing the amount of feed supplied to the pigs receiving oil. The latter method has been used in the present investigations. This means that the diets were not iso-energetic (cf. Table 3.5 and 3.6), but the pigs were fed iso-energetically (cf. Tables 3.9–3.13).

Source of protein. According to previous experience in measuring nitrogen and energy metabolism with a maximum of nitrogen retention and a minimum

Table 3.3 Supplementation of trace minerals and vitamins per kg diet
Tabel 3.3 Tilsætning af mikrominerale og vitaminer pr. kg foder

MgO	700 mg	Thiamin	10 mg
Ferrous fumarate	200 mg	Riboflavin	10 mg
$MnSO_4$	125 mg	Niacin	50 mg
ZnO	125 mg	Pyridoxine	20 mg
$CuSO_4$	125 mg	Pantothenic acid	25 mg
$CoSO_4$	10 mg	Biotin	500 μg
KJ	1 mg	Folacin	2 mg
Na_2SeO_3	20 μg	Cyanocobalamin	40 μg
Retinol	1.5 mg	Inositol	100 mg
Cholecalciferol	25 μg	Choline	1 g
α-tocopherol	40 mg	Ethoxyquin	125 mg
Menadione	5 mg		

Table 3.4 Fatty acid composition of soya bean oil and barley (weight %)
Tabel 3.4 Fedtsyresammensætning af sojaolie og byg (vægt %)

Fatty acids	Soya bean oil	Barley
Lauric acid (12:0)	trace	(0.1)
Myristic acid (14:0)	(0.1)	(<1)
Palmitic acid (16:0)	10 (8–12)	20 (16–25)
Palmitoleic acid (16:1)	(trace)	(<1)
Stearic acid (18:0)	2 (2–3)	1 (1–2)
Oleic acid (18:1)	26 (19–29)	12 (11–13)
Linoleic acid (18:2)	54 (52–56)	58 (54–62)
Linolenic acid (18:3)	8 (6–10)	9 (6–10)
Linoleic acid/Linolenic acid (18:2/18:3)	6.8	6.4

of heat increment caused by excretion of superfluous nitrogen in the urine *(Thorbek, 1975)*, the diets were planned to provide 14–16% digestible crude protein until 60 kg live weight, and 10–12% digestible crude protein the rest of the experimental period. Acid-precipitated casein was used as the protein source in all experiments except series B (cf. Table 3.2). The casein contained 8.32 g of lysine and 3.37 g of methionine + cystine per 16 g N. Since the protein in casein is almost completely (99.4%) digested by pigs *(Eggum, 1973)*, the above mentioned amounts of lysine, methionine and cystine may almost be identical to the available amounts. Thus, the requirements for these amino acids seemed to be covered according to Danish standards *(Andersen and Just, 1975)*. *Eggum (1973)* also observed a much higher biological value of casein for pigs (86) than for rats (61–71), so there seemed to be no need to add any amino acids separately. From a live weight of 60 kg the protein content of the diets was reduced by substituting casein with glucose or potato meal.

Vitamins and minerals. The requirement for vitamins and minerals according to Danish standards *(Andersen and Just, 1975)* was estimated to be covered through addition of the mineral and vitamin mixtures shown in Table 3.2 and 3.3. By choosing those amounts shown in Table 3.3, the following considerations were made: *1.* A possible amount of minerals and vitamins in the basal diets was neglected. *2.* The effect on the microflora and the absorption processes of the experimental diets having somewhat altered structure and a higher digestibility than commercial feed mixtures for pigs (cf. Table 3.2) was unknown. Therefore, the vitamin concentrations were doubled compared to the standards. For pyridoxine which was found to influence the rate of development of EFA deficiency *(Witten and Holman, 1952; Zehaluk and Walker, 1973)* the concentrations were quadruple. *3.* The amounts applied to the pigs in similar studies by *Sewell and McDowell (1966), Hill et al. (1961)* and *Howard et al. (1965)*, and their remarks on the diets were also considered.

The vitamins and trace minerals were aded to the feed as a premix in glucose. It was kindly provided by Leo Pharmaceutical Products, Ballerup, Denmark.

Source of crude fibre. Beech sawdust (Mørkøv Sawmill Ltd., Mørkøv, Denmark) free from pentachlorphenol and resin, heated to 102°C was used as a source af crude fibre in most of the series (cf. Table 3.2). We simply could not afford to buy cellulose.

Chemical composition of the feed. The feed compounds were mixed thoroughly before representative samples were taken for analysis. The feed was mixed for each experimental period and the chemical composition determined for each period in question according to the *Weende* method. The average chemical composition and the standard deviation of the diets used in each series until a live weight of 60 kg and above is shown in Table 3.5 and 3.6, respectively. It is evident from Table 3.5 and 3.6 that the chemical composition was very uniform from one balance period to the other indicated by relatively small coefficients of variation (SD/mean × 100), especially when the amounts of fat were low.

The average fat percentage, the average fatty acid composition and the average energy concentration of the feed used throughout the experimental period were used for calculation of the avarage linoleate intake expressed as percen-

Table 3.5 Chemical composition of the experimental feed used in the various series until a live weight of 60 kg (mean ± SD)

Tabel 3.5 Den kemiske sammensætning af forsøgsfoderet i de forskellige serier benyttet indtil 60 kg levende vægt (gns. ± SD)

er.	Linoleate		DM	Crude protein (N×6.25)	Crude fat (HC1+EE)	Crude fibre	Crude ash	NFE	Carbon	GE	GE/ Protein
No.	energy%	n	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	MJ/kg	kJ/g N
3	0.4	5	900±1.0	183± 4.0	9.5±1.4	38± 2.0	56±0.3	614± 3.1	388± 1.5	15.76±0.07	540
	9.5	5	895±1.2	180± 5.3	93.3±1.0	30± 1.8	54±0.3	538± 5.8	417± 3.2	17.61±0.02	611
2	0.04	4	908±0.3	172± 2.3	3.9±1.2	32± 2.6	46±0.3	654± 4.6	368± 8.9	14.92±0.07	543
	0.2	4	883±0.7	170± 2.9	25.5±3.8	36± 1.9	42±0.3	609± 7.0	367±10.3	15.13±0.07	556
1	0.3	4	910±2.1	177± 7.1	7.2±5.3	32± 1.5	43±1.2	651± 8.9	375± 5.2	15.24±0.12	539
	1.0	4	910±1.5	173±15.0	12.0±3.2	36± 8.1	43±0.5	646±12.8	378± 4.3	15.37±0.02	555
	2.0	4	913±1.7	183±11.8	20.9±2.2	40±10.7	45±1.2	624±17.9	381± 1.7	15.55±0.05	531
	2.7	4	913±1.3	172±10.4	28.7±2.2	37± 7.9	45±0.6	631±17.9	383± 0.9	15.65±0.05	569
5	0.1	5	900±1.0	178± 8.0	3.8±1.0	36± 1.9	38±0.7	645± 7.8	378± 3.9	15.74±0.05	552
	0.8	5	898±0.8	171± 7.1	11.8±1.4	35± 3.1	38±0.8	643± 6.7	384± 2.2	15.91±0.12	583
	1.5	5	899±0.6	169± 8.9	20.1±1.8	37± 0.7	39±1.0	633± 9.0	386± 1.4	16.04±0.07	592
	2.2	5	900±1.5	174± 4.8	28.3±2.2	38± 1.0	39±0.9	621± 6.0	392± 3.4	16.29±0.07	586
6	0.2	3	877±2.3	189± 7.9	6.8±1.4	45± 4.8	52±0.7	585±12.5	384±10.2	15.82±0.13	524
	1.1	3	875±4.0	186± 9.7	14.9±0.9	39± 5.0	52±0.4	583±10.0	390± 9.9	15.96±0.12	536
	2.1	3	878±3.7	187± 1.3	21.7±1.4	37± 2.9	53±0.3	580± 2.7	392± 6.9	16.09±0.08	540
4	0.7	5	880±6.1	182± 6.5	11.9±1.8	40± 4.5	49±0.7	597± 3.7	390± 4.1	15.88±0.17	544
	1.6	5	877±5.2	184± 5.9	20.0±1.9	37± 4.9	48±0.8	587± 6.2	392± 4.8	16.00±0.17	544
	2.3	5	879±5.4	191± 4.6	28.4±2.0	38± 5.3	49±2.1	572± 7.3	397± 5.8	16.24±0.16	532

Table 3.6 Chemical composition of the experimental feed used in the various series above a live weight of 60 k (mean ±SD)

Tabel 3.6 Den kemiske sammensætning af forsøgsfoderet i de forskellige serier benyttet efter 60 kg levende væ (gns. ± SD)

Ser. No.	Linoleate energy%	n	DM g/kg	Crude protein (N×6.25) g/kg	Crude fat (HCl+EE) g/kg	Crude fibre g/kg	Crude ash g/kg	NFE g/kg	Carbon g/kg	GE MJ/kg	GE/ Protein kJ/g N
B	0.4	1	894	139	7.6	38	53	656	385	15.44	692
	9.5	1	878	140	94.0	34	51	559	408	17.14	765
E	0.1	3	903±1.6	138± 4.5	3.3±0.7	37±4.7	37±1.4	688± 8.7	383±5.7	15.65±0.04	708
	0.8	3	902±1.9	140± 6.7	11.4±0.9	36±4.0	38±1.0	677±12.3	386±3.5	15.76±0.09	704
	1.5	3	901±1.8	138± 1.9	20.3±0.6	42±4.5	38±0.4	663± 4.3	391±1.7	15.99±0.03	727
	2.2	3	902±0.3	140±10.4	29.0±5.9	37±2.0	39±0.3	658±11.5	395±2.7	16.11±0.04	722
G	0.2	2	884±2.1	156± 6.2	8.3±0.8	43±0.7	50±0.4	628±10.1	392±1.2	15.77±0.03	633
	1.1	2	887±1.8	153± 8.0	15.6±3.0	40±1.0	51±0.1	628± 6.4	395±5.3	15.87±0.03	648
	2.1	2	888±4.6	151± 8.0	23.3±3.2	40±2.8	51±9.5	622± 2.5	400±6.0	16.07±0.07	664
H	0.7	1	868	160	10	44	50	604	378	15.48	605
	1.6	1	865	158	18	37	47	606	387	15.57	618
	2.3	1	867	163	27	38	48	591	389	15.87	608

tage of the gross energy (energy%). Thus, the more energy (feed) the pigs received during the growth period, the more linoleic acid they actually consumed as shown in Figure 3.1.

3.1.4 Feeding plans

Feed intake. The feed intake was restricted to avoid feed residuals in the balance periods. This was especially the case in the first period to minimize also the risk for diarrhoea. Otherwise it was near *ad libitum* intake as it was adjusted according to the appetite of the pigs during the preliminary periods (cf. Chapter IV). A daily increasing scale (20 g feed per day) based on experience from earlier experiments with pigs *(Thorbek, 1975)* was applied. The feed was supplied by hand twice daily at 7 a.m. and at 3 p.m. The average values for feed intake during the collection periods in the individual series are shown in Tables 3.8–3.13. The average intake of gross energy and metabolizable energy in relation to live weight was almost identical for all series as shown in Figure 4.1 and 4.2, respectively.

The appropriate amounts of feed were weighed out for each day of the experimental period in question and kept in plastic bags.

Water supply. Tap water was supplied by hand according to the voluntary intake observed during the preliminary period. As can be seen from Tables 3.8–3.13, the average water consumption varied from series to series and was not always related to the dry matter intake. Especially, when glucose was used as the main source of carbohydrate, it was found necessary to reduce the amount of water, partly because the feed was fluent, partly because the pigs could other-

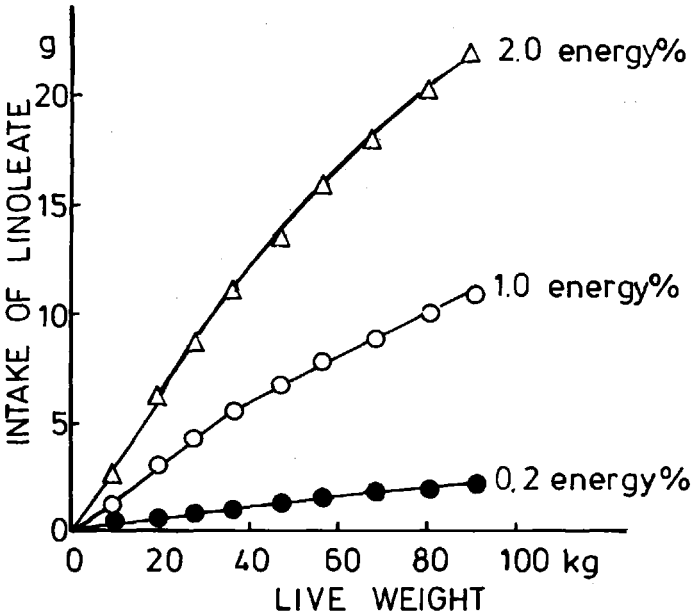

Figure 3.1. Daily intake (g) of linoleate from feed containing 0.2, 1.0 or 2.0% of gross energy (energy%) as linoleate during the growth period
Dagligt indtag (g) af linoleat fra foder med 0.2, 1.0 eller 2.0% af bruttoenergien (energi%) som linoleat gennem vækstperioden

wise not eat the whole ration. Even, if water was offered after they had eaten, they refused to drink more.

3.1.5 Techniques applied in the balance experiments

Sampling and preparation of feed, faeces and urine for analyses. In part of the original feed sample the content of dry matter was determined while the rest of the sample was milled and used for determination of dry matter, nitrogen, crude fat and crude ash together with carbon and energy. By means of the values for dry matter content in the original and in the milled sample, the chemical composition determined in the milled sample was recalculated in order to express the content in the original sample.

Faeces and urine were collected twice a day and treated as described by *Thorbek (1975)* with the following modifications: The volume of urine kept for analysis was divided into two airtight plastic bottles. One was added 100 ml sulphuric acid (4:1 v/v water:acid) and used for nitrogen analysis. The other was

added 5 g mercury iodide to prevent bacterial growth and used for determination of carbon and energy.

Analytical procedures. All chemical analyses except the carbon determination, were carried out as described by *Jakobsen and Weidner (1973)*. The determination of nitrogen by the Kjeldahl procedure was modified for the use of an autoanalyzer (Kjel-Foss Automatic 16200. N. Foss Electric Ltd., Hillerød, Denmark, 1975). The carbon content was determined by means of a Wösthoff instrument as described by *Neergaard et al. (1969)*. To minimize the analytical work, energy in urine was determined only in period I and II of each series, whereas the carbon content was measured in all samples. The energy content per unit of carbon in the urine was calculated, and this amount was applied throughout the series to calculate the energy content from the measured carbon centent in the urine. The energy content thus calculated on the basis of the carbon determinations in the urine was very constant throughout the growth period.

Table 3.7 Reproducibility (CV%) of the determination of dry matter (DM), crude fat (HCl+EE) and individual fatty acids in a semi purified diet and a conventional diet without and with supplementation of 4% soya bean oil

Tabel 3.7 Reproducerbarhed (CV%) af bestemmelsen af tørstof (DM), råfedt (HCl+EE) og individuelle fedtsyrer i et delvist »renset« og et konventionelt foder uden og med tilskud af 4% sojaolie

Diet	Semi purified[1])				Conventional[2])			
Oil	−oil		+oil		−oil		+oil	
	%	CV%	%	CV%	%	CV%	%	CV%
DM	85.16	0.5	88.41	0.1	85.48	0.1	86.91	0.3
Crude fat	0.80	7.3	5.53	17.6	3.42	2.2	8.04	2.6
Lauric acid[3])	0.005	10.0	0.007	7.1	0.002	0.0	0.002	0.0
Myristic acid	0.019	5.0	0.024	2.1	0.013	4.4	0.017	5.6
Myristoleic acid	0.003	0.0	0.002	25.0	0.002	28.9	0.001	0.0
Palmitic acid	0.128	1.9	0.562	17.0	0.592	0.6	1.030	1.8
Palmitoleic acid	0.008	21.7	0.014	14.7	0.017	2.9	0.025	3.8
Stearic acid	0.032	1.6	0.219	17.5	0.084	2.3	0.279	3.6
Oleic acid	0.095	4.8	1.097	19.0	0.389	2.9	1.432	3.3
Linoleic acid	*0.061*	*20.1*	*2.376*	*19.8*	*1.332*	*2.3*	*3.794*	*2.6*
Linolenic acid	*0.011*	*21.6*	*0.367*	*19.6*	*0.147*	*2.6*	*0.532*	*2.7*
Sum of fatty acids	0.362	3.7	4.670	18.8	2.577	1.9	7.114	2.6
Fatty acids, % of crude fat	45.60	11.0	84.43	3.2	75.43	1.3	88.50	0.4

The results represent the mean of 4 samples per mixture.

[1]) Basal diet used in series G + H, cf. Table 3.2.

[2]) Barley and 16% soya bean meal and 2% meat and bone meal.

[3]) In all cases expressed as percentage of dry matter.

Crude fat of feed and faeces was extracted with diethylether after HCl-hydrolysis (HCl + EE), as this method extracts more fat and fatty acids than ether extraction alone (EE) *(Harfiel, 1965; Thomsen, 1969; Thorbek and Henckel, 1977)*. Table 3.7 shows the reproducibility (CV%) of the determination of the individual fatty acids in a semi purified and a conventional diet without and with addition of 4% soya bean oil. It is evident that the reproducibility of the individual fatty acids is greater in the conventional diet than in the semi purified diet probably because of the heterogeneity caused by the sawdust added to the latter diet. For linoleic and linolenic acid the reproducibility is 20% in the semi purified diet and 2.5% in the conventional diet apparently independent of their dietary levels.

The fatty acid composition of dietary, faecal, biliary and plasma lipids was determined by means of gas liquid chromatography (GLC) as described by *Christensen* (1973).

Analytical precision. Nitrogen determinations in feed and faeces were carried out in triplicate, all other analyses were performed in duplicate. The largest permissible deviations in double or triple determinations were according to the EEC-standards as outlined in the Official Journals of the EEC.

As the nitrogen and carbon balances are important ingredients in measuring nitrogen retention and energy metabolism, the analytical precision of nitrogen and carbon in feed, faeces and urine is of great importance. In order to measure the analytical repeatability in the determination of nitrogen, carbon and energy in feed, faeces and urine, the method described by *Rasch et al. (1958)* and discussed by *Thorbek (1975)* has been applied, using the daily routine work with duplicate or triplicate analyses to estimate the standard deviation (SD) and the coefficient of variation (CV% = SD × 100/mean value). Compared to earlier results obtained on various feedstuff compounds commonly used in the diets of pigs *(Thorbek, 1975)* and calves *(Thorbek, 1980)*, the CV% was greater (2–5% vs. 1–2%) in some of the rations (series C, D and E), whereas it was of the same magnitude in the others. This was probably caused by the choise of carbohydrate source in the rations. The CV% for nitrogen determinations in faeces was also slightly greater than previously observed by *Thorbek (1975; 1980)*. This may be attributed to the small amount of faeces voided by the pigs and the sawdust in the faeces which made a homogenous sampling very difficult. Otherwise the precision of the determinations of nitrogen in urine, carbon and energy in feed, faeces and urine was of the same magnitude as reported by *Thorbek (1975; 1980)*. The linoleate level of the feed did not influence the analytical precision of nitrogen and carbon.

3.1.6 Techniques applied in the respiration experiments

In order to measure the CO_2-production and O_2-consumption of the animals a respiration plant constructed and described by *Thorbek (1969)* was used. The gas exchange of the pigs was measured over a 24 hour period by means of an open-air circulation respiration unit with two chambers (C and D). The temperature in the respiration chambers was maintained in accordance with the temperature in the stable, starting at 20°C in the first periods and gradually decreasing to 18°C in the last periods. The relative humidity in the chambers was between 60 and 65%.

Calibration of the respiration unit was carried out frequently by means of carbon dioxide as described by *Thorbek (1969)*. During the experimental time 23 calibrations were performed with each chamber with an inlet of 400 litres CO_2 during 18 hours. The mean difference between in- and outgoing CO_2 was –0.80 (range –6.5 – + 6.4) litres for chamber C and –0.55 (range –8.9 – + 2.5) litres for chamber D corresponding to 0.2% of the inlet volume of CO_2. There was no systematic error connected with the measurements from the two chambers.

As the loss of carbon through CO_2 is about 50% of the carbon intake, the precision obtained in the determination of CO_2 in the outgoing air is considered to be high and in correspondance with the precision obtained in the determination of carbon in the feed.

The heat production, HE(CN), was calculated by means of the carbon- and nitrogen balances measured over a 7-days' period of collection with the respiration experiment placed in the middle of the period. The heat production was also calculated according to the RQ-method (HE(RQ)). The accepted set of constants of factors proposed by Brouwer (1965) have been used for all calculations except that one calorie was replaced with 4.1855 joule. Methane production was measured in Series B and C as described by *Thorbek (1969)*. Because of technical troubles the methane production could not be measured in the other series.

3.1.7 Statistical evaluation of the results

The present experiments were carried out in series in which initial and final live weights, experimental time and feed composition were not always identical as described in the previous sections. Therefore, all results were treated statistically first within series, and at last the total material was considered. As the statistical evaluation of the results varied according to the nature of the measured parameters, the statistical methods employed in each case will be discussed in the corresponding sections. Unless otherwise stated the range of statistical significance is indicated by the following symbols: NS ($P>0.05$), * ($P\leq0.05$), ** ($P\leq0.01$) and *** ($P\leq0.001$).

3.2 Individual series, background and journal of animals

As already described the present experiments were carried out in six series (B-C-D-E-G-H) which were not replicates. The reason for this was that the experience gained in one experiment had to be used in the design of the following experiment, because the results obtained were almost never expected. Instead of continuing with a pre-fixed experimental plan, which would be possible and seem logical after having performed series G and H, it was decided to stop and present the results obtained for the following reasons: *1.* The results show that the requirement for EFAs to conventional pigs of the Danish Landrace breed is low and generally will be met if the pigs are weaned at 5 weeks of age or later, and receive barley or another grain as the major energy source. *2.* The production conditions have changed considerably and conclusively since these experiments were started in 1976. New breeds have been introduced which produce more meat, have a greater daily gain and a better feed conversion efficiency than the Danish Landrace breed, and consequently will be expected to have a greater requirement for EFAs. Moreover, early weaning is becoming more frequent and desirable. This will also augment the requirement for EFAs. *3.* The use of alternative feedstuffs is becoming more common. Many of these are low in EFAs.

Surely, further experiments are highly needed, but they must be carried out under actual or realistic future rearing conditions. This is not specific for EFAs, but general for all essential nutrients.

The following outlines the details about the experimental animals of the individual series and the purpose of each series in question.

3.2.1 Series B

In previous experiments pigs receiving 0.4 energy% linoleic acid in their diet were deficient in EFAs after 120 days as judged by an increase in the concentration of eicosatrienoic acid (20:3, n-9) and a decrease in that of arachidonic acid in their total lipids of plasma and tissues *(Christensen, 1973; 1974a)*. The same experiments showed, however, that a dietary level of 6.4 energy% linoleate was not enough to sustain initial concentrations of EFAs in plasma and tissue lipids. They also indicated that this level might not suffice for an adequate function of mitochondria isolated from liver, heart and skeletal muscle. It was, therefore, decided to carry out an experiment, which would embrace two distinct levels of linoleic acid, namely about 0 and 10 energy% linoleate.

Series B was conducted with a total of 8 barrows from two litters, each from the fourth litter of the mother sow. The pigs were weaned at 8 weeks and weighed an average of 12.8 kg (range 11.5–13.8 kg). After one week of adaptation at NIAS they were submitted to a balance and respiration trial in order to measure their nitrogen balances and energy metabolism. The purpose was to

take these measurements into consideration at the distribution of the animals in experimental groups. From arrival until one week after termination of this experimental period all pigs received a commercial mixture for pigs based on barley and 16% soya bean meal and 2% meat and bone meal. When the results from this period were calculated the pigs were distributed on two groups according to nitrogen retention. Group 1 received a basal diet containing 0.4 energy% linoleic acid composed as shown in Table 3.2, whereas Group 2 received 9.5 energy% linoleic acid. The composition of the basal diet was similar to that used previously *(Christensen, 1973)*. The chemical composition of the diets is shown in Tables 3.5 and 3.6. The pigs were fed these diets for 112 days. During the experimental period 8 balance and respiration trials were performed with each pig. In the last period, however, the feed consumption was poor, so the results from this period have been deleted for all pigs. Pig No. 3 of Group 2 died in the preliminary period of period V. On *post mortem* examination it showed a stress condition (PSE = Pale Soft Exudative muscle). These pigs were not halothane tested, so we did not know their status of stress susceptibility in beforehand. The initial and final physiological age and the corresponding live weight are shown in Table 3.1.

The daily intake of feed, water, gross energy and crude protein during the growth period are apparent from Table 3.8. Pig No. 4 of Group 2 did not eat the total ration during the respiration experiment in period II and VIII. As the results from the measurements of gas exchange were influenced, this pig was deleted from these periods. By mistake the feed intake of the pigs of Group 2 was not reduced. So they received about 11% more gross energy than the pigs of Group 1 as showed in Table 3.8.

Table 3.8 Series B. The average daily intake of feed, gross energy, crude protein and water of pigs fed 0.4 (Group 1) or 9.5 (Group 2) energy% linoleate during the growth period

Tabel 3.8 Serie B. Det gennemsnitlige daglige indtag af foder, bruttoenergi, råprotein og vand hos grise fodret med 0,4 (Hold 1) eller 9,5 (Hold 2) energi% linoleat gennem vækstperioden

Bal. per. No.	Days on exp. diet	Live weight, kg Group 1	n	Group 2	n	Feed g	Water litres	Energy, MJ Group 1	Group 2	Protein, g Group 1	Group 2
II	11	28.0	4	28.9	3	1100	3.4	17.3	19.4	201	198
III	25	37.3	4	39.6	4	1400	4.2	22.1	24.7	256	252
IV	39	47.6	4	51.9	4	1700	5.2	26.8	29.9	310	306
V	53	57.4	4	64.5	3	2000	6.0	31.5	35.2	365	360
VI	67	68.9	4	77.0	3	2300	7.0	35.5	39.4	321	322
VII	81	81.1	4	89.7	3	2600	7.8	40.1	44.6	362	364
VIII	95	91.2	4	100.0	2	2800	8.4	43.2	48.0	390	392

The feedstuff composition of the diets used in this series seemed to be adequate from a digestive point of view as judged from the appetite of the pigs and the consistency of the faeces. No EFA deficiency symptoms were observed.

3.2.2 Series C

As the pigs in series B receiving 0.4 energy% linoleic acid did not show any visible signs of EFA deficiency symptoms and thrived equally well as the pigs receiving 9.5 energy% linoleic acid, it was decided to perform the next experiment with pigs receiving virtually no linoleic acid by feeding a semi purified diet based on glucose and casein as used by *Witz and Beeson (1951).*

From a physiological point of view, however, such a »fat-free« diet, is inadequate in other aspects than the lack of EFAs. It will be expected to provide a poor absorption of fat soluble vitamins, to have a relatively great absorption rate in the gastrointestinal tract, a relatively high stimulation of appetite, and a relatively high stimulation of insulin secretion. So, it was decided to perform this series of experiments to compare this both »fat free« and »EFA free« diet with a fat enriched, but »EFA free« diet. Beef tallow provided the fat source low in linoleic acid.

Series C was carried out with 8 littermates, 4 barrows and 4 sows, from the fourth litter of the mother sow. They were 8 weeks at weaning and 80 days old when arriving at NIAS. They were fed a mixture of barley and skim milk powder, vitamins and minerals from the day of arrival and during the first experimental period. Then 3 balance and respiration experiments were performed with the experimental feed (cf. Table 3.9). The composition of the basal diet is shown in Table 3.2, and the chemical composition of the diets used is shown in Table 3.5. Beef tallow was considered to have an apparent digestibility of 50%. The exchange of 2.5% beef tallow with an iso-energetic amount of glucose increased the concentration of linoleic acid in the feed from 0.04 to 0.2 energy%,

Table 3.9 Series C. The average daily intake of feed, gross energy, crude protein and water of pigs fed 0.04 (Group 1) or 0.2 (Group 2) energy% linoleate during the growth period

Tabel 3.9 Serie C. Det gennemsnitlige daglige indtag af foder, bruttoenergi, råprotein og vand hos grise fodret med 0,04 (Hold 1) eller 0,2 (Hold 2) energi% linoleat gennem vækstperioden

Bal. per. No.	Days on exp. diet	Live weight, kg Group 1	n	Group 2	n	Feed g	Water litres	Energy, MJ Group 1	Group 2	Protein, g Group 1	Group 2
II	11	30.1	4	30.8	4	1100	3.4	16.4	16.6	189	187
III	25	38.2	4	39.0	4	1400	4.4	20.9	21.2	241	238
IV	39	47.6	4	47.4	2	1700	5.2	25.4	25.7	292	289

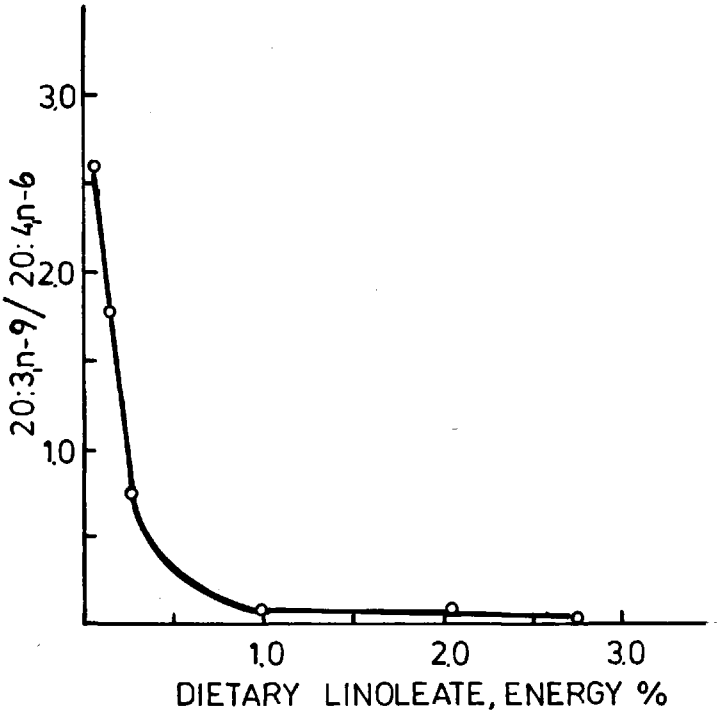

Figure 3.2. The ratio between 20:3,n-9 and 20:4,n-6 in plasma lipids of pigs fed different concentrations of linoleate

Forholdet mellem 20:3,n-9 og 20:4,n-6 i plasma lipider fra grise fodret med forskellige linoleatkoncentrationer

which in both cases would be expected to provide insufficient amounts of EFAs. As judged from the ratio between eicosatrienoic acid (20:3,n-9) and arachidonic acid (20:4,-6), as shown in Figure 3.2, this was also found to be the case. However, no visible signs of EFA deficiency were noticed.

In period IV pigs No. 3 and 4 of Group 2 were not subjected to balance experiments, as they had diarrhoea and distended abdomens. They were treated twice daily for 3 days with 400 mg tylan and 2.5 g metamizoli, and pig No. 4 furthermore received one tablet of penbritin dissolved in 20 ml acetyltributyrylcitrate. After this treatment they improved. For several reasons, however, it was decided to finish this experiment. Firstly, the amount of faeces was very scarce (50–100 g per day), and the faeces was very difficult to brush off the metabolic cages, as it adhered to the steel wire network. This was especially the case for faeces from the pigs receiving beef tallow. Secondly, the pigs appeared very ex-

cited between the meals, especially before the morning meal, and were about to jump out of the pens and had foam around the mouth. Thirdly, the glucose dissolved in the water, and made the feed almost fluent. Even, if the pigs seemed hungry before receiving their meals, they would hardly eat up between the meals. Obviously, the composition of the feed was not adequate, and in this respect, there was no apparent difference between the group receiving no fat and the group receiving 2.5% beef tallow in the diet.

Later, it showed up that the digestibility of the cellulose used in the diets was higher than expected. The apparent digestibility coefficient averaged 78% for all pigs, but it varied between 66 and 92%. On this basis it was concluded that the major reason for the digestive disturbances observed might rather be attributed to the relatively high digestibility of the cellulose than to the use of glucose in the diets. Addition of beef tallow had no apparent effect on appetite and made a quantitative collection of faeces difficult. It was, therefore, decided not to include beef tallow in further studies.

3.2.3 Series D

This series was a pilot experiment with the purpose to feed early weaned piglets within a reasonable range of linoleate concentrations (0–3 energy%) during the growth period to a final live weight of 90 kg.

8 littermates, 4 barrows and 4 sows, from the third litter of the mother sow, weaned at 6 weeks of age and weighing an average of 10.1 kg (range 9.6–10.9 kg) were brought to the NIAS for this series of experiments.

After one week of preparation (see section 3.1.1) the pigs were divided into four groups (one barrow and one sow per group) receiving 0.3, 1.0, 2.0 and 2.7 energy% linoleic acid in their diet, respectively. The basal diet was based on glucose and casein as shown in Table 3.2, but cellulose was substituted with beech sawdust. The chemical composition of the experimental diets is shown in Table 3.5. Table 3.10 shows the daily intakes of feed and water. These pigs were not able to drink so much water as the pigs in series C. It is apparent from Table 3.10 that the pigs received almost identical daily amounts of gross energy and crude protein during the experimental periods. After termination of period No. IV the feed intake began to diminish. The pigs were very excited before the meals and seemed hungry, but they were not able to eat the whole ration. One pig of Group 4 vomited while eating, and one pig of Group 2 had diarrhoea. No pigs showed any signs of EFA deficiency. It was decided to finish this experiment, as the composition of the feed seemed to be inadequate from a digestive point of view.

Because of the bad experience with the glucose diet in this and the previous experiment, it was decided to use another carbohydrate source in future experiments. To the disadvantages mentioned in section 3.2.2 by using a »fat free«

Table 3.10 Series D. The average daily intake of feed, gross energy, crude protein and water of pigs fed 0. (Group 1), 1.0 (Group 2), 2.0 (Group 3) or 2.7 (Group 4) energy% linoleate during the growth perio

Tabel 3.10 Serie D. Det gennemsnitlige daglige indtag af foder, bruttoenergi, råprotein og vand hos grise fodr med 0,3 (Hold 1), 1,0 (Hold 2), 2,0 (Hold 3) eller 2,7 (Hold 4) energi% linoleat gennem vækstperioder

Bal. per. No.	Days on exp. diet	Live weight kg	n	Feed, g Group 1	Group 2	Group 3	Group 4	Water, litres Group 1+2	Group 3+4	Energy, MJ Group 1	Group 2	Group 3	Group 4	Protein, g Group 1	Group 2	Group 3	Group 4
I	11	16	8	590	580	570	560	1.0	1.1	9.0	8.9	8.9	8.8	101	108	99	93
II	25	21	8	790	780	770	760	1.6	1.8	12.0	12.0	12.0	11.9	135	145	134	126
III	39	28	8	1190	1180	1170	1160	3.0	3.0	18.2	18.2	18.2	18.1	218	190	225	206
IV	53	37	8	1490	1480	1470	1460	3.0	3.0	22.7	22.8	22.9	22.8	273	238	282	259

diet, one major claim by using glucose as the carbohydrate source may be added, namely that it readily dissolves and is osmotically active in the digestive tract. This may be the reason for a diminished feed intake after some time. This reduced feed intake occurred in all groups independent of the linoleate supply.

The ratios between 20:3,n-9 and 20:4,n-6 of plasma lipids from the pigs of series C and D at slaughter is shown in Figure 3.2. It is evident that a ratio above 0.2 is obtained, if the diet contains less than 0.8 energy% linoleic acid. These ratios were obtained after 50–60 days on the experimental diets.

3.2.4 Series E

From the previous series it was evident that a reasonable range of dietary linoleate to be investigated was between 0 and 3% of the energy intake. It also occurred that glucose was inadequate as a main source of carbohydrate from a physiological point of view.

On this background series E was carried out with 8 littermates, 4 barrows and 4 sows, from the third litter of the mother sow. They were weaned at 6 weeks of age and weighed an average of 12.9 kg (range 11.8–14.1 kg). After one week of preparation (see section 3.1.1) the pigs were divided into four groups (one sow and one barrow per group) receiving 0.1, 0.8, 1.5 and 2.2 energy% linoleic acid in their diet, respectively. The basal diet was based on glucose, tapioca-meal and partly hydrolyzed maize starch as shown in Table 3.2. The palatability of this diet seemed to be adequate. The pigs always ate their ration within 20 min. The chemical composition of the diets is shown in Tables 3.5 and 3.6. The experimental period lasted 112 days during which eight balance periods were performed. The daily intakes of feed and water during the experimental period are shown in Table 3.11. From Table 3.11 it is evident that the daily intakes of gross energy and crude protein were almost identical for all groups.

After 47 days on the experimental diet the female of Group 1 suddenly died from volvolus. The apparent digestibility of the dry matter was 91% (see Table

3.2) which still seemed to be too high. We, therefore, added 30 g pectin daily to the diet of all groups from the beginning of period IV. The pectin constituted 1.8% of the daily feed intake in period IV decreasing to 1.1% in period VIII. The addition of pectin clearly improved the consistency of the faeces.

After 94 days on the experimental diet the female of Group 3 died. At autopsy she showed lung oedema, enlarged and loose heart, and white musculature in the dorsal and loin muscles. There was no obvious reason for these findings. The pig was halothane negative, and the level of vitamin E which was analyzed in the diets of the pigs of this period was 36, 41, 48 and 44 mg α-tocopherylacetate per kg feed for Group 1, 2, 3 and 4, respectively. The pigs of Group 4 had injured hoofs and were not able to stay in the metabolic cages. So they were deleted from period VII and VIII. Energy metabolism was, however, measured in period VIII by means of the RQ-method. The barrow of Group 3 had hurt its left foreleg and was, therefore, not able to stay in the metabolic cage in period VIII. Because of these leg troubles the appetite of the pigs was depressed and the feed intake somewhat reduced.

No visible signs of EFA deficiency were noticed during the experimental period.

3.2.5 Series G

The experience of the previous series showed that the digestibility of the diets was high, the apparent digestibility of the dry matter ranging from 91 to 96% (cf. Table 3.2). However, it also showed that the range of linoleic acid intake should be of the order of 0 to 3% of the daily gross energy intake. So, it was evident that the basal diet had to be based on low fat and purified feed compounds.

Table 3.11 Series E. The average daily intake of feed, gross energy, crude protein and water of pigs fed 0.1 (Group 1), 0.8 (Group 2), 1.5 (Group 3) or 2.2 (Group 4) energy% linoleate during the growth period

Tabel 3.11 Serie E. Det gennemsnitlige daglige indtag af foder, bruttoenergi, råprotein og vand hos grise fodret med 0,1 (Hold 1), 0,8 (Hold 2), 1,5 (Hold 3) eller 2,2 (Hold 4) energi% linoleat gennem vækstperioden

Bal. per. No.	Days on exp. diet	Live weight		Feed, g				Water	Energy, MJ				Protein, g			
		kg	n	Group 1	Group 2	Group 3	Group 4	litres	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
	11	20	8	800	790	780	770	2.0	12.6	12.6	12.5	12.5	143	135	132	134
I	25	26	8	1100	1090	1080	1070	2.6	17.3	17.3	17.3	17.4	196	186	183	186
II	39	36	8	1400	1390	1380	1370	3.0	22.0	22.1	22.1	22.3	249	237	234	238
V	53	45	7	1700	1690	1680	1670	3.8	26.8	26.9	26.9	27.2	303	288	285	290
V	67	56	7	2000	1990	1980	1970	4.4	31.5	31.7	31.8	32.1	356	340	335	342
VI	81	66	7	2300	2290	2280	2270	5.0	36.0	36.1	36.5	36.6	318	321	314	316
VII	95	77	4	2500	2490	2480	–	5.4	39.1	39.2	39.7	–	345	349	341	–
VIII	109	87	3	2700	2690	–	2670	6.0	42.2	42.4	–	42.7	373	377	–	367

We were lucky to compose a basal diet containing 20% maize starch, 20% potato meal and 30% tapioca meal as carbohydrate sources, which together with the other compounds shown in Table 3.2, contained only 0.2 energy% linoleic acid and apparently was tasteful to the pigs. The apparent digestibility of the dry matter was 88%. The consistency of the faeces was satisfactory. Apparently, tapioca meal is a better source of carbohydrate than glucose from a digestive point of view.

This experiment was designed to consist of 12 pigs, 6 sows and 6 barrows, from 2 litters. However, because of diarrhoea after transportation to NIAS, we had to exchange the barrows of one litter with the barrows of another litter. So, we actually used 6 pigs (3 sows and 3 barrows) from one litter, 3 barrows from another litter, and 3 sows from a third litter. All piglets were from the third litter of the mother sows and weaned at 5 weeks of age weighing between 10 and 12 kg. After one week of preparation (cf. section 3.1.1) the pigs were divided into 3 groups according to litter and sex. They received 0.2,1.1 and 2.1 energy% linoleic acid in their diets, respectively. The duration of the first experimental period was 14 days, whereas the following 4 periods lasted 21 days each. For technical reasons some of the measurements in period III and IV had to be postponed one week. The initial and final age and live weights of the pigs are apparent from Table 3.1. Table 3.12 shows the average intakes of feed and water during the experimental period. The pigs drank more water than expected, but there was no tendency that Group 1 drank more water than the other groups. It is apparent from Table 3.12 that all groups received almost identical daily amounts of energy and crude protein during the experimental period.

Pig No. 9 (a barrow) of Group 2 hurt its leg in the respiration chamber during the measurement in period III. This pig was not able to stay in the metabolic

Table 3.12 Series G. The average daily intake of feed, gross energy, crude protein and water of pigs fed 0.2 (Group 1), 1.1 (Group 2), or 2.1 (Group 3) energy% linoleate during the growth period

Tabel 3.12 Serie G. Det gennemsnitlige daglige indtag af foder, bruttoenergi, råprotein og vand hos grise fodret med 0,2 (Hold 1), 1,1 (Hold 2), eller 2,1 (Hold 3) energi% linoleat gennem vækstperioden

Bal. per. No.	Days on exp. diet	Live weight kg	n	Feed, g Group 1	Group 2	Group 3	Water litres	Energy, MJ Group 1	Group 2	Group 3	Protein, g Group 1	Group 2	Group 3
I	11	20	12	800	790	780	3.0	12.7	12.6	12.5	151	147	145
II	32	32	12	1300	1290	1280	4.0	20.6	20.6	20.6	245	240	238
III	56	49	11	1760	1750	1810[1)]	6.3	27.8	27.9	29.1	332	326	337
IV	81	67	11	2200	2190	2180	8.5	34.7	34.8	34.8	342	335	330
V	102	83	10	2600	2590	2580	9.5	41.0	41.1	41.1	405	397	390

[1)] 60 days on exp. diet.

cage for the rest of period III and for period IV and V. The other barrow of Group 2 unfortunately hurt its right foreleg in period V and had to be deleted from the balance period.

In period IV pig No. 1 of Group 1 (a barrow) lost some of its hair and had some chaps in the neck region. In period V this was also the case for the two sows of Group 1. No such dermal changes or hair loss were observed in the other pigs. These changes occurred at about 60–70 days of the experimental period and might be a consequence of the low linoleate intake.

3.2.6 Series H

As the feed composition used in series G seemed to be satisfactory from a digestive point of view, a similar basal diet was used in series H (cf. Table 3.2). Series G also indicated that 0.2 energy% dietary linoleate might not suffice for a normal development of the hair coat and the skin. So, we decided to perform Series H in the same manner as series G. Three distinct linoleate levels were chosen, namely 0.7, 1.6 and 2.3 energy% for Group 1, 2 and 3, respectively.

A total of 12 pigs, 6 sows and 6 barrows, were used for this series, and again troubles with diarrhoea after transportation from the farm to NIAS occurred and changed the original experimental plan. So, 6 piglets, 3 sows and 3 barrows, were from the same litter, the fifth litter of the mother sow. They were weaned at 5 weeks of age and weighed an average of 9 kg. Three barrows were from the fourth litter of the mother sow and weaned at 6 weeks of age weighing about 10 kg each. Three sows were from the fourth litter of another mother sow, weaned at 5 weeks of age and weighed about 9 kg. After 10–14 days of preparation (cf. section 3.1.1) they entered the experimental period which lasted a total of 98 days. The first period lasted 14 days, whereas the following 4 periods lasted 21 days each. The initial and final age and live weights are shown in Table 3.1. The

Table 3.13 Series H. The average daily intake of feed, gross energy, crude protein and water of pigs fed 0.7 (Group 1), 1.6 (Group 2) or 2.3 (Group 3) energy% linoleate during the growth period

Tabel 3.13 Serie H. Det gennemsnitlige daglige indtag af foder, bruttoenergi, råprotein og vand hos grise fodret med 0,7 (Hold 1), 1,6 (Hold 2) eller 2,3 (Hold 3) energi% linoleat gennem vækstperioden

Bal. per. No.	Days on exp. diet	Live weight kg	Feed, g			Water litres all	Energy, MJ			Protein, g		
			Group 1	Group 2	Group 3		Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
I	11	17	600	590	580	3.0	9.5	9.4	9.4	110	108	111
II	32	27	1100	1090	1080	4.0	17.5	17.4	17.5	201	200	206
III	53	41	1500	1490	1480	5.0	23.8	23.8	24.0	274	274	282
IV	74	57	1900	1890	1880	6.2	30.2	30.2	30.5	347	347	358
V	95	73	2300	2290	2280	7.2	35.6	35.6	36.2	368	361	372

daily intakes of feed and water during the growth period are shown in Table 3.13. The pigs in this series did not drink so much as the pigs in series G, even if the basal feed composition was the same. Because of the risk for diarrhoea during the first experimental period, the feed intake was kept at a low level in this period. from Table 3.13 it is apparent that the pigs in the three groups received almost identical daily amounts of gross energy and crude protein during the experimental period.

The pigs in this series did not show any signs of dermal lesions or hair loss. Both in series G and H the appetite of the pigs was a little reduced at about 60 kg live weight. It improved when the concentration of crude protein in the diet was reduced.

3.2.7 Series K

Three female littermates of Danish Landrace weaned at 5 weeks of age were used for studies on the fatty acid composition of bile lipids. They were not subjected to digestibility or balance experiments.

The pigs were fed the same basal diets as in Series G and H from about 15 kg live weight. They received one of three dietary levels of linoleate: 0.2, 1.2 or 2.3 energy%. After 65 days on these diets the pigs were sacrified and the gallbladder with its content was removed for analysis of the concentrations of total lipid and fatty acids. The results from these analyses are shown in Chapter V.

IV. Daily gain in weight and feed conversion efficiency

The requirement of linoleate to cover maximum daily gain in weight and maximum feed conversion efficiency was determined by feeding various levels of linoleate ranging from 0.04 to 9.5% of gross energy (energy%) during the growth period as outlined in Chapter III.

The daily gain obtained at a certain live weight was calculated from the weighings before and after the pigs entered the metabolic cages for the balance trials. This means that the calculations were based on a seven days weight increase during the collection periods. The pigs were weighed before receiving their afternoon meal. Daily gain in relation to live weight is shown for the total material in Figure 4.3.

Feed conversion efficiency or feed utilization is expressed as the feed conversion ratio, defined as the feed consumption expressed in units of metabolizable energy (ME) or feed units for swine (FE_s) per kg gain in weight. Thus, the better the feed conversion efficiency, the lower the feed conversion ratio. The calculations were based on the actually measured intakes of ME (see Chapter VII) divided by the total gain in the adjusted growth period (see below). The conversion of ME to FE_s was based on the mean intakes of ME per kg dry matter found for the individual series, using the calculation formula by *Andersen and Just (1979)*. Then the total intake of ME or FE_s was divided by the total gain in the adjusted growth period to obtain the feed conversion ratio.

The mean values of daily weight gains and feed conversion ratios for the total growth period in question (e.g. 20–90 kg) were adjusted to the same live weight at the beginning and end of the growth period. These values are shown in Tables 4.2–4.7. Table 4.8 shows the mean values of daily gain and feed conversion efficiency in the various weight classes between 20 and 90 kg obtained for the total material.

4.1 Intake of energy in relation to live weight

When comparing weight gains and feed conversion ratios it is important that the pigs have received similar daily amounts of energy and essential nutrients. In Chapter III it was shown that the pigs within a series of experiments received almost identical amounts of gross energy (GE), crude protein, vitamins and minerals axcept in Series B, where Group 2 received about 11% more GE or 7% more ME than Group 1. The intake of ME was measured in all experiments, and the results are described in Chapter VII.

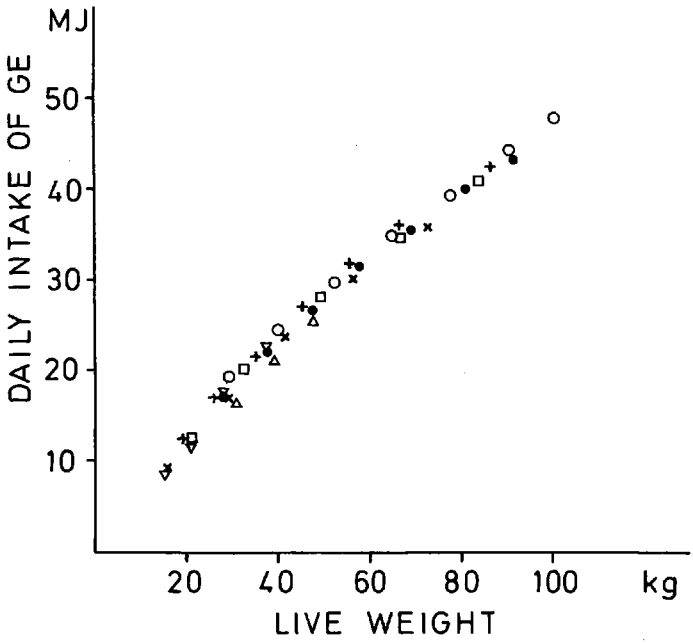

Figure 4.1. Daily intake of gross energy (GE) in relation to live weight in the individual series of experiments. (• Series B Group 1, ○ Series B Group 2, △ Series C, ▽ Series D, + Series E, □ Series G, and × Series H)

Dagligt indtag af bruttoenergi i relation til levendevægt i de enkelte forsøgsserier. (• Serie B Hold 1, ○ Serie B Hold2, △ Serie C, ▽ Serie D, + Serie E, □ Serie G og × Serie H)

Figure 4.1 shows that the intake of GE in relation to live weight was a little lower in Series C than in the other series, where the intake of GE practically was identical. The intake of ME in relation to live weight was about 10% lower in Series C, G and H than in Series B, D and E as shown in Figure 4.2.

The mean daily intakes of GE and ME in various weight classes of the growth period have been deduced from Figure 4.1 and 4.2, respectively, and are shown in Table 4.1 together with the corresponding daily intakes of FE_s calculated as described by *Andersen* and *Just (1979)*. The actual intakes of GE and ME in the individual series may vary 10% from the mean values. The feed intake was restricted to minimize the risk for diarrhoea in the first balance period and later to avoid feed residuals in the balance periods. However, the intake was adjusted according to the appetite of the pigs during the preliminary periods as described in section 3.1.4. Table 4.1 shows that the energy intake of the pigs in the present investigations was of the same order or a little greater than the daily

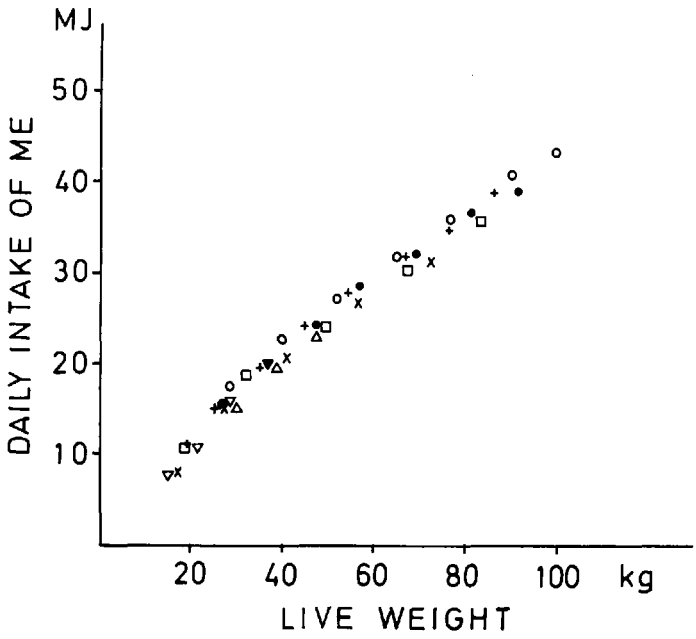

Figure 4.2. Daily intake of metabolizable energy (ME) in relation to live weight in the individual series of experiments. Same symbols as in Figure 4.1

Dagligt indtag af omsættelig energi (ME) i relation til levendevægt i de enkelte forsøgsserier. Samme symboler som i Figur 4.1

Table 4.1 Mean values of daily intake of energy in various weight classes compared to Danish standards

Tabel 4.1 Middelværdier for dagligt energiindtag i forskellige vægtklasser sammenlignet med danske normer

LW kg	Feed kg	Present investigations			Andersen and Just	
		GE,MJ	ME,MJ	FE_s	FE_s (1975)	FE_s (1979)
20	0.8	12.5	11.0	0.9	0.9	1.0
30	1.1	19.0	16.0	1.3	1.2	1.4
40	1.5	23.5	21.0	1.7	1.6	1.7
50	1.7	28.5	25.0	2.0	1.9	2.0
60	2.0	32.5	29.0	2.4	2.2	2.2
70	2.3	36.0	32.5	2.6	2.5	2.5
80	2.5	40.0	36.0	2.9	2.8	2.8
90	2.7	43.0	39.0	3.2	3.0	3.0

allowances based on a restricted feeding standard recommended for Danish Pigs *(Andersen and Just, 1975; 1979)*. This means that the consumption of the experimental diets based on highly purified feed compounds was equal to or above the recommended intakes based on conventional feed compounds such as barley and soya bean meal.

4.2 Daily gain and feed conversion efficiency in the individual series of experiments

In *Series B* Group 1 received 0.4 and Group 2 9.5 energy% linoleate during the growth period. However, the pigs were not fed iso-energetically, as the pigs of Group 2 received about 11% more GE or 7% more ME daily during the growth period than Group 1.

Table 4.2 Series B. Mean values of daily gain in weight and feed conversion ratio in barrows fed 0.4 (Group 1) or 9.5 (Group 2) energy% linoleate from 25 to 90 kg live weight. Group 2 received 11% more gross energy than Group 1

Tabel 4.2 Serie B. Middelværdier for daglig tilvækst og foderudnyttelse hos galte fodret med 0,4 (Hold 1) eller 9,5 (Hold 2) energi% linoleat fra 25 til 90 kg levendevægt. Hold 2 fik 11% mere bruttoenergi end Hold 1

	Group 1	Group 2	t-test
Number of pigs	4	3	
Daily gain, g	756	860	4.12**
SEM	12	26	
Feed conversion ratio			
ME, MJ/kg gain in weight	35.36	33.76	1.07 ns
SEM	0.80	1.38	
FE_s/kg gain in weight	2.89	2.80	

The pigs of Group 2 had a greater daily gain throughout the growth period resulting in a significantly ($P<0.01$) greater mean daily gain and a lower ($P>0.05$) mean feed conversion ratio calculated for the growth period 25–90 kg as shown in Table 4.2.

As the pigs were not fed iso-energetically it cannot be excluded that the greater daily gain and the better feed conversion efficiency of the pigs in Group 2 were due both to a greater energy intake and a greater linoleate intake. On the other hand, there seems no reason to conclude that the pigs of Group 1 receiving 0.4 energy% linoleate did not perform maximally. The growth curve for these pigs was similar or even better than that of the pigs in the other series as can be seen from Figure 4.3.

Series C was carried out with two groups of pigs (2 sows and 2 barrows per group) fed iso-energetically without (Group 1) or with 2% beef tallow (Group 2) providing 0.04 and 0.2 energy% linoleate, respectively. One barrow and one sow had digestive troubles in period IV and were not subjected to balance trials.

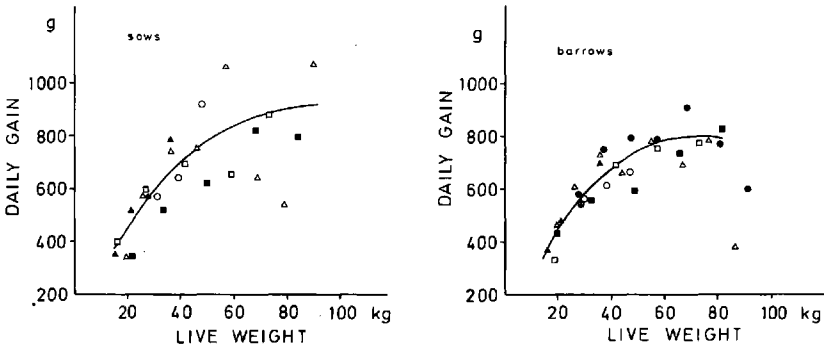

Figure 4.3. Mean values of daily gain in weight for barrows and sows within each series of experiments during the growth period. (● Series B Group 1, ○ Series C, ▲ Series D, △ Series E, ■ Series G, and □ Series H)

Middelværdier for daglig tilvækst hos galte og sogrise inden for hver forsøgsserie gennem vækstperioden. (● Serie B Hold 1, ○ Serie C, ▲ Serie D, △ Serie E, ■ Serie G og □ Serie H)

As there was no apparent difference in growth rate between the two groups, the results were pooled and a Student's t-test performed to see whether daily gains and feed conversion ratios were the same for barrows and sows. From Table 4.3 it is seen that the mean daily gain calculated for the growth period 30–50 kg was greater for sows (666 g) than for barrows (621 g) although not statistically significant ($P>0.05$). The feed conversion ratio was significantly lower ($P<0.05$) for sows than for barrows.

Table 4.3 Series C. Mean values of daily gain in weight and feed conversion ratio in pigs fed 0.04 (Group 1) and 0.2 (Group 2) energy% linoleate from 30 to 50 kg live weight

Tabel 4.3 Serie C. Middelværdier for daglig tilvækst og foderudnyttelse hos grise fodret med 0,04 (Hold 1) og 0,2 (Hold 2) energi% linoleat fra 30 til 50 kg levendevægt

	Barrows	Sows	t-test
	Group 1+2	Group 1+2	t
Number of pigs	3	3	
Daily gain, g	621	666	1.94 ns
SEM	22	8	
Feed conversion ratio			
ME,MJ/kg gain in weight	33.19	29.17	
SEM	1.02	0.60	3.40*
FE_s/kg gain in weight	2.70	2.37	

Table 4.4 Series D. Mean values of daily gain in weight and feed conversion ratio in pigs fed 0.3 (Group 1), 1.0 (Group 2), 2.0 (Group 3) or 2.7 (Group 4) energy% linoleate from 15 to 40 kg live weight

Tabel 4.4 Serie D. Middelværdier for daglig tilvækst og foderudnyttelse hos grise fodret med 0,3 (Hold 1), 1,0 (Hold 2), 2,0 (Hold 3) og 2,7 (Hold 4) energi% linoleat fra 15 til 40 kg levendevægt

		Barrows			Sows	
		Daily gain	Feed conversion ratio		Daily gain	Feed conversion ratio
Group	n	g	ME,MJ/kg gain	n	g	ME,MJ/kg gain
1	1	508	28.87	1	588	25.60
2	1	508	28.50	1	595	25.30
3	1	494	28.54	1	534	26.83
4	1	554	25.50	1	520	26.50
Mean	4	516	27.85[1)]	4	559	26.06[2)]
SEM		13	0.79		19	0.36
t (»sex«)		1.88 ns	2.07 ns			

[1)] 2.27 FE_s/kg gain, [2)] 2.12 FE_s/kg gain

It cannot be excluded that some of the pigs were already affected by digestive disturbances which occurred in this series as described in section 3.2.2.

Series D was carried out with four groups of pigs each comprising one barrow and one sow. Group 1,2,3 and 4 were fed iso-energetically and received 0.3, 1.0, 2.0 and 2.7 energy% linoleate, respectively. From Table 4.4 it is evident that the pigs receiving 0.3 and 1.0 energy% linoleate showed similar or even better weight gains than the pigs receiving 2.0 and 2.7 energy%. The mean daily gain calculated for the growth period 15–40 kg tended to be greater and the feed conversion ratio lower for sows than for barrows as shown in Table 4.4.

Table 4.5 Series E. Mean values of daily gain in weight and feed conversion ratio in pigs fed 0.1 (Group 1), 0.8 (Group 2) or 2.2 (Group 4) energy% linoleate from 20 to 90 kg live weight

Tabel 4.5 Serie E. Middelværdier for daglig tilvækst og foderudnyttelse hos grise fodret med 0,1 (Hold 1), 0,8 (Hold 2) eller 2,2 (Hold 4) energi% linoleat fra 20 til 90 kg levendevægt

		Barrows			Sows	
		Daily gain	Feed conversion ratio		Daily gain	Feed conversion ratio
Group	n	g	ME,MJ/kg gain	n	g	ME,MJ/kg gain
1	1	667	39.90	–	–	–
2	1	596	45.81	1	754	34.60
4	1	610	44.81	1	691	37.71
Mean	3	624	43.51[1)]	2	723	36.12[2)]

[1)] 3.55 FE_s/kg gain, [2)] 2.95 FE_s/kg gain

In *Series E* one barrow and one sow per group were fed iso-energetically one of four linoleate levels (0.1, 0.8, 1.5 and 2.2 energy%) during the growth period 20–90 kg.

The variation in daily gain was relatively big during the whole growth period which may be due to digestive disturbances and leg troubles as discussed in section 3.2.4. The sow of Group 1 and 3 died and the barrow of Group 3 had hurt its leg and was deleted from the balance trials.

The means of daily gain and feed conversion ratio calculated for the growth period 20–90 kg for the rest of the pigs are shown in Table 4.5. In this series the barrow receiving 0.1 energy% linoleate gained as much or more in weight as the barrows receiving greater linoleate levels. The mean daily gain was lower and the feed conversion ratio greater for barrows than for sows.

Series G was carried out with three groups of pigs (2 sows and 2 barrows per group) receiving 0.2, 1.1 and 2.1 energy% linoleate iso-energetically during the growth period from 15 to 80 kg. Because of leg troubles two barrows were excluded from the balance periods and their live weights were not recorded regularly. No distinct differences between groups were apparent. A Student's t-test did not show any significant ($P>0.05$) differences between barrows and sows with respect to mean daily gain and mean feed conversion efficiency calculated for the growth period 15–80 kg as shown in Table 4.6.

Series H was carried out with three groups of pigs (2 barrows and 2 sows per group) receiving 0.7, 1.6 and 2.3 energy% linoleate, respectively, and fed iso-energetically during the growth period from 15 to 80 kg live weight. All pigs thrived well in this experiment. There were no distinct differences between the groups in daily gain. A Student's t-test showed no statistically significant differences ($P>0.05$) between barrows and sows with respect to mean daily gain and

Table 4.6 Series G. Mean values of daily gain in weight and feed conversion ratio in pigs fed 0.2 (Group 1), 1.1 (Group 2) and 2.1 (Group 3) energy% linoleate from 15 to 80 kg live weight

Tabel 4.6 Serie G. Middelværdier for daglig tilvækst og foderudnyttelse hos grise fodret med 0,2 (Hold 1), 1,1 (Hold 2) og 2,1 (Hold 3) energi% linoleat fra 15 til 80 kg levendevægt

	Barrows	Sows	t-test
Group	1+2+3	1+2+3	t
n	4	6	
Daily gain, g	658	638	0.86 ns
SEM	7	18	
Feed conversion ratio			
ME,MJ/kg gain in weight	33.52	32.84	0.74 ns
SEM	0.66	0.61	
FE_s/kg gain in weight	2.74	2.68	

Table 4.7 Series H. Mean values of daily gain in weight and feed conversion ratio in pigs fed 0.7 (Group 1), 1.6 (Group 2) and 2.3 (Group 3) energy% linoleate from 15 to 80 kg live weight

Tabel 4.7 Serie H. Middelværdier for daglig tilvækst og foderudnyttelse hos grise fodret med 0,7 (Hold 1), 1,6 (Hold 2) og 2,3 (Hold 3) energi% linoleat fra 15 til 80 kg levendevægt

	Barrows	Sows	t-test
Group	1+2+3	1+2+3	t
n	6	6	
Daily gain, g	650	681	1.91 ns
SEM	15	6	
Feed conversion ratio			
ME,MJ/kg gain in weight	30.98	30.59	0.74 ns
SEM	0.70	0.90	
FE_s/kg gain in weight	2.51	2.49	

feed conversion ratio calculated for the growth period 15–80 kg (see Table 4.7). It is seen from Tables 4.6 and 4.7 that the pigs in Series G and H had similar daily gains, but that the pigs in Series G had a slightly greater feed conversion ratio than the pigs in Series H. As the pigs in these two series were fed and treated identically, these differences in feed utilization may be due to differences in genetic origin, mainly. From chapter VI and VII it seems that the pigs in Series G were more fat than the pigs in Series H.

All series. As there was no systematic effect of linoleate intake on daily gain within a series of experiments, but a general tendency towards lower daily gains

Table 4.8 All series. Mean values of daily gain and feed conversion efficiency in different live weight classes estimated for barrows (b) and sows (s) from all the series of experiments

Tabel 4.8 Alle serier. Middelværdier for daglig tilvækst og foderudnyttelse i de forskellige vægtklasser beregnet for galte (b) og sogrise (s) fra alle forsøgsserierne

	Daily gain		Feed conversion per kg gain in weight					
Live weight	g		kg feed		ME, MJ		FE_s	
kg	b	s	b	s	b	s	b	s
20	450	450	1.8	1.8	24.4	24.4	2.0	2.0
30	575	575	1.9	1.9	27.8	27.8	2.3	2.3
40	675	700	2.2	2.1	31.1	30.0	2.5	2.4
50	725	775	2.3	2.2	34.5	32.3	2.8	2.6
60	775	825	2.6	2.4	37.4	35.2	3.1	2.9
70	800	875	2.9	2.6	40.6	37.1	3.3	3.0
80	800	900	3.1	2.8	45.0	40.0	3.6	3.2
90	(500)	925	(5.4)	2.9	(78.0)	42.2	(6.4)	3.5

for barrows than for sows, the mean values of daily gain in the different live weight classes were calculated for all the barrows and sows, respectively, within each series. The results are shown graphically in Figure 4.3. It is evident that the variation between the individual series increases with increasing live weight, especially for the sows. The barrows drastically reduced their live weight gain after 85 kg, irrespectively of the linoleate intake. From the energy intakes shown in Table 4.1 and the mean daily gain in the different live weight classes estimated from Figure 4.3 and tabulated in Table 4.8, the efficiency of feed conversion to live weight gain was calculated for barrows and sows, respectively, comprising the total experimental material. These values shown in Table 4.8 are of course rough estimates since the daily gain obtained at almost identical intakes of ME was quite variable.

4.3 Discussion

As described in Chapter 2.2 some authors have observed a reduced growth rate and an increased feed utilization in EFA deficient pigs, and others have not.

In the present investigations no systematic differences in daily gain in weight and feed conversion efficiency between pigs fed iso-energetically and iso-nitrogenously from 0.04 to 2.7 energy% linoleate during the growth period in question were observed, although the pigs fed below 0.8 energy% linoleate were EFA deficient as judged from the ratio between 20:3,n-9 and 20:4,n-6 as shown in Figure 3.2 and discussed in Chapter 2.2

It may be claimed that the pigs fed the lowest concentrations of linoleate (Group 1 in Series C) were only raised from 30 to 50 kg live weight and thus might have shown depressed daily gain and increased feed utilization if raised to a greater weight. This cannot be excluded. *Leat (1959; 1962)* however, raised piglets from 3 weeks of age until a live weight of 90 kg on diets containing 0.03 energy% linoleate without any growth rate depression compared to pigs receiving concentrations of linoleate up to 3.5 energy%. In Series E the pigs were fed from 0.1 to 2.2 energy% linoleate during the growth period 20 to 90 kg without any distinct differences between weight gains and feed conversion ratios. In Series G and H the pigs received from 0.2 to 2.3 energy% linoleate during the growth period from 15 to 80 kg live weight and had similar daily gains and feed conversion ratios throughout the growth period. Even at slaughter at about 100 kg live weight no systematic differences in feed consumption and live weight gain were observed.

The present investigations (Series B) clearly demonstrate the necessity of feeding iso-energetically, as the effect of adding soya bean oil to the diet as a linoleate source can otherwise not be clearly split up in effects of raising the energy level of the feed and raising the linoleate level of the feed.

From Figure 4.3 it is evident that the variation in daily gain at a certain live weight is big between the series of experiments and increases with increasing live weight. Considering the relatively small variations in energy intake as shown in Figures 4.1 and 4.2, the variation in daily gain and thus feed conversion efficiency is greater than expected. Some of the variation can be explained by variations in genetic strain both within and between series, to different composition of the feed, compensatory growth caused by variable feed intake, and accidental effects. The main reason, however, that the variation within a series is greater than expected, is probably that the daily gain in weight is based on the weighings before and after the seven days balance trial.

As discussed by *Just (1970)* and *Thorbek (1975)* the weight of the pigs before and after the collection period is dependent on the time of defaecation and the amount of faeces voided. Apparently, also the activity of the pigs is greater just after having left the metabolic cages *(Just, 1970)*. It is believed that especially the amount of faeces voided before and after the balance trial may be the main reason for the big variations in daily gains in the present experiments. The daily weighing of faeces during the collection periods ranged from zero to several hundred grams dependent on the live weight. The different intake of water in the various series of experiments (cf. Chapter III) may further accentuate the variation between series.

The variation in mean daily gain in weight and mean feed conversion efficiency for the total growth period for all the series of experiments expressed as the coefficient of variation (CV% = mean/standard variation × 100) was 4.5 and 5.0%, respectively, and almost identical for barrows and sows. This variation is not greater than that found by *Just (1970)* in his balance experiments.

The mean values of daily gain and feed conversion efficiency obtained for the whole material in the individual weight classed between 20 and 90 kg live weight are shown in Table 4.8. Although these values are rough estimates they show that the pigs have performed quite satisfactorily on the experimental diets. Generally, the barrows showed a lower daily gain and higher feed conversion ratio than the sows. These findings might be expected since the barrows generally deposited more fat than the sows (see Chapter VII).

As discussed earlier (Chapter III) the pigs in Series C, D, and E had digestive disturbances due to the high digestibility of the feed dry matter. The feed composition based on tapioca meal, maize starch and potato meal as used in Series G and H, was better from a digestive point of view. On these diets the pigs of the two series gained an average of 650 g daily with a feed conversion ratio of 2.6 FE_s/kg gain in weight from 15 to 80 kg live weight. The live weight gain was reduced after 80 kg, especially in the barrows. This might be due to the relatively great intake in the preceeding period compared to the standards for restricted feeding as shown in Table 4.1. A feed conversion ratio of 2.6 FE_s/kg

gain in weight seems to be quite high. For example *Madsen et al. (1976)* found in SPF-pigs with a similar feeding schedule as used here a daily gain of 699 g and a feed conversion of 2.80 FE_s/kg gain for the growth period 20–80 kg. The present results indicate an efficient utilization of the energy rich experimental diets.

4.4 Conclusions

As the pigs receiving 0.04 energy% linoleate were only raised from 30 to 50 kg, and only one pig receiving 0.1 energy% linoleate was brought up from 20 to 90 kg live weight, the conclusions in the following are mainly based on the results from pigs fed iso-energetically and iso-nitrogenously from 0.2 to 2.3 energy% linoleate during the growth period from 15 to 90 kg live weight, and from pigs receiving an extra supply of 90 g soya bean oil per kg basal diet providing 9.5 energy% linoleate.

1. The various linoleate levels employed fed iso-energetically and iso-nitrogenously had no systematic effect on daily gain in weight and feed conversion efficiency.
2. Generally, the barrows showed a lower daily gain and a higher feed conversion ratio than the sows.
3. On the diets based on tapioca meal, maize starch, potato meal, casein and beech sawdust used in Series G and H, the pigs (n = 22) gained an average of 650 g and had a feed conversion ratio of 32 MJ ME/kg gain in weight corresponding to about 2.6 FE_s/kg gain in weight calculated for the growth period from 15 to 80 kg live weight. These results indicate an efficient utilization of the experimental diets.
4. The variation in mean daily gain in weight and mean feed conversion efficiency for all the series of experiments expressed as the coefficient of variation was 4.5 and 5.0%, respectively, and identical for barrows and sows.
5. In Series B the pigs of Group 2 (9.5 energy% linoleate) received an additional supply of 90 g soya bean oil per kg feed which resulted in an intake of 11% more GE or 7% more ME than the pigs of Group 1 (0.4 energy% linoleate) receiving the basal diet only.
   The pigs of Group 1 gained an average of 756 g daily, whereas the pigs of Group 2 gained 860 g daily from 20–90 kg live weight, the difference being statistically significant ($P<0.01$). The feed conversion ratio was 35.4 and 33.8 MJ ME/kg gain in weight (2.9 and 2.8 FE_s/kg), respectively, the difference being non significant ($P>0.05$).
6. *Pigs of Danish Landrace weaned at 5 weeks of age and fed 0.2 energy% linoleate during the growth period until a slaughter weight of 90 kg can be expected to perform maximally with respect to daily gain in weight and feed conversion efficiency.*

It cannot be excluded that pigs receiving less than 0.2 energy% linoleate can also perform maximally. However, such low levels are only present in highly purified diets, which may have deleterious effects on appetite and digestion, and thereby indirect effects on weight gain and feed utilization.

V. Digestibility of nutrients and energy

The dietary intake of linoleate sufficient to cover the requirements of the digestive apparatus for linoleic acid was determined by feeding different levels of linoleate ranging from 0.04 to 9.5% of gross energy (energy%) during the growth period using the digestibility of nutrients and energy as response factors.

The digestibility of dry matter (DM), organic dry matter (OM), nitrogen (N), N-free extracts (NFE), crude fat (HCl + EE), crude fibre (CF), gross energy (GE), and fatty acids was determined as the difference between the amount of substance in feed and faeces, and therefore in all cases represents the apparent digestibility. The apparent digestibility coefficient is then the amount of apparent digested substance in percent of the ingested amount of the substance.

The digestibilities of the above-mentioned components were determined during the balance trials. Details about the animals, their intake of feed and water, and the sampling and analytical procedures are given in Chapter III.

The results from the digestibility trials were evaluated within each series. There was no difference between »sex«, and in all cases, except for crude fibre and crude fat, there was also no difference between periods (i.e. age or weight). Therefore, except for crude fibre and crude fat, the data were pooled within each group of each series, and the results treated statistically either by the Student's t-test or by analysis of variance.

The precision or reproducibility of the determinations of the digestibility coefficients was expressed by the coefficient of variation (CV%) where the standard deviation (SD) was either the pooled one or the individual ones in percent of the mean.

5.1 Digestibility of DM, OM, N, NFE and GE

Between the groups in Series B, D, E, G and H no significant differences ($P \geq 0.05$) were found in the digestibility of DM, OM, N, NFE and GE. Also no statistically significant differences were found between Series G and H, where the feed composition was the same. Therefore, the data for all groups within each series were pooled, and so were the data for Series G and H. The mean values and their standard errors (SEM) are presented in Table 5.1. Clearly, the F-values show that the digestibility of each substance is different between the series, which is due to the composition of the basal diets.

In Series C Group 2 received beef tallow in the diet and this significantly de-

Table 5.1 Apparent digestibility (%). Mean values of dry matter (DM), organic dry matter (OM), nitrogen (N), nitrogen free extracts (NFE) and gross energy (GE) in Series B, D, E and G + H irrespective of the linoleate intake

Tabel 5.1 Tilsyneladende fordøjelighed (%). Middelværdier for tørstof (DM), organisk tørstof (OM), kvælstof (N), kvælstoffri ekstraktstof (NFE) og brutto energi (GE) i serie B, D, E og G + H uafhængigt af linolsyreindtaget

Series n	B 50	D 32	E 38	G+H 116	Pooled SD	F-test f
DM	93.4	92.8	91.2	87.9		
SEM	0.12	0.19	0.13	0.14	1.20	333***
OM	95.4	93.9	92.1	90.0		
SEM	0.11	0.17	0.12	0.12	1.05	378***
N	91.7	94.9	91.3	88.4		
SEM	0.21	0.16	0.25	0.21	1.88	116***
NFE	98.0	97.6	97.3	96.1		
SEM	0.04	0.11	0.07	0.08	0.67	123***
GE	94.7	92.9	91.0	88.8		
SEM	0.12	0.20	0.14	0.13	1.19	343***

pressed the digestibility of DM, OM and GE, whereas it significantly increased the digestibility of crude fat, and did not influence the digestibilty of N, CF and NFE as shown in Table 5.2.

The digestibility of the diets used in Series B, C, D and E was greater than in Series G and H, where tapioca meal was included in the diets at the expense of glucose or maize starch. As discussed earlier (Sections 3.1.5 and 3.2) the former diets caused digestive troubles, whereas no such troubles were observed with the latter diets. This high digestibility of all major nutrients naturally reduced

Table 5.2 Apparent digestibility (%). Mean values of nutrients and energy in the pigs of Series C receiving no fat (Group 1) or 2% beef tallow (Group 2) in their diets

Tabel 5.2 Tilsyneladende fordøjelighed (%). Middelværdier for næringsstoffer og energi hos grisene i Serie C, der ikke har fået fedt i foderet (Hold 1) eller har fået 2% oksetalg (Hold 2)

Series C	Group 1		Group 2		t-test
Nutrient[1)]	Mean	SEM	Mean	SEM	df = 20
DM	96.7	0.21	95.3	0.34	3.62**
OM	98.1	0.14	96.6	0.28	4.83***
N	96.7	0.25	96.6	0.15	0.27 NS
FAT	52.8	2.27	64.1	2.18	3.59**
CF	87.8	2.32	80.1	3.49	1.88 NS
NFE	99.2	0.05	99.0	0.16	1.08 NS
GE	97.8	0.15	95.4	0.31	7.25***

[1)] Abreviations as in Table 5.1. CF = crude fibre.

the amount of faeces voided. The difficulties in sampling and analysing the faeces have been mentioned in Section 3.1.5. Despite all these troubles the precision in determining the digestibility of DM, OM, N, NFE and GE was found to be quite high. Using the pooled SD shown in Table 5.1, it is seen that the precision of determining the digestibility of NFE was rather high, the CV% being about 0.7, whereas the digestibility of DM, OM and GE was a little lower, the CV% being between 1.1. and 1.4. For nitrogen the precision was about 2% and almost identical in all series.

5.2 Digestibility of crude fat

Both the digestibility of crude fat (HCl + EE) and the precision of the determinations were highly influenced by the amount of dietary fat. Therefore, the results are shown for the individual series in Tables 5.2, 5.3, 5.4, 5.5, 5.6 and 5.7 for Series C, B, D, E, G and H, respectively. It is apparent from these tables that a low amount of dietary fat generally resulted in a low digestibility coeffi-

Table 5.3 Series B. Intake and apparent digestibility of crude fat in pigs fed 0.4 (Group 1) or 9.5 (Group 2) energy% linoleate from 25 to 90 kg live weight. Mean values of 7 balance periods

Tabel 5.3 Serie B. Indtag og tilsyneladende fordøjelighed af råfedt hos grise fodret med 0,4 (Hold 1) eller 9,5 (Hold 2) energi% linoleat fra 25 til 90 kg levendevægt. Middelværdier for 7 balance perioder

Series B Linoleate (GE %)	Group 1 0.4	Group 2 9.5
n	28	22
Intake, g	16	185
Digested, %	60.7	93.0
SEM	1.30	0.23
CV, %	11.2	1.3

Table 5.4 Series D. Mean values of intake and apparent digestibility of crude fat in pigs fed 0.3 to 2.7 energy% linoleate from 15 to 40 kg live weight

Tabel 5.4 Serie D. Middelværdier for indtag og tilsyneladende fordøjelighed af råfedt hos grise fodret med 0,3 til 2,7 energi% linoleat fra 15 til 40 kg levendevægt

Series D	Group 1		Group 2		Group 3+4
Linoleate (GE %)	0.3		1.0		2.0–2.7
Per No.	I-II	III-IV	I-II	III-IV	I-IV
n	4	4	4	4	16
Intake, g	2.5	14.5	6.0	19.5	25.5
Digested, %	34.7	71.7	53.3	73.4	81.8
SEM	4.38	3.36	6.52	2.81	1.05
CV, %	21.9	9.4	23.2	7.5	6.8

Table 5.5 Series E. Intake and apparent digestibility of crude fat in pigs fed 0.1 to 2.2 energy% linoleate from 15 to 60 kg live weight. Mean values of 5 balance periods

Tabel 5.5 Serie E. Indtag og tilsyneladende fordøjelighed af råfedt hos grise fodret med 0,1 til 2,2 energi% linoleat fra 20 til 60 kg levendevægt. Middelværdier for 5 balanceperioder

Series E Linoleate (GE %)	Group 1 0.1	Group 2 0.8	Group 3 1.5	Group 4 2.2
n	8	10	10	10
Intake, g	5	16	28	39
Digested, %	23.0	68.2	81.4	84.7
SEM	3.04	2.01	0.84	0.58
CV, %	37.3	9.3	3.3	2.2

Table 5.6 Series G. Mean values of intake and apparent digestibility of crude fat in pigs fed 0.2 to 2.1 energy% linoleate from 15 to 80 kg live weight

Tabel 5.6 Serie G. Middelværdier for indtag og tilsyneladende fordøjelighed af råfedt hos grise fodret med 0,2 til 2,1 energi% linoleat fra 15 til 80 kg levendevægt

Series G	Group 1	Group 2		Group 3
Linoleate (GE %)	0.2	1.1		2.1
Per No.	I-V	I	II-V	I-V
n	20	4	12	20
Intake, g	13	12	30	39
Digested, %	46.4	64.7	73.1	81.2
SEM	2.12	1.64	1.01	0.67
CV, %	20.4	5.1	4.8	3.7

Table 5.7 Series H. Mean values of intake and apparent digestibility of crude fat in pigs fed 0.7 to 2.3 energy% linoleate from 15 to 80 kg live weight

Tabel 5.7 Serie H. Middelværdier for indtag og tilsyneladende fordøjelighed af råfedt hos grise fodret med 0,7 til 2,3 energi% linoleat fra 15 til 80 kg levendevægt

Series H	Group 1		Group 2	Group 3	
Linoleate (GE %)	0.7		1.6	2.3	
Per No.	I	II-V	I-V	I	II-V
n	4	16	20	4	16
Intake, g	7	19	28	17	47
Digested, %	49.0	62.9	75.6	77.1	83.9
SEM	12.5	1.24	1.14	0.78	0.69
CV, %	12.5	7.9	6.8	2.0	3.3

cient and a low precision of the determinations, and *vice versa*. Low intakes of crude fat also resulted in low intakes of linoleic acid. However, the measurement of the digestibility of fat and especially fatty acids is complicated mainly because of the appreciable quantities of endogenous fat excreted into the small intestine with the bile and the action of the microbes in the gastrointestinal tract, especially in the hind gut. Therefore, some attention was paid to the fatty acid composition of faecal and bile lipids, and the digestibility of linoleic acid.

5.2.1 Fatty acid composition of faecal lipids

It is now well recognised that the microbes in caecum and colon hydrogenate unsaturated fatty acids to such an extent that the fatty acid composition of the faecal lipids does not reflect the undigestible fatty acids. Because of this recognition only few determinations of the fatty acid composition of faecal lipids were performed in the present investigations, mainly to see, if the amount of linoleic acid in faecal lipid was influenced by different intakes of linoleic acid. Table 5.8 summarizes the results from the digestibility trials with the pigs of Series C and B receiving 0.04, 0.4 and 9.5 energy% linoleate in their diets. It is evident that the faecal lipids contain more fatty acids at the high than at the low

Table 5.8 Concentrations and proportions by weight of long chain fatty acids in total lipids of faeces from pigs fed three different levels of linoleate

Tabel 5.8 Koncentrationer og vægtfordelingsprocenter af langkædede fedtsyrer i total lipid fra gødning fra grise fodret med tre forskellige linoleatniveauer

Series (Per. No.)	C (II)		B (VI)		B (VI)	
Linoleate (GE %)	0.04		0.4		9.5	
No. of pigs	4		3		3	
Fatty acid[1)]	Mean	SD	Mean	SD	Mean	SD
12:0	0.10	0.08	0.23	0.06	0.13	0.06
14:0	1.85	0.60	2.03	0.40	0.90	0.10
14:1	4.53	1.93	8.30	1.65	2.97	0.31
15:0	1.95	1.88	7.67	0.74	2.70	0.17
16:0	36.50	1.67	26.57	0.45	24.99	0.68
16:1	ND	ND	2.47	1.59	0.80	0.36
17:0	4.90	0.62	4.42	0.26	1.47	0.21
18:0	45.33	4.44	34.17	6.40	47.40	3.64
18:1	ND	ND	9.37	2.23	11.40	1.89
18:2	1.13	0.90	2.20	0.82	3.87	1.03
20:0	2.43	1.39	2.20	0.71	1.80	0.16
18:3 + 20:1	1.28	0.26	0.37	0.23	1.53	1.74
mg/100 mg total lipid	36.20	2.10	33.20	1.16	51.92	3.68

[1)] Named by the number of carbon atoms in the chain and the number of double bonds, the n indicating the position of the first double bond counted from the methyl group of the end of the fatty acid chain. ND indicates no detectable amounts (less than 0.01 mg per 100 mg fatty acids).

intakes of fat and that linoleic acid shows the same trend. Even at the lowest intake of about 160 mg linoleic acid in Series C (0.04 energy% linoleate) the faecal lipids still contain linoleic acid. It is also apparent from Table 5.8 that changes occur in the distribution of most fatty acids. Palmitoleic acid (16:1) and oleic acid (18:1) were not present in detectable amounts at an intake of 0.04 energy% linoleate. Apparently, these fatty acids had been fully hydrogenated to palmitic or stearic acid, respectively, or converted into other fatty acids. Fatty acids with an uneven carbon number in the chain such as pentadecanoic acid (15:0) and heptadecanoic acid (17:0) were also present in appreciable amounts. As nonadecanoic acid (19:0) was added as internal standard the concentration of this fatty acid could not be calculated, but in other experiments, where 17:0 was used as the internal standard, it was found that 19:0 also occurred in faecal lipids. The presence of these fatty acids indicate microbial activity in the alimentary canal of all the pigs.

5.3 Digestibility of fatty acids

Because of excretion to the small intestine of bile lipids, microbial activity in the alimentary canal and disquamation of cells, the digestibility of fatty acids determined as the feed-faeces difference does not give a true estimate of the amounts of absorbed fatty acids. In some cases notably for stearic acid it may even be quite misleading, as more 18:0 may be excreted in faeces than was ingested. Table 5.9 shows the apparent digestibility of palmitic, stearic and linoleic acid at three different linoleate intakes. It is seen that the digestibility of linoleic acid was very high and increased with increasing amount of dietary linoleate. However, the digestibility of stearic acid was extremely low, and in one case more 18:0 was excreted in faeces than was ingested. For all these fatty acids the digestibility increased with increasing intakes. This trend was the same

Table 5.9 Apparent digestibility (%) of palmitic, stearic and linoleic acid in pigs fed three different levels of linoleate

Tabel 5.9 Tilsyneladende fordøjelighed (%) af palmitin-, stearin- og linolsyre hos grise fodret med tre forskellige linoleatniveauer

Series (Per. No.)	C (II)			B (VI)			B (VI)		
Linoleate (GE %)	0.04			0.4			9.5		
No. of pigs	4			3			3		
Fatty acid[1)]	Intake	Digested		Intake	Digested		Intake	Digested	
	g	%	SD	g	%	SD	g	%	SD
16:0	0.98	72.2	6.4	5.1	85.7	0.51	22	91.2	1.75
18:0	0.38	13.2	11.3	1.0	20.6	13.91[2)]	7	49.4	7.54
18:2	0.16	96.6	4.1	3.6	98.3	0.66	94	99.7	0.12

[1)] See Table 5.8

[2)] 2 pigs only, as one digestibility coefficient was negative.

as for crude fat. The low digestibility of 18:0 was probably due to microbial hydrogenation of 18:2 and 18:1. It should be stressed, however, that 18:2 may include both linoleic acid and other 18:2 isomers, including the trans forms, as no specific identification of 18:2 was performed.

Tables 5.8 and 5.9 also show that the greater amounts of unsaturated fatty acids ingested, the greater amounts apparently escape hydrogenation. These results are confirmed by the lower methane production obtained at the high linoleate intakes, indicating a reduced microbial activity in the alimentary canal as discussed in Chapter VII.

5.3.1 Fatty acid composition of bile lipids

The linoleic acid content of the faecal lipids may not only be of dietary origin, but also of microbial or endogenous origin, and may stem from disquamated cells *(Clement, 1975)*. As no information on the fatty acid composition of bile lipids from pigs was available, it was decided to pay attention to this in a later experiment. This was done in Series K, where 3 female pigs of Danish Landrace were fed the same basal diets as used in Series G and H from about 15 kg live weight. The pigs received 0.2, 1.2 and 2.3 energy% dietary linoleate. After 65 days on these diets the pigs were sacrificed and the gallbladder with its bile content was removed for analysis. The concentrations of total lipids and total fatty acids of gallbladder bile are shown in Table 5.10, and for comparison the same data are shown for blood plasma lipids. It is seen that the lipid content of bile is much greater for the pig receiving 2.3 energy% linoleate than for the other pigs, whereas the concentrations of total fatty acids in total lipids are identical for all three levels of dietary linoleate.

The fatty acid composition (mg per 100 mg total fatty acids) of total lipids from bile and plasma of these pigs is shown in Table 5.11. From the ratios between 20:3,n-9 and 20:4,n-6 it is obvious that the pig fed 0.2 energy% linoleate

Table 5.10 Concentrations of total lipid and total fatty acids in plasma and gallbladder bile of pigs fed three different levels of linoleate

Tabel 5.10 Koncentrationer af total lipid og total fedtsyrer i plasma og galdeblæregalde fra grise fodret med tre forskellige linoleatniveauer

Series K Linoleate (GE %)	Pig No. 1 0.2	Pig No. 2 1.2	Pig No. 3 2.3
Total lipids (mg/100 ml)			
Plasma	220	315	243
Bile	670	610	910
Fatty acids (mg/100 mg total lipid)			
Plasma	64.17	43.09	47.24
Bile	49.78	50.26	49.00

Table 5.11 Proportions by weight of long chain fatty acids in total lipid of plasma and gallbladder bile of pigs fed three different levels of linoleate

Tabel 5.11 Vægtfordelingsprocenter af langkædede fedtsyrer i total lipid fra plasma og galdeblæregalde fra grise fodret med tre forskellige linoleatniveauer

Series K	Pig No. 1		Pig No. 2		Pig No. 3	
Linoleate (GE %)	0.2		1.2		2.3	
Fatty acid[1)]	Plasma	Bile	Plasma	Bile	Plasma	Bile
12:0	0.12	ND	0.12	ND	0.21	ND
14:0	1.46	0.48	1.07	0.34	1.29	0.31
16:0	19.34	28.81	17.57	27.08	18.97	29.22
16:1	4.44	4.88	3.16	3.24	2.50	2.39
18:0	13.11	10.06	14.27	12.83	14.31	12.71
18:1	41.80	37.83	36.71	31.50	28.77	24.14
18:2	5.49	6.21	13.46	12.28	19.50	16.08
18:3	0.36	0.30	0.60	0.40	0.83	0.65
20:3,n-9	7.12	5.79	1.51	2.39	0.13	1.53
20:3,n-6	ND	ND	0.16	ND	0.19	ND
20:4,n-6	4.41	3.84	7.98	7.40	9.80	9.92
20:5,n-3	0.65	0.68	0.95	1.09	0.78	1.00
22:4,n-6	0.19	ND	0.35	ND	0.32	ND
22:5,n-3	0.53	0.26	1.32	0.72	1.42	0.92
22:6,n-3	0.98	0.86	0.77	0.73	0.98	1.13
20:3,n-9 / 20:4,n-6	1.61	1.51	0.19	0.32	0.01	0.15

[1)] See Table 5.8

was EFA deficient. The ratios decrease with increasing dietary intakes, but they are greater for bile lipids than for plasma lipids. As for plasma lipids the proportions of 16:1 and 18:1 decrease with increasing intakes. Also, 18:2 and 20:4,n-6 increase with increasing intakes, and so does 18:3 from the soya bean oil. It is also apparent that bile lipids contain about 15% polyunsaturated fatty acids, which are excreted to the small intestine, where some may be reabsorbed, some may reach the hind gut, where the microbes probably are using them in their own metabolism. Anyway, none of the polyunsaturated fatty acids mentioned above were found in the faecal lipids (cf. Table 5.8). Until now, there is no experimental proof of absorption of long chain fatty acids from the caecum and/or colon. It is also apparent from Table 5.11 that bile lipids generally contain greater proportions of 16:0 and smaller proportions of 14:0, 18:0, 18:1 and 22:5,n-3 than plasma lipids, and apparently do not contain 12:0, 20:3,n-6 and 22:4,n-6. As liver bile is not concentrated in the gallbladder of pigs *(Kolb, 1967)*, the gallbladder bile lipids and their fatty acid concentrations are likely to reflect the concentrations of total lipids and fatty acids in the freshly secreted liver bile.

Thus, it is evident that EFAs are excreted through the bile, and that the fatty acid composition of the bile lipids is affected in the same way as the plasma fatty acids during EFA deficiency.

5.4 Digestibility of crude fibre

From Table 3.2 is is evident that the origin of crude fibre was different in the various series. Tapioca meal, casein and soya bean meal contained some crude fibre, the composition of which was not identical. Furthermore, cellulose was added in Series B and C, while beech sawdust was added in the other series. In Series E the pigs also received 30 g pectin daily from period VI. In all cases the variation in the digestibility of crude fibre was great both within periods and between periods. The reason for this was partly the source of crude fibre especially sawdust, partly the relatively small amounts of faeces voided, which made quantitative and representative sampling difficult, and also the lower precision of the chemical determination of crude fibre. Therefore, the digestibility (%) of crude fibre (Mean ± SEM) will be dealt with in the following for each series.

In *Series B* there was no significant difference ($P>0.05$) between the two groups receiving either 0.4 (Group 1) or 9.5 (Group 2) energy% dietary linoleate, but the digestibility was significantly lower in period II (55.0 ± 3.83,n=7) than in periods III to VIII (79.2 ± 1.06,n=43). The precision of the determination of crude fibre in this series was in the latter case 9.6%.

The digestibility of crude fibre in *Series C* is shown in Table 5.2. No significant difference ($P>0.05$) was found between the two groups showing that beef tallow did not affect the digestibility of crude fibre. The average digestibility was 84.3 ± 2.14 (n=22) determined with a precision of 11.9%. Both in Series B and C the digestibility of crude fibre was much higher than expected, resulting in digestive disturbances as described in section 3.2.

In *Series D* beech sawdust was added to a diet otherwise low in fibre material. This reduced the digestibility of crude fibre to 31.5 ± 2.60 (n=30), and the precision of the determination to 44.8%. In two cases more crude fibre was found in the faeces than in the feed.

In *Series E* the digestibility of crude fibre varied more than 100%. The pectin improved the consistency and the amount of faeces, but the digestibility coefficients still varied much, and often more crude fibre was found to be voided than ingested, which of course was due to the difficult sampling of faeces as described above.

Similar variations were found in *Series G + H*. In 24 cases more crude fibre was found in the faeces than in the feed. The digestibility of crude fibre in the remaining 92 cases was 17.8 ± 1.25 determined with as low a precision as 67.3%.

5.5 Discussion

The apparent digestibility of DM, OM, N, NFE, CF, crude fat and GE was not influenced by the dietary levels of linoleate ranging from 0.04 to 9.5 energy% although the lowest linoleate intakes were inadequate as judged from the 20:3,n-9/ 20:4,n-6 ratios of plasma and bile lipids (cf. Figure 3.2 and Table 5.11). There was no apparent effect of »sex« on the digestibility coefficients which was also not expected from the studies by *Madsen (1963)*. The live weight range in question (15–100 kg) did not influence the digestibility coefficients. These findings are in accordance with those by *Madsen (1963), Just (1970)* and *Thorbek (1975)* for Danish Landrace pigs. The digestibility coefficients were, however, highly influenced by the composition of the basal diets as shown in Tables 5.1 and 5.2. The rations used in Series B, C, D, and E were composed of maize starch, glucose and casein, which were highly digestible, whereas the rations used in Series G and H contained about 30% tapioca meal, which clearly lowered the digestibility coefficients. Also the inclusion of beech sawdust in Series D, E, G and H lowered the digestibility of crude fibre compared to that of the cellulose used in Series B and C. Consequently, more faeces was voided in Series G and H than in the other series. However, generally all the semi purified diets which were used in the present studies had higher digestibilities than traditionel swine rations consisting of barley, maize or sorghum together with skim milk powder or a protein mixture (soya bean meal and meat and bone meal) *(Thorbek, 1975)*. The precision of the determinations of DM, OM, N, NFE and GE was of the same order as found for traditionel swine rations *(Just, 1970; Thorbek, 1975)*, whereas the precision of the determination of crude fibre was very low, partly caused by the small amounts of faeces voided, partly by the source of crude fibre.

The effect of increasing concentrations of dietary fat on the apparent digestibility of crude fat and fatty acids is in accordance with most other investigations in pigs (e.g. *Freeman et al., 1968; Just, 1970; Sundstøl, 1974; Just et al., 1980)*. At the low dietary levels of fat, the endogenous amount of fat voided in faeces had a relatively great effect on the apparent digestibility and the precision of the determination as evidenced in Tables 5.2 to 5.7. By means of isotope technique *Freeman et al. (1968)* found that endogenous fat amounted to 12.9 g per day in pigs at an intake of approximately 1 kg dry matter, while *Sundstøl (1974)* found 9.0 g in balance trials with pigs between 29 and 83 kg on a fat free diet. In the present studies the lowest fat intake was 2.5 g per day for the pigs in Series D, Group 1, (Table 5.4) and 1.6 g was excreted. Even if all the excreted fat be recognized as endogenous fat, it would give no more than 2 g endogenous fat per kg ingested dry matter. *Eggum et al. (1977)* found 6 g endogenous fat per kg feed dry matter in rats.

As shown in Table 5.12 about 8 g fat is excreted to the gut through the bile

Table 5.12 Daily excretion of bile and biliary total lipids, total fatty acids and linoleic and arachidonic acid in pigs fed three different linoleate levels

Tabel 5.12 Daglig udskillelse af galde og galde total lipid, total fedtsyrer samt linol- og arakidonsyre hos grise fodret med tre forskellige linoleatniveauer

Series K Linoleate (GE %)	Pig No. 1 0.2	Pig No. 2 1.2	Pig No. 3 2.3
Bile, l[1)]	1.2	1.2	1.2
Total lipid, g	8.04	7.32	10.92
Fatty acids, g	4.00	3.68	5.35
18:2, mg	249	452	860
20:4, mg	154	273	531

[1)] Sambrook (1978)

on a low fat diet. These calculations are based on the bile flow measured by *Sambrook (1978)* in pigs receiving a fat free diet of similar composition as used in the present studies, although the inclusion of fat in the ration may increase the bile flow *(Juste et al., 1983)*. Obviously, most of this fat must have been reabsorbed, as the amounts of fat used by microbes as energy source is generally believed to be neglegible.

The fatty acid composition of faecal total lipids shown in Table 5.8 indicates that the relative proportion of 18:2 in faeces increases with increasing intake of 18:2. Actually, the methane production was reduced in pigs fed 9.5 energy% linoleate compared to pigs receiving 0.4 energy%, indicating a depressive effect of fat on the microbial activity (see Chapter VII). Thus, greater amounts of 18:2 may have escaped hydrogenation. The high digestibility of 18:2 and the low digestibility of 18:0 shown in Table 5.9 is probably due to hydrogenation of unsaturated C18-fatty acids to stearic acid which has been found to occur in the hind gut of pigs *(Bayley and Lewis, 1965; Freeman et al., 1968; Carlson and Bayley, 1968; Just and Mason, 1974; Mason and Just, 1976; Just et al., 1980; Eggum et al., 1982)*. The occurrance of fatty acids in faecal lipids with an uneven number of carbon atoms such as 15:0 and 17:0 further indicates microbial activity. Consequently, it is impossible to predict the absorbed amounts of linoleic acid from the differences between ingested and excreted amounts.

No studies on digestibility of feed components in the previously reported studies on EFA deficiency or EFA requirements in pigs have been performed. In EFA deficient rats showing visible deficiency symptoms, reduced feed utilization and increased heat production, there was no effect on the digestibility of dry matter *(Müller, 1975)*.

In the early studies on EFA deficiency in swine, *Witz and Beeson (1951)* found that »the most striking abnormality noted in the *post mortem* macroscopic examination was the abnormally small gallbladders of the pigs on the fat

free diets. There was only a small amount of bile present in the gallbladder«. These findings have not been confirmed by others and also not by the present studies. Bile was present in the gallbladders of all the pigs. However, the concentrations of total fatty acids and individual fatty acids were highly influenced by the dietary linoleate level. As shown in Table 5.11 the fatty acid composition of the bile fatty acids showed similar changes as for plasma total lipids and 20:3,n-9/ 20:4,n-6 ratios similar or greater than for plasma lipids. These findings indicate that the biliary lipids excreted by the liver follow the same changes as the fatty acid composition of other organ lipids, and that EFAs are excreted from the organism to the small intestine even in EFA deficiency. It is, however, known that part of these endogenous fatty acids may be reabsorbed through the portal vein, some part utilized by the microbes in the hind gut or hydrogenated or decomposed to other fatty acids *(Clement, 1975)*. Anyway, the polyunsaturated fatty acids found in the bile lipids (Table 5.11) were not present in the faecal lipids (Table 5.8).

An impaired bile formation as observed by *Witz and Beeson (1951)* in EFA deficient pigs might lead to fat malabsorption. This has actually been observed in EFA deficient rats *(Barnes et al., 1941; Snipes, 1968)*. However, *Clark et al. (1973)* demonstrated that fat malabsorption in EFA deficient rats was not due to alteration of intraluminal digestive functions, nor to changes in mucosal membrane uptake of fat, but to a reduction of mucosal lipid esterifying capacity and especially a delay in removal of newly synthesized triglyceride from the mucosa. This may be due to changes in the lipid and fatty acid composition of the epithelial cells of the intestines *(Enser and Barley, 1962; Yurkowski and Walker, 1970)*. A delay of the rate of transfer of amino acids and sugar from the tissue uptake site to the serosal site was also noted in *in vitro* studies with everted gut sacs from EFA deficient rats *(Imami et al., 1970)*. Recent studies have shown that arachidonic acid through the formation of prostaglandins may protect the gastric mucosa against various injurious agents *(Nutr. Rev. 1983, 41, 90–91)*.

EFA restriction may have an inhibitory effect on intestinal 1,25-dihydroxycholecalciferol-dependent calcium absorption *(Hay et al., 1980)*, and on the absorption of vitamin E *(Gallo-Torres et al., 1978)*. However, all animals received intramuscular injections of vitamin A, D and E at about 20 and 40 kg live weight, and received twice the recommended dietary allowances. Although, specific studies on the availability of these and other trace elements were not performed, there was no evidence of altered supply as a consequence of low linoleate intakes. These observations are in accordance with the findings by *Müller (1975)* who observed that intramuscular injections of fat soluble vitamins to EFA deficient rats raised on fat free diets had no effect on their performance or appearance.

5.6 Conclusions

1. The apparent digestibility of DM, OM, N, NFE and GE was not affected by the dietary levels of soya bean oil in the diets, but were significantly ($P<0.001$) affected by the composition of the basal diets.
   Within each series of experiments the digestibility coefficients were not affected by »sex« and periods (i.e. age or weight). The digestibility coefficients ranged between 88 and 98% and were determined with a precision below 2%.
   The digestibility of the experimental diets was greater than generally found for conventional swine rations.
2. The inclusion of 2% beef tallow in the diet significantly depressed the digestibility of DM, OM and GE, and significantly increased the digestibility of crude fat, whereas it did not influence the digestibility of N, CF and NFE.
3. The digestibility of crude fibre varied between the series due to the source. In Series G and H, where beech sawdust was included, more crude fibre was excreted in faeces than ingested in 24 cases. The digestibility of crude fibre in the remaining 92 cases was 18% determined with as low a precision as 67%.
   In series B and C, where cellulose was used as crude fibre source, the apparent digestibility coefficients were found to be 79 and 84%, respectively, which in both cases was much greater than expected. The precision of the determination was 9.6 and 11.9%, respectively.
4. Both the digestibility of crude fat, determined with ether extraction after HCl hydrolysis (HCl + EE), and the precision of the determination were highly influenced by the amount of dietary fat. A low amount of dietary fat generally resulted in a low digestibility coefficient and a low precision of the determination, and *vice versa*.
5. The amount of endogenous fat excreted in faeces was estimated to be no more than 2 g per kg dry matter intake, although the daily amount of biliary fat was estimated to be about 8 g.
6. Faecal lipids contained greater concentrations of total fatty acids including linoleic acid at the high than at the low intakes of fat.
   Even at the lowest intake of linoleate (0.04 energy%), the faecal lipids still contained linoleic acid, probably incorporated into microbial lipids. At this low level of dietary linoleate, palmitoleic (16:1) and oleic acid (18:1) were not present, probably because of hydrogenation of free unsaturated fatty acids.
   Fatty acids with an uneven carbon number (15:0, 17:0, 19:0) were found in all faecal lipids indicating microbial activity in the alimentary canal of all the pigs.
7. The greater amounts of polyunsaturated fatty acids ingested, the greater

amounts apparently escaped hydrogenation. These findings indicate a depressive effect of polyunsaturated fatty acids on microbial activity in the gut of pigs. These findings were confirmed by a lower methane production obtained at the high linoleate intake (Chapter VII).

8. EFAs were found to be excreted via the bile in amounts related to the dietary intake.
   The ratio 20:3,n-9/20:4,n-6 of bile lipids was slightly greater than that of plasma total lipids and decreased with increasing intake of linoleate.
9. *In pigs of Danish Landrace weaned at 5 weeks of age the requirement of dietary linoleate for adequate digestion of feed components and gross energy is below 0.2 energy%, if not zero during the live weight range of 15 to 90 kg.*

VI. Nitrogen metabolism

The dietary linoleate level sufficient to secure maximum nitrogen retention and thus maximum meat production in slaughter pigs was determined by feeding different levels of linoleate ranging from 0.04 to 9.5% of gross energy (energy%) during the growth period from 15 to 100 kg live weight.

Nitrogen metabolism was measured in balance trials carried out during the growth period as described in details in Chapter III. The nitrogen retention (RN) is the difference between nitrogen intake (IN) and nitrogen excreted in faeces (FN) and urine (UN).

In Chapter V it was found that the various linoleate levels ranging from 0.04 to 9.5 energy% did not affect the digestibility of nitrogen (DN). However, the digestibility of nitrogen varied between the series due to different composition of the basal rations. Consequently, the efficiency of nitrogen utilization is in the following expressed as a percentage of digested nitrogen instead of ingested nitrogen, i.e. RN/DN × 100 (RN/DN, % or RN/DN), thus allowing comparisons of the utilizability of the apparently absorbed amounts of nitrogen between the individual series. The mean values of nitrogen intake, digested nitrogen, retained nitrogen and the efficiency of utilization of nitrogen for the different series in question are discussed in Section 6.1 and the results are compiled in Tables 6.1–6.6 for the different balance periods. The nitrogen retention is expressed in relation to metabolic live weight in Section 6.2.

It is a well known fact that the intake of nitrogen and energy at a certain live weight highly affects the utilization of nitrogen. For that reason all the pigs received similar daily amounts of gross energy and crude protein during the growth period as shown in Chapter III. Until a live weight of 60 kg they received 551 kJ GE/g N (range 524–592) except Group 2 in Series B, which received 11% more GE than Group 1 (cf. Table 3.5). From about 60 kg live weight the concentration of the dietary nitrogen was reduced and thereby the ratio GE/g N increased to an average of 666 kJ/g N (range 605–727) as shown in Table 3.6. Also in this case Group 2 in Series B received 11% more gross energy than Group 1. As shown in Chapter IV (Figure 4.2) the pigs also received very similar daily amounts of metabolizable energy (ME) constituting an average of 90% of GE.

Thus the pigs received an average of 496 kJ ME/g N until a live weight of 60 kg and 599 kJ ME/g N from 60 kg live weight until slaughter. The mean daily intakes of crude protein in different live weight classes are compared in Table 6.7 with the daily allowances recommended to Danish pigs at the time where the present experiments were carried out.

Details about the sampling technique and analytical procedures in the balance trials are given in Chapter III.

6.1 Utilization of nitrogen during the growth period

The efficiency of the utilization of nitrogen (RN/DN) was evaluated within each series either statistically or by eye. It was obvious that the difference in RN/DN at the beginning and the end of the growth period was too big to allow the results from the different balance periods to be pooled. Where appropriate, an analysis of variance was employed to test the effect of period, linoleate level, and »sex« on RN/DN.

The mean values of the amounts of ingested, digested, and retained nitrogen, the mean values of RN/DN and their standard errors (SEM) together with the mean live weights in the different balance periods are presented in Tables 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6 for Series B, C, D, E, G and H, respectively. The results and the statistical evaluation of the results are described for each series in the following.

Series B comprised only barrows receiving either 0.4 (Group 1) or 9.5 (Group 2) energy% linoleate. The daily intake of crude protein was identical for the two groups, but Group 2 received 11% more GE and 7% more ME daily throughout the growth period. This difference in energy intake did not affect the digestibility of nitrogen, energy or other nutrients as already discussed in Chapter V. However, it reduced the nitrogen retention and the efficiency of nitrogen utilization as shown in Table 6.1.

RN evaluated as a quadratic function of metabolic live weight showed a significant ($F=7.40^{**}$) difference between groups.

Series C. As shown in Table 3.8 the daily intake of crude protein was similar for the two groups receiving either 0.04 (Group 1) or 0.2 (Group 2) energy% linoleate, whereas the energy intake was 0.2–0.3 MJ greater for Group 2 than for Group 1, caused by the inclusion of beef tallow. It was shown in Table 5.2 that the inclusion of beef tallow in the diet of Group 2 did not affect the digestibility of crude protein, but lowered the digestibility of GE with 2.4 units. So, the daily amounts of digestible crude protein and digestible energy was almost identical for the two groups. The mean values of nitrogen intake and digested nitrogen are shown in Table 6.2.

Table 6.1 Mean values of intake of nitrogen (IN), digested nitrogen (DN) and retained nitrogen (RN) in barrows fed 0.4 (Group 1) or 9.5 (Group 2) energy% linoleate during the growth period. Group 2 received 11% more GE than Group 1

Tabel 6.1 Middelværdier for kvælstofindtag (IN), fordøjet kvælstof (DN) og aflejret kvælstof (RN) hos galte fodret med 0,4 (Hold 1) eller 9,5 (Hold 2) energi% linoleat gennem vækstperioden. Hold 2 fik 11% mere bruttoenergi (GE) end Hold 1

	Live weight, kg				Group 1+2		RN, g		RN/DN, %			
Per.	Group		Group		IN	DN	Group	Group	Group 1		Group 2	
No.	1	n	2	n	g	g	1	2	Mean	SEM	Mean	SEM
II	28	4	29	3	31.9	29.3	21.0	20.3	71.7	0.86	70.1	1.36
III	37	4	40	4	40.6	37.9	26.4	24.8	69.7	1.19	65.6	1.64
IV	48	4	52	4	49.3	45.7	27.1	24.3	58.9	1.36	53.7	1.08
V	57	4	65	3	58.0	53.7	29.5	26.0	54.7	1.21	48.7	1.22
VI	69	4	77	3	51.4	46.6	26.1	22.9	56.4	1.87	48.7	3.13
VII	81	4	90	3	58.1	52.7	25.5	24.4	48.8	2.92	45.9	1.66
VIII	91	4	100	2	62.6	56.7	25.7	21.8	45.6	2.32	35.3	2.30

Retained nitrogen was in all cases greater for females than for castrated males. RN evaluated as a quadratic function of metabolic live weight showed no significant difference between the two groups (F = 0.74). The pooled mean values of RN and RN/DN of the two groups for barrows and sows, respectively, are shown in Table 6.2. It is apparent that the retained amounts of nitrogen reached a plateau already at 39 kg live weight both for barrows and sows. In all the other series nitrogen retention steadily increased beyond this live weight. As already discussed (Section 3.2.2) digestive disturbances occurred in this series because of the high digestibility of the diets, and the experiments were stopped. So, whether this trend was a result of the low linoleate levels or of the composition of the diet cannot be decided.

Series D. The daily intake of crude protein varied a little between the four groups receiving 0.3, 1.0, 2.0 and 2.7 energy% linoleate, respectively, but there was no systematic differences in the daily intakes as evidenced in Table 3.9. The daily intake of gross energy was similar for all groups, which is also apparent from Table 3.9. In Chapter V it was shown that the various linoleate levels did not affect the digestibility of crude protein and gross energy. Therefore, the pooled mean values of nitrogen intake and retained nitrogen are shown for each balance period in Table 6.3.

The values for RN and RN/DN were in all periods greater for sows than for barrows. The regression analysis of RN as a quadratic function of metabolic live weight showed that the differences between groups were statistically significant (F = 4.52**). On examination of the data, however, it was evident that there

Table 6.2 Series C. Mean values of intake of nitrogen (IN), digested nitrogen (DN) and retained nitrogen (RN) in barrows (b) and sows (s) fed 0.04 or 0.2 energy% linoleate during the growth period

Tabel 6.2 Serie C. Middelværdier for kvælstofindtag (IN), fordøjet kvælstof (DN) og afleret kvælstof (RN) hos galte (b) og sogrise (s) fodret med 0,04 eller 0,2 energi% linoleat gennem vækstperioden

Per.	LW	IN	DN	RN, g		RN/DN, %			
No.	kg	g	g	b	s	b	SEM	s	SEM
II	31[1)]	30.1	29.0	15.9	17.5	54.8	0.90	60.2	2.85
III	39[1)]	38.3	37.1	18.7	20.5	50.4	1.63	55.5	2.60
IV	48[2)]	46.5	45.2	18.7	20.6	41.8	0.15	45.4	4.31

[1)] 8 pigs per period (4 b and 4 s), [2)] 6 pigs (3 b and 3s)

was no systematic effect of the dietary linoleate levels on nitrogen retention. Therefore, these differences may be attributed to other factors due to the small number of animals. Obviously, the linoleate levels ranging between 0.3 and 2.7 energy% had no clear effect on nitrogen retention and efficiency of nitrogen utilization, and consequently the results were pooled within »sex« and period. The pooled values are shown in Table 6.3.

Series E. As in Series D this series comprised only one barrow and one sow per group, but the balance trials continued until 87 kg live weight. The four groups receiving 0.1, 0.8, 1.5 and 2.2 energy% linoleate, respectively, received similar daily amounts of crude protein and gross energy as shown in Table 3.10. The various linoleate levels did not affect the digestibility of crude protein and

Table 6.3 Series D. Mean values of intake of nitrogen (IN), digested nitrogen (DN) and retained nitrogen (RN) in barrows (b) and sows (s) fed 0.3, 1.0, 2.0 or 2.7 energy% linoleate during the growth period

Tabel 6.3 Serie D. Middelværdier for kvælstofindtag (IN), fordøjet kvælstof (DN) og afleret kvælstof (RN) hos galte (b) og sogrise (s) fodret med 0,3, 1,0, 2,0 eller 2,7 energi% linoleat gennem vækstperioden

Per.	LW	IN	DN	RN, g		RN/DN, %			
No.	kg	g	g	b	s	b	SEM	s	SEM
I	16	16.1	15.3	9.9	11.3	65.0	3.47	73.4	2.11
II	21	21.6	20.6	12.9	13.6	62.5	1.76	65.6	4.95
III	28	33.5	31.9	18.2	20.6	57.6	0.72	64.2	1.54
IV	37	42.1	39.7	21.3	24.9	53.9	4.56	62.4	2.45

8 pigs per period (4 b and 4 s)

Table 6.4 Series E. Mean values of intake of nitrogen (IN), digested nitrogen (DN) and retained nitrogen (RN) in barrows (b) and sows (s) fed 0.1, 0,8, 1.5 or 2.2 energy% linoleate during the growth period

Tabel 6.4 Serie E. Middelværdier for kvælstofindtag (IN), fordøjet kvælstof (DN) og aflejret kvælstof (RN) hos galte (b) og sogrise (s) fodret med 0,1, 0,8 1,5 eller 2,2 energi% linoleat gennem vækstperioden

Per.	LW	IN	DN	RN, g		RN/DN, %			
No.	kg	g	g	b	s	b	SEM	s	SEM
I	20[1)]	21.8	19.6	13.7	13.4	71.1	3.05	69.2	1.40
II	26[1)]	30.0	27.2	18.1	17.9	72.4	0.32	66.1	2.13
III	36[1)]	38.3	35.1	20.0	21.9	57.0	2.41	62.5	1.85
IV	45[2)]	46.6	42.8	22.8	25.4	52.8	2.65	60.2	0.38
V	56[2)]	54.9	50.6	23.4	26.0	46.0	1.56	51.9	1.97
VI	66[2)]	50.8	46.2	19.8	26.7	42.6	6.23	57.5	1.72
VII	77[3)]	55.2	49.9	22.8	26.5	45.6	3.78	52.8	–
VIII	87[4)]	59.6	52.8	16.5	29.9	31.8	2.85	54.7	–

[1)] 4 b and 4 s, [2)] 4 b and 3 s, [3)] 3 b and 1 s, [4)] 2 b and 1 s

gross energy as discussed in Chapter V. So, the pooled values of nitrogen intake and digested nitrogen in the individual periods are shown in Table 6.4.

From period III the sows retained more nitrogen and had a higher efficiency of utilization of nitrogen than the barrows. This material was not treated statistically, because two sows died and some accidents occurred as described in section 3.2.4. When drawing the nitrogen retention or RN/DN in relation to live weight, no systematic effect of the various linoleate levels was apparent. Therefore, the data were pooled within »sex« and period, and they are shown in Table 6.4.

Series G. The daily intakes of crude protein and gross energy varied a little between groups as shown in Table 3.11, but these differences were not supposed to affect nitrogen and energy metabolism to any appreciable extent. The three linoleate levels used in this series (0.2, 1.1 and 2.1 energy%) did not affect the digestibility of crude protein and gross energy as discussed in Chapter V. So, the pooled values of IN and DN have been shown in Table 6.5.

This material (n = 56) was subjected to a two way unbalanced analysis of variance with groups, »sex« (including litter) and interaction between groups and »sex« as independent variables, and RN/DN as the dependent variable. This analysis showed that there was no significant effect ($P>0.05$) of linoleate levels ($F = 2.32$) or »sex« ($F = 0.007$), and no interaction ($F = 0.058$) between linoleate level and »sex« on the efficiency of utilization of nitrogen. The mean values of RN and RN/DN are shown for barrows and sows in Table 6.5.

Table 6.5 Series G. Mean values of intake of nitrogen (IN), digested nitrogen (DN) and retained nitrogen (RN) in barrows (b) and sows (s) fed 0.2, 1.1 or 2.1 energy% linoleate during the growth period

Tabel 6.5 Serie G. Middelværdier for kvælstofindtag (IN), fordøjet kvælstof (DN) og aflejret kvælstof (RN) hos galte (b) og sogrise (s) fodret med 0,2, 1,1 eller 2,1 energi% linoleat gennem vækstperioden

Per.	LW	IN	DN	RN, g		RN/DN, %			
No.	kg	g	g	b	s	b	SEM	s	SEM
I	20[1)]	23.7	20.8	13.5	12.4	64.9	1.25	59.4	3.70
II	32[1)]	38.6	34.4	19.5	20.2	56.8	0.86	58.9	3.03
III	49[2)]	53.2	47.6	21.9	24.2	46.2	1.12	50.7	1.03
IV	67[2)]	53.7	47.5	19.4	21.8	40.9	2.19	46.0	2.26
V	83[3)]	63.6	55.8	20.3	24.6	36.5	2.69	43.9	4.93

[1)] 6 b and 6 s, [2)] 5 b and 6 s, [3)] 4 b and 6 s

Analysis of variance of RN/DN on linoleate levels and »sex«:
Interaction: F = 0.058 ns
Linoleate level: F = 2.32 ns
»Sex«: F = 0.007 ns

Series H. The daily intake of crude protein and gross energy for the three groups of Series H receiving 0.7, 1.6 and 2.3 energy% linoleate, respectively, are shown in Table 3.12. The intakes of crude protein were similar for all groups, whereas the intakes of energy were a little greater for Group 3. The digestibility of nitrogen and energy was not affected by the various linoleate levels employed as shown in Chapter V. The pooled values for nitrogen ingested and digested in the individual periods are shown in Table 6.6.

Table 6.6 Series H. Mean values of intake of nitrogen (IN), digested nitrogen (DN) and retained nitrogen (RN) in barrows (b) and sows (s) fed 0.7, 1.6 or 2.3 energy% linoleate during the growth period

Tabel 6.6 Serie H. Middelværdier for kvælstofindtag (IN), fordøjet kvælstof (DN) og aflejret kvælstof (RN) hos galte (b) og sogrise (s) fodret med 0,7, 1,6 eller 2,3 energi% linoleat gennem vækstperioden

Per.	LW	IN	DN	RN, g		RN/DN, %			
No.	kg	g	g	b	s	b	SEM	s	SEM
I	17	17.5	15.1	8.0	10.2	54.0	3.42	65.8	2.32
II	27	32.4	28.5	18.7	19.8	66.0	2.31	68.0	2.22
III	41	44.3	39.3	21.9	23.8	55.5	1.55	60.9	1.27
IV	57	56.1	50.5	23.7	25.3	47.2	1.59	49.7	2.08
V	73	58.7	51.7	24.6	27.6	48.6	2.07	52.2	0.74

12 pigs per period (6 b and 6 s)
Analysis of variance of RN/DN on linoleate levels and »sex«:
Interaction: F = 1.02 ns
Linoleate level: F = 0.46 ns
»Sex«: F = 6.02 *

The values of RN/DN (n = 60) were subjected to a two way balanced analysis of variance with groups, »sex« (including litter) and interaction between groups and »sex« as independent variables. This analysis showed that there was no significant effect (P>0.05) of the various dietary linoleate levels (F = 0.46) on the efficiency of the utilization of nitrogen, but the effect of »sex« was statistically significant (F = 6.02*). There was no statistically significant interaction between linoleate levels and »sex« (F = 1.02).

From Table 6.6 it is evident that the nitrogen retention was lower in period I than in period II. This may be due to a reduced feed intake at the beginning in order to prevent diarrhoea. On the other hand, the nitrogen retention still increased until the end of the balance trial, whereas it reached a plateau or decreased in all the other series.

Series G + H. In Series G and H the same feed composition was used, and the pigs were treated as similar as possible. Each group comprised two sows and two barrows, and the linoleate levels were intermittent. In order to get as much information from the material as possible, the effect of the different linoleate levels in question (0.2–0.7–1.1–1.6–2.1–2.3 energy%) on RN/DN was estimated in an analysis of covariance (Freund and Littell, 1981), which adjusted for the influence of live weight (period) and replications, where replications included both litter and »sex«. The results (n = 116) showed that there was no significant (P>0.05) effect of the dietary linoleate levels on RN/DN (F = 3.34), but a significant effect of live weight (F = 40.9***) and »sex« (litter) (F = 6.82***). However, the effect of linoleate levels was close to reach the 5% significance level, P being 0.07. The model only described 68% of the variation ($R^2 = 0.68$), and the variability was relatively high, the CV% being 11.1.

6.2 Nitrogen retention in relation to metabolic live weight

As a standard procedure at the Department of Animal Physiology, nitrogen retention is treated statistically by means of regression analyses as described by *Henckel (1973)*. In this procedure RN is treated as a quadratic function of metabolic live weight, i.e. RN in relation to $LW^{0.75}$ and $LW^{1.50}$ *(Thorbek, 1975)*.

By using the individual measurements of nitrogen retention and live weight for barrows (n = 112) and sows (n = 110) from Series C, D, E, G and H, it was shown that »sex« differences were highly significant (F = 15.7***). Then the total material also comprising Series B, which included only barrows, was analysed again for each »sex« within linoleate levels. The results showed that there was a significant effect of treatments (linoleate levels) on nitrogen retention both for barrows (F = 6.30***) and sows (F = 2.04**). However, when examining which groups contributed significantly to the overall effect, it was found that there was no systematic effect on nitrogen retention of adding linoleate to the diets. Obviously, other factors contributed more to the overall effect on nit-

rogen metabolism. In this respect it should be emphasized that the effect of the groups also included the effect of genotype and variation between genotypes together with other factors caused by the fact that all the experiments could not be carried out at the same time.

In order to be able to compare the results from the present studies with results presented in the literature, the material was pooled within »sex«. For barrows the results with (n = 162) and without (n = 112) Series B are presented, as Series B only comprised barrows. The following functions and the precision of the determination together with the calculated maximum retention of nitrogen are shown in the following (RSD = standard deviation of residuals):

For barrows (n = 162): $RN,g = 1.982\,kg^{0.75} - 0.0409\,kg^{1.50}$
(including Series B) $SD = 0.055 \quad 0.0024$
$RSD = 3.41\,g, CV\% = 16.6$
$RN_{max}, g = 24.0$ at 24.2 $kg^{0.75}$~70.1 kg LW

For barrows (n = 112): $RN,g = 1.904\,kg^{0.75} - 0.0409\,kg^{1.50}$
(excluding Series B) $SD = 0.062 \quad 0.0029$
$RSD = 2.98\,g, CV\% = 16.0$
$RN_{max}, g = 22.6$ at 23.5 $kg^{0.75}$~66.5 kg LW

For sows (n = 110): $RN,g = 1.916\,kg^{0.75} - 0.0351\,kg^{1.50}$
$SD = 0.065 \quad 0.0030$
$RSD = 3.16\,g, CV\% = 15.4$
$RN_{max}, g = 26.1$ at 27.4 $kg^{0.75}$~82.2 kg LW

With the relatively big variation in the material, the maximum nitrogen retention obtained with (N = 162) or without (n = 112) the pigs of Series B is probably not significant. The maximum nitrogen retention was found to be 2.1–3.5 g greater for sows than for barrows, but it is more striking that the sows reach maximum later in the growth period than the barrows, i.e. at 82 kg live weight versus 66–70 kg live weight.

The nitrogen retention in relation to metabolic live weight for the present investigations including the whole material is presented graphically in Figure 6.1.

6.3 Discussion

Nitrogen metabolism is known to be influenced by many endogenous and exogenous factors such as genetic background, sex, body weight, age and intake of nitrogen, energy and essential nutrients. EFAs may be expected to play a direct role in nitrogen metabolism through their functions on enzymes and/or an indirect role through the provision of energy from mitochondrial oxidative

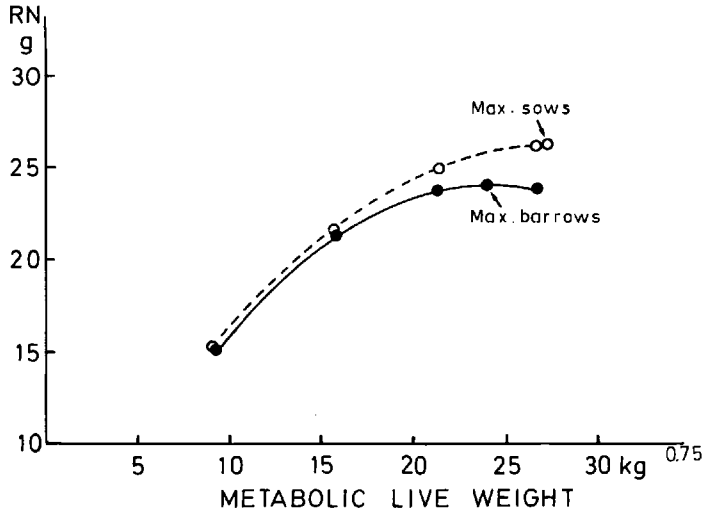

Figure 6.1. Nitrogen retention in relation to metabolic live weight for barrows (n = 162) and sows (n = 110)
Kvælstof retention i relation til metabolisk legemsvægt hos galte (n = 162) og sogrise (n = 110)

phosphorylation, but actually only few studies have been concerned with the possible role of EFAs in nitrogen metabolism. *Jakobsen (1972)* reported that EFA deficient rats fed 0.51 energy% linoleate excreted more nitrogen in faeces and urine, and had greater concentrations of urea in the liver mitochondria than rats fed 7.92 energy% linoleate. This effect was attributed to a reduced ATP supply due to an impairment of the oxidative phosphorylation in the liver mitochondria of the EFA deficient rats *(Jakobsen, 1972; Setia and Jakobsen, 1975)*. Although *Christensen (1974a)* observed a depressed ATP synthesis in the mitochondria of liver, heart and skeletal muscle from EFA deficient pigs, the proportions of meat, fat and bone in the carcass were not affected *(Christensen, 1974b)*. Carcass composition was also not affected by EFA deficiency in the studies of *Witz and Beeson (1951), Leat (1962), Leat et al. (1964) and Babatunde (1967). Ehrensvärd et al. (1976)* seemed to find a stimulating effect of linoleic acid on protein synthesis in pigs. They compared a diet high in linoleic acid with an iso-energetic and iso-nitrogenous diet containing a high proportion of medium chain saturated fatty acids and found significant improvements in daily gain, feed conversion ratio and nitrogen retention and a reduction in the fat lean ratio in the carcass gain with the diet high in linoleic acid. Similarly, *Petersen et al. (1970)* found that cocks receiving 12% soya bean oil in their diet produced more meat than their control animals. However, *Boyd and*

McCracken (1980) failed to show an increase in lean meat production in pigs fed high linoleate levels from 13 to 40 kg live weight.

Staun et al. (1970) and *Staun and Bruhn (1971)* added 25 g soya bean oil daily to a conventional pig ration supplied either restrictedly or *ad libitum* from 20 to 60 kg live weight. The authors found no significant effects on the proportions of meat and fat in the carcasses, when the pigs were slaughtered at 90 kg live weight. A rough estimate of the linoleate concentrations shows that the diets may have contained about 5.3 energy% linoleate at 20 kg live weight decreasing to 3.8 energy% linoleate at 60 kg live weight, the basal ration containing about 2.1 energy% linoleate. In the present studies lonoleate levels ranging from 0.04 to 9.5 energy% did not affect the apparent digestibility of nitrogen. The nitrogen retention and the efficiency of nitrogen utilization were found to be depressed in the case of the highest linoleate level employed, possibly because the soya bean oil was added without substitution of an iso-energetic amount of the basal ration. Thereby, the pigs of this group (Group 2 in Series B) received relatively more gross energy and relatively less protein than the pigs of Group 1. A daily intake of 9.5 energy% linoleate during the growth period from 20 to 90 kg would correspond to a daily supply of 90 g soya bean oil per kg diet. This amount can be expected to depress the nitrogen retention as evidenced in the present studies.

Jordan and Weatherup (1976) found that fat levels above 18.3% by weight had a depressing effect on the amount of energy deposited as protein, whereas lower fat levels (9.8 and 1.6%) had no significant effects. These diets were fed from 8 days until approximately 3 weeks of age. Recent investigations suggest that the two prostaglandins, $PGF_{2\alpha}$ and PGE_2, play an important role in the control of protein balance in skeletal muscle, $PGF_{2\alpha}$ in stimulating protein synthesis *(Rodemann and Goldberg, 1982; Reeds and Palmer, 1983; Smith et al., 1983)*, and PGE_2 in stimulating protein degradation *(Rodemann and Goldberg, 1982; Rodemann et al., 1982)*. As both $PGF_{2\alpha}$ and PGE_2 are produced from arachidonic acid, it appears that the dietary levels of linoleic acid and thereby the intracellular levels of arachidonic acid may play a role in controlling the proportions of $PGF_{2\alpha}$ and PGE_2 and thereby protein balance. Further investigations are needed to establish a quantitative relationship. In the present studies, therefore, the lower RN observed in the pigs receiving 90 g soya bean oil as an extra supply to the diet may be due partly to a lower protein/energy ratio and partly to the relatively high intake of linoleic acid.

The lowest level of 0.04 energy% linoleate was obtained in Group 1 of Series C as the natural amount present in the basal diet. This level is apparently the lowest level one can obtain unless the casein is extracted with an organic solvent. In this case it was observed that the nitrogen retention reached a plateau already at 39 kg live weight both in females and castrated males. The pigs of

Group 2 receiving 0.2 energy% linoleate by the inclusion of beef tallow showed the same trend. It is believed that this reduction in nitrogen retention in these two groups in Series C was a consequence of digestive disturbances due to the high digestibility of the diets (cf. Table 5.2). As evidenced in Figure 3.3 the 20:3, n-9/ 20:4,n-6 ratio of the plasma lipids was greater in Group 1 than in Group 2, and both levels suggest an EFA deficiency according to *Holman (1960)*. However, in Series E and G the pigs receiving 0.1–0.2 energy% linoleate retained similar amounts of nitrogen as their littermates receiving greater dietary linoleate levels. As the pigs fed 0.04 energy% linoleate were only brought up to about 50 kg live weight, it cannot be decided whether such low dietary linoleate concentrations may or may not affect nitrogen retention and consequently meat production in pigs raised to a normal slaughter weight of 90 to 100 kg. It seems, however, justified to conclude, that if such low linoleate levels should have depressed nitrogen retention in the present studies, then it must have been a direct effect on protein synthesis, since there was no effect on energy metabolism as shown in Chapter VII.

Dietary linoleate concentrations between 0.2 and 2.3 energy% did not have a significant effect on the nitrogen retention and the efficiency of the utilization of nitrogen. However, a positive effect of increasing the dietary linoleate concentration to 2.3 energy% was noticed, which just failed to reach the 5% significant level ($P = 0.07$). The variability in the material was greater than wanted, partly because some pigs had to be substituted with other pigs from another litter, partly because the various linoleate levels were not tested at the same time. The precision (CV%) of the determination of the efficiency of the utilization of nitrogen varied in Series G and H between 3.5 and 27.5% for females and 3.7 and 15.5% for castrated males. The average CV% for the determination of nitrogen retention in relation to metabolic live weight was 16.6% for barrows and 15.4% for sows, which is greater than the CV% (11%) found by *Thorbek (1976)* for barrows ($n = 381$), but a little lower than that (18.5%) found by *Thorbek et al. (1984)* for barrows ($n = 59$).

Generally, the sows deposited 1–3 g more nitrogen than the barrows, which is in accordance with the findings of *Just (1970), Ludvigsen (1980)* and *Fuller et al. (1980)*. However, it is apparent from Table 6.8 and Figure 6.1 that the nitrogen retention was almost similar in sows and barrows until 40 kg live weight (15.9 $kg^{0.75}$). A reason for this may be that the intake of digestible crude protein was slightly lower than the levels recommended by *Andersen and Just (1975; 1979)* until about 32 kg live weight as shown in Table 6.7. This was caused by a reduced feed intake in the first balance periods partly in order to avoid diarrhoea, partly to avoid feed residuals. If this had been taken into consideration, the protein concentration of the ration should have been 20% crude protein per kg feed instead of 18% from about 15 to 30 kg live weight. Probably, this lower

intake of digestible crude protein met the requirement for utilizable protein in the castrated males, but not in the females. It may also have influenced the pattern of the nitrogen retention curve, which otherwise might have been steeper until 30 kg live weight. It cannot be excluded that some compensatory nitrogen retention occurred in the following live weight range, where the intakes of digestible nitrogen were above the recommended allowances as shown in Table 6.7.

Despite the lower nitrogen intake according to the recommended allowances until about 30 kg live weight, it is evident from Table 6.8 that the daily nitrogen retention both in females and castrated males was greater than found in previous studies with Danish Landrace pigs. In all investigations cited in Table 6.8 maximum nitrogen retention was reached within the live weight range of 20 to 100 kg. *Böhme et al. (1976)* report nitrogen retentions of 14.0 and 16.9 g in male piglets of the German Landrace measured at 13 and 17 kg live weight, respectively, corresponding to an efficiency of utilization of digestible nitrogen of 73 and 70%, respectively. These values are greater than observed in the present studies. In 25 kg Large White gilts *Edmunds et al. (1980)* measured a nitrogen retention of 16.0±0.44 g daily, which is comparable to the findings in the present studies. In Pietrain and Large White × Landrace female pigs measured at 30 and 60 kg live weight, nitrogen retention was not significantly affected by breed, but highly significantly affected by the energy intake *(Fuller et al., 1976)*. The greatest nitrogen retention in the latter studies was 17.1 g at 30 kg live weight and 20.9 g at 60 kg live weight, which is about the same value obtained in the present studies at 30 kg live weight, but lower than that obtained at 60 kg live weight.

As shown in Figure 6.1 nitrogen retention is not a linear function of metabolic live weight in the live weight range of 20 to 90 kg. The curves indicate a quadratic function as found by *Thorbek (1975)*. By using all the individual measurements the present data showed a maximum N retention of 24.0±3.41 g at 70.1 kg live weight (24.2 $kg^{0.75}$) for barrows (n = 162) and 26.1±3.16 g at 82.2 kg live weight (27.4 $kg^{0.75}$) for sows (n = 110). Thus, the most marked difference in the nitrogen retention pattern during the growth period between sows and barrows

Table 6.7 Mean values of daily intake (g) of digestible crude protein during the growth period

Tabel 6.7 Gennemsnitligt dagligt indtag (g) af fordøjeligt råprotein gennem vækstperioden

Live weight, kg	20	30	40	60	80
Andersen and Just (1975)	140	185	225	255	265
Andersen and Just (1979)	150–170	200–220	230–250	250–270	270–290
Present investigations	120–130	180–210	290–320	250–290	320–340

Table 6.8 Nitrogen retention (g) in relation to live weight in the present and earlier balance experiments with Danish Landrace pigs

Tabel 6.8 Kvælstofretention (g) i relation til levendevægt i nærværende og tidligere balanceforsøg med grise af Dansk Landrace

LW kg	Lund (1935) s	Thorbek (1975)[1] b	Just (1970) s	Just (1970) b	Thorbek et al. (1984)[2] b	Present (1985) s	Present (1985) b
20	14.4	11.6	12.6	12.2	12.0	15.0	15.1
40	20.8	16.8	19.5	18.3	19.0	21.6	21.2
60	22.6	19.5	21.6	19.0	25.1	25.0	23.7
80	21.2	20.5	22.8	20.1	28.2	26.1	23.8

[1] carried out 1964–66. [2] carried out 1975–76 s = sows, b = barrows.

is a greater capacity for nitrogen retention over a longer period in sows than in barrows. Compared to the nitrogen retention curve obtained with barrows (n = 381) in 1964–66 by *Thorbek (1975),* the barrows in the present investigations deposited about 2.5 g more nitrogen daily during the whole growth period, but reached their maximum nitrogen retention at 70 kg live weight, whereas the barrows in Thorbek's experiments did not reach their maximum N retention until 84 kg live weight. In later studies with barrows (n = 59) fed a high energy level almost corresponding to the level used in the present studies, *Thorbek et al. (1984)* found a maximum N retention of 28.9 g at 97 kg live weight. As shown in Table 6.8, the RN was lower at 20 kg live weight compared to the present studies. The greater RN at heavier live weight may, therefore, be due to compensatory growth.

The generally greater nitrogen retention found in the present studies may be due to an improvement in the genetic material caused by intensive selection of Danish Landrace pigs for meat production. This would seem a reasonable explanation when the results are compared with those obtained by *Thorbek (1975)* in 1964–66, those by Just (1970) in 1966–69, and those by *Thorbek et al. (1984)* in 1975–76, but not when the results are compared with those by *Lund (1935)* in 1932–34. The protein norm used by *Lund* in 1932–34 was almost identical to the one used to-day.

Differences in nitrogen retention may occur as a consequence of nitrogen and energy intake, and both factors vary in the abovementioned studies. Another factor influencing the level of nitrogen retention is the size of N losses in faeces and urine. These may have been greater in the early studies on nitrogen retention, but the technique in the balance studies is similar in the present investigations as in the investigations by *Just (1970), Thorbek (1975)* and *Thorbek et al. (1984).* The smallest N losses from urine are obtained when catheters are placed in the urinary bladder as discussed recently by *Just et al. (1982),* and consequently lower nitrogen retentions will be found in such studies compared to the conventional sampling method.

Another factor may have contributed to the greater N retention obtained in the present studies, namely the composition of the diet. The feed components were highly digestible with readily available nutrients and energy. In the above-mentioned studies grains were used combined with a protein mixture.

Lund (1935) showed that a low protein intake would result in a lower nitrogen retention, but in a maximum efficiency of utilization of nitrogen being rather constant at about 65% during the growth period from 20 to 100 kg live weight compared to a high protein intake, which would result in a maximum nitrogen retention but decreasing efficiency of N utilization from 59 to 39% during the growth period. Recently, these findings have been confirmed by *Jentsch and Hoffmann (1977)* in the live weight range of 30 to 125 kg. In young pigs measured during the growth period from 8 to 45 kg, *Hoffmann et al. (1977)* found a constant utilization of digestible nitrogen of 75% at a low nitrogen intake and a decreasing utilization of digestible nitrogen from 70 to 53% at a high nitrogen intake. In the present studies RN/DN ranged from 55 to 71% in barrows and 58 to 69% in sows at 20–30 kg live weight and from 36 to 48% in barrows and 43–52% in sows at 80 kg live weight. These values are comparable to those obtained by *Hoffmann et al. (1977)* and *Jentsch and Hoffmann (1977)* at the high N intakes, where casein provided the protein. However, on an average they are greater than the values obtained with grains and protein mixtures by *Thorbek (1975),* who found a maximum efficiency of N utilization of 61% at 24 kg and 46% at 80 kg live weight or by *Just (1970),* who found that the sows deposited about 62 and 39% of the digested nitrogen at 24 and 82 kg live weight, respectively, and the barrows 59 and 35%, respectively. In later studies *Thorbek et al. (1984)* obtained a mean nitrogen utilization of 60% in barrows fed commercial feed mixtures.

So, it occurs that in the present studies both a high nitrogen retention and a high efficiency of nitrogen utilization were obtained, probably caused by the high digestibility and high availability of nutrients and energy combined with a relatively low N intake until 30 kg live weight possibly resulting in compensatory nitrogen retention at the relatively high N intake in the rest of the live weight range in question. As already shown in Chapter IV the feed conversion efficiency was also found to be quite high on these experimental diets.

6.4 Conclusions

1. Nitrogen retention (RN) reached a plateau at 39 kg live weight both for barrows and sows in Series C receiving 0.04 or 0.2 energy % linoleate. These pigs received the highly purified diets based on glucose and casein. The experiments were stopped at about 50 kg live weight, because of digestive disturbances.
2. The different linoleate levels (0.2–0.7–1.1–1.6–2.1–2.3 energy %) fed iso-ni-

trogenously and iso-energetically from 15–80 kg live weight in Series G and H (n = 116) had no significant (P>0.05) effect on the utilization of digestible nitrogen (RN/DN).

3. In Series B, comprising barrows only, Group 2 (9.5 energy% linoleate) received 7% more GE than Group 1 (0.4 energy % linoleate), but the same daily digestible amounts of nitrogen as Group 1, due to an extra supply of 90 g soya bean oil per kg diet. Group 2 deposited 1–3 g less nitrogen daily during the growth period from 25 to 90 kg live weight than Group 1. This finding is attributed both to a higher energy/protein ratio of the diet of Group 2 and to the linoleic acid concentration of the diet, as the latter may control protein synthesis and proteolysis through the production of $PGF_{2\alpha}$ and PGE_2.
4. The sows deposited significantly (P<0.001) more nitrogen during the growth period than the barrows.
5. There was no statistically significant (P>0.05) interaction between periods (duration of linoleate feeding) and groups (linoleate levels) or between groups and »sex«.
6. The individual values for RN and the corresponding values for metabolic live weight were used in a quadratic function to describe the maximum nitrogen retention. For the barrows the calculations were performed with Series B (n = 162) or without Series B (n = 112). The calculations gave the following equations:

   For barrows (n = 162): RN, g/d = 1.982 LW, $kg^{0.75}$ – 0.0409 LW, $kg^{1.50}$ with a maximum of 24.0 g N at 70.1 kg LW.
   For barrows (n = 112): RN, g/d = 1.904 LW, $kg^{0.75}$ – 0.0409 LW, $kg^{1.50}$ with a maximum of 22.6 g N at 66.5 kg LW.
   For sows (n = 110): RN, g/d = 1.916 LW, $kg^{0.75}$ – 0.0351 LW, $kg^{1.50}$ with a maximum of 26.1 g N at 82.2 kg LW.

   The maximum nitrogen retention was 2.1–3.5 g greater for sows than for barrows, and the sows reached maximum later (at 82 kg LW) than the barrows (66–70 kg LW).
7. The efficiency of utilization of nitrogen (RN/DN) ranged from 55–71% in barrows and 58–69% in sows at 20–30 kg live weight decreasing to 36–48% in barrows and 43–52% in sows at 80 kg live weight.
   These values are slightly greater than obtained with conventional pigs of Danish Landrace fed conventional swine rations.
8. *In pigs of Danish Landrace weaned at 5 weeks of age the requirement for dietary linoleate to cover maximum nitrogen retention during the growth period from 15 to 90 kg live weight is 0.2 energy %.* Lower concentrations may depress nitrogen retention. The highest level of 9.5 energy% linoleate given

as an extra supply of 90 g soya bean oil per kg diet depressed nitrogen retention. Thus, there may be an optimum supply of linoleate with respect to nitrogen metabolism, which apparently lies between 0.2 and 9.5 energy %.

VII. Energy metabolism

The effect of the different dietary linoleate levels ranging from 0.04 to 9.5 energy% on energy metabolism was measured in balance and respiration trials during the growth period as described in Chapter III, and the requirement for linoleic acid is derived from these results.

The intake of gross energy (GE) and its digestibility (DE) was described in Chapter III and V, respectively. So, it remains to describe the metabolizability (ME/GE) and the utilization of metabolizable energy (ME) for total energy retention (RE), the proportions of energy retained in protein (RPE) and fat (RFE), and heat production (HE). Furthermore, the efficiency of utilization of ME for growth (ME) and the partial efficiencies of protein (k_p) and fat (k_f) retention were calculated.

Part of the results concerning energy metabolism in young pigs (15–50 kg live weight) was presented at the 8th Symposium on Energy Metabolism *(Christensen et al., 1980)*.

7.1 Principles of measurements, calculations and statistical evaluations

7.1.1 Measurements and calculations

The standard procedures employed at the Department of Animal Physiology were used both for the measurements and the calculations. The factors used for calculations of the energy balances from the carbon and nitrogen balances and the gas exchange measurements in the respiration chambers were those proposed by *Brouwer (1965)*. A detailed description of the calculations is given by *Thorbek (1975)* and *Thorbek et al. (1984)*. The following is a short summary of the measurements performed in the present studies.

Figure 7.1 summarizes the fate of the dietary energy (GE) in the organism. Metabolizable energy (ME) is the difference between GE and the loss of energy in faeces (FE), urine (UE) and methane (CH_4E), i.e.

$$ME = GE - (FE + UE + CH_4E) \quad (7a)$$

The metabolizability is expressed as ME in percent of GE (ME/GE,%).

The methane production was not measured in all pigs because of technical problems. However, as will be seen in the following, methane production was low in the growth period in question (15–100 kg live weight) and therefore may be totally neglected.

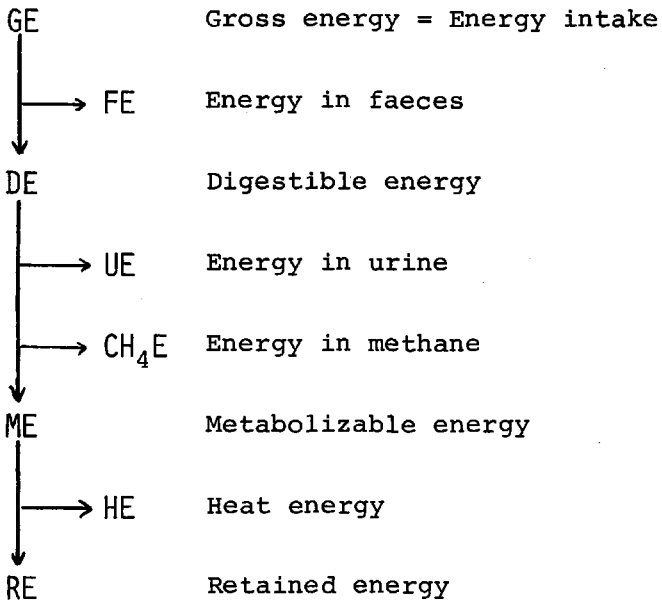

Figure 7.1. The individual components of an energy balance
(RE = GE – (FE + UE + CH_4E + HE)
De individuelle komponenter i en energibalance (RE = GE – (FE + UE + CH_4E + HE)

Part of ME is retained (RE) and part is dissipated as heat (HE), i.e.

(7b) $$ME = RE + HE$$

RE was calculated from the nitrogen and carbon balances, and so was the amount of energy retained in protein (RPE) and fat (RFE), anticipating that all retained carbon in N-free material was deposited as fat. Thus

(7c) RE,kJ = 149.1 × g deposited N + 51.9 × g deposited C in N-free material

(7d) $$RE = RPE + RFE$$

The total heat production or heat energy (HE) was then calculated as the difference between ME and RE called HE(CN), i.e.

(7e) $$HE(CN) = ME - RE$$

HE(CN) is shown in section 7.2 for the individual series of esperiments.

The total heat production (HE) was also calculated from the measurements of the gas exchange (volumes of oxygen consumption and carbon dioxide pro-

duction), the methane production and the nitrogen excretion in the urine (UN). The HE is termed HE(RQ), where RQ refers to the respiratory quotient (litres CO_2/litres 0_2), and according to *Brouwer (1965)* was calculated as follows:

(7f) $$HE(RQ),kJ = 16.18 \times \text{litres } 0_2 + 5.02 \times \text{litres } CO_2 - 2.17 \times \text{litres } CH_4 - 5.99 \times \text{g UN}$$

HE(RQ) is only shown for the total material (see section 7.3) in comparison with HE(CN) which was also calculated for the total material. In order to calculate the efficiency of utilization of metabolizable energy (RE/ME_g), ME which comprises metabolizable energy for maintenance (ME_m) and growth (ME_g), has to be split up into its components:

(7g) $$ME = ME_m + ME_g$$

This can only be done if ME_m is measured *per se* or knowledge about the value has been obtained in previous experiments. ME_m was not measured in the present experiments, but the value obtained in fasting experiments with pigs *(Thorbek and Henckel, 1976)* have been adopted. According to the latter authors $ME_m,kJ = 4060 + 210 \times LW,kg^{0.75}$. The efficiency of utilization of energy for growth was evaluated for the total material, and the results are presented in section 7.5. From the following equation:

(7h) $$ME_g = b_1 \times RPE + b_2 \times RFE$$

the partial efficiencies of protein and fat retention were calculated, k_p being $1/b_1$ and k_f $1/b_2$.

7.1.2 Statistical evaluation of results

The whole material was treated statistically by means of regression analyses *(Henckel, 1973)* at A/S Regnecentralen, Copenhagen. In some cases analyses of variance or covariance have been carried out at NEUCC, Lyngby, by means of ANOVA or GLM procedures as described by *Freund and Littell (1981)*.

Specific attention was paid to the heat production. A regression analysis of HE(RQ) in relation to metabolic live weight ($kg^{0.75}$) including the total material until 50 kg live weight (N = 179) within linoleate levels × »sex« showed that statistically significant differences existed between linoleate levels (F = 2.13**). Thus the total material could not be pooled. From this material it appeared that statistical significant differences in $HE(RQ)/LW^{0.75}$ might exist between barrows and sows. Therefore, regression analyses were performed using all the data from all the series (C-D-E-G-H) representing both barrows (N = 112) and sows (N = 110) to test the effect of »sex« on $RN/LW^{0.75}$–$LW^{1.50}$, $HE(RQ)/LW^{0.75}$ and $RE(CN)/ME_g$. These analyses showed that statistically significant effects of »sex« existed with respect to nitrogen retention (F = 15.7*) and heat

production (F = 5.16*), but not with respect to the efficiency of utilization of energy for growth. Then, the material was divided into barrows and sows and the effect of linoleate levels tested by means of regression analyses with respect to $CO_2/LW^{0.75}$, $0_2/LW^{0.75}$, $HE(RQ)/LW^{0.75}$, $HE(CN)/LW^{0.75}$, $RE(CN)/ME_g$ and $ME_g = b_1 \times RPE + b_2 \times RFE$.

Although statistically significant differences occurred between linoleate levels within »sex« a critical examination of the results did not show any systematical effects of the different linoleate levels except in Series B, where the two groups were not fed iso-energetically. So, for all other series, the results concerning energy metabolism and gas exchange from the different groups were pooled within »sex«, and mean values and their standard errors (SEM) were calculated for each series of experiments. These results are shown in Section 7.2 and 7.3.

In order to be able to compare the results obtained in the present experiments with previous experiments carried out at the department or described in the literature, the total material was pooled within »sex« and the above-mentioned criteria were calculated. The results from these calculations are described in Section 7.4 and 7.6.

7.2 Energy intake, energy loss and energy retention in the individual series of experiments

Series B comprised 4 barrows receiving 0.4 energy% linoleate (Group 1) and 4 barrows receiving 9.5 energy% linoleate (Group 2) from 25 to 100 kg live weight. However, the two groups were not fed iso-energetically. As shown in Table 7.2.1 Group 2 received on an average 11.4% more GE than Group 1 during the growth period. The loss of energy in faeces (FE), urine (UE) and methane (CH_4E) is shown in Table 7.2.2 both in absolute values and in percent of GE, and the results from the statistical evaluation are shown in Table 7.2.3.

As can be seen from these tables there was no statistical significant ($P>0.05$) difference between the two linoleate levels in loss of energy in faeces and urine. FE/GE was about 5% during the whole growth period, whereas UE/GE increased significantly ($P<0.001$) from 1.9% at 28 kg live weight to 3.0% at 100 kg live weight. The methane production was significantly ($P<0.001$) greater in Group 1 than in Group 2, the energy loss being 0.6 and 0.3% of GE, respectively, at 28 kg live weight icreasing to 1.1 and 0.9% of GE, respectively, at 90 kg live weight. This difference in methane production is shown graphically in Figure 7.2.

The total loss of energy in faeces, urine and methane for the growth period in question amounted to 9.1% of GE for Group 1 and 8.2% of GE for Group 2 and this difference was statistically significant ($P<0.05$). Thus, as an average for the whole growth period Group 2 received 7.3% more ME daily than Group

Table 7.2.1 Series B. Energy metabolism. Mean values of gross energy (GE), metabolizable energy (ME), heat energy (HE), retained energy (RE) and energy retained in protein (RPE) and fat (RFE) in barrows fed 0.4 (Group 1) or 9.5 (Group 2) energy% linoleate during 7 balance periods

Tabel 7.2.1 Serie B. Energiomsætning. Middelværdier for bruttoenergi (GE), omsættelig energi (ME), varmeenergi (HE), aflejret energi (RE) samt energi aflejret i protein (RPE) og fedt (RFE) hos galte fodret med 0,4 (Hold 1) eller 9,5 (Hold 2) energi% linoleat gennem 7 balanceperioder

Period	No.	II		III		IV		V		VI		VII		VIII	
Group	No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2
LW	kg	28	29	37	40	48	52	57	65	69	77	81	90	91	100
Pigs	n	4	3	4	4	4	4	4	3	4	3	4	3	4	2
GE	kJ	17333	19375	22060	24660	26787	29944	31514	35228	35512	39424	40144	44567	43232	47995
ME	kJ	15579	17817	20112	22785	24374	17433	28674	32253	32337	36194	36524	41132	39363	43697
SEM		94	103	65	28	98	93	33	140	57	282	230	368	100	473
ME/GE	%	89.9	92.0	91.2	92.4	91.0	91.6	91.0	91.6	91.1	91.9	91.0	92.3	91.1	91.1
HE	kJ	9216	10101	11282	11905	12734	13183	14036	15071	15407	16765	17226	17175	16943	20048
SEM		292	161	353	247	207	217	509	379	414	144	842	492	499	593
HE/ME	%	59.9	56.7	56.1	52.2	52.2	48.1	48.9	46.7	47.6	46.3	48.6	41.8	43.0	45.9
RE	kJ	6362	7716	8830	10880	11640	14249	14638	17181	16930	19429	18799	23956	22420	23649
SEM		224	61	361	235	253	223	539	425	445	358	995	859	521	121
CV	%	7.0	1.4	8.2	4.3	4.3	3.1	7.4	4.3	5.3	3.2	10.6	6.2	4.6	0.7
RE/ME	%	40.1	43.3	43.9	47.8	47.8	51.9	51.1	53.3	52.4	53.7	51.4	58.2	57.0	54.1
RPE	kJ	3135	3067	3941	3693	4044	3629	4391	3879	3896	3421	3801	3640	3830	2977
SEM		56	73	47	89	110	87	102	137	138	300	235	148	179	137
RPE/RE	%	49.3	39.7	44.6	33.9	34.7	25.5	30.0	22.6	23.0	17.6	20.2	15.2	17.1	12.6
RFE	kJ	3228	4649	4889	7186	7581	10621	10247	13302	13034	16008	14998	20316	18590	20672
SEM		257	117	344	212	262	242	583	330	436	93	901	887	559	17
RFE/RE	%	50.7	60.3	55.4	66.1	65.3	74.5	70.0	77.4	77.0	82.4	79.8	84.8	82.9	87.4

Table 7.2.3 Series B. Results of two way unbalanced analysis of variance on measurements of energy metabolism. F-values and mean square of error (MSE)

Tabel 7.2.3 Serie B. Resultater fra tosidet ubalanceret variansanalyse på målinger af energiomsætningen. F-værdier og residualmiddelkvadratsum (MSE)

Source of variation Degrees of freedom		Period 6	Group 1	Interaction 6	MSE 36
FE/GE	%	3.07 ns	1.91 ns	1.44 ns	0.50
UE/GE	%	36.5***	0.26 ns	0.62 ns	0.039
CH_4E/GE	%	16.0***	36.6***	0.69 ns	0.022
ME/GE	%	1.02 ns	4.26*	1.08 ns	0.65

1. In both cases the metabolizability (ME/GE) was quite high being 90.0% for Group 1 and 91.8% for Group 2.

Because of different live weights between the groups in the balance periods, analyses of covariance adjusting for live weight ($LW^{0.75}$) were performed to test ME, HE(CN), RE, RPE and RFE between the two groups. The results showed that statistically significant differences existed between groups with respect to the intake of ME (F = 67.5***), retained energy (F = 17.1***) and the amount of energy retained in protein (F = 7.77**) and fat (F = 29.3***), but not with respect to heat production (F = 0.87).

The mean values of retained energy (RE) determined on the basis of the nitrogen and carbon balances increased during the growth period from 6362 to 22420 kJ/day for Group 1 and from 7716 to 23649 kJ/day for Group 2. As shown in Table 7.2.1 RE/ME was 40.1 and 43.3% for Group 1 and 2, respectively, at 28–29 kg live weight increasing to 57.0 and 54.1%, respectively, at 91–100 kg live weight. Generally, more energy was retained in Group 2 than in Group 1, and conversely, generally more energy was lost as heat (HE) in Group 1 than in Group 2. The total loss of energy in faeces, urine, methane and heat amounted to an avaerage of 53.1% of GE for Group 1 and 51.4% of GE for Group 2.

The most marked difference between the two groups is found in the proportions of retained energy in protein (RPE/RE) and fat (RFE/RE) as evidenced in Table 7.2.1. During the whole growth period the pigs of Group 2 deposited about 8% units more of the retained energy in fat than did the pigs of Group 1. Figure 7.3 shows the difference in fat retention (g/day) between the two groups during the growth period in question.

Series C was carried out with two groups of pigs (two barrows and two sows per group) fed iso-energetically without (Group 1) or with (Group 2) 2% beef tallow. Group 1 received 0.04 energy% linoleate and Group 2 0.2 energy% linoleate from 30 to 50 kg live weight. Two of the pigs had digestive troubles in Period IV and were not subjected to balance and respiration trials. The results

Table 7.2.2 Series B. Mean values of energy loss in faeces (FE), urine (UE) and methane (CH_4E) in barrows fed 0.4 (Group 1) or 9.5 (Group 2) energy% linoleate during 7 balance periods

Tabel 7.2.2 Serie B. Middelværdier for energitab i faeces (FE), urin (UE) og methan (CH_4E) hos galte fodret med 0,4 (Hold 1) eller 9,5 (Hold 2) energi% linoleat gennem 7 balanceperioder

Period	No.	II		III		IV		V		VI		VII		VIII	
Group	No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2
LW	kg	28	29	37	40	48	52	57	65	69	77	81	90	91	100
Pigs	n	4	3	4	4	4	4	4	3	4	3	4	3	4	2
GE	kJ	17333	19375	22060	24660	26787	29944	31514	35228	35512	39424	40144	44567	43232	47995
FE	kJ	1317	1143	1324	1208	1393	1497	1513	1620	1918	1893	2047	1872	2162	2400
SEM		64	99	95	38	72	118	23	87	70	211	210	269	131	422
FE/GE	%	7.6	5.9	6.0	4.9	5.2	5.0	4.8	4.6	5.4	4.8	5.1	4.2	5.0	5.0
UE	kJ	330	349	458	515	752	833	970	1086	803	954	1064	1143	1217	1457
SEM		7.9	16	21	25	23	18	25	25	34	56	60	48	58	80
UE/GE	%	1.9	1.8	2.1	2.1	2.8	2.8	3.1	3.1	2.3	2.4	2.7	2.6	2.8	3.0
CH_4E	kJ	99	59	149	140	256	199	361	257	423	368	482	395	469	424
SEM		20	0.3	18	19	29	23	2.9	19	24	39	42	23	34	3.0
CH_4E/GE	%	0.6	0.3	0.7	0.6	1.0	0.6	1.1	0.7	1.2	0.9	1.2	0.9	1.1	0.9
Total loss	%	*10.1*	*8.0*	*8.8*	*7.6*	*9.0*	*8.4*	*9.0*	*8.4*	*8.9*	*8.1*	*9.0*	*7.7*	*8.9*	*8.9*

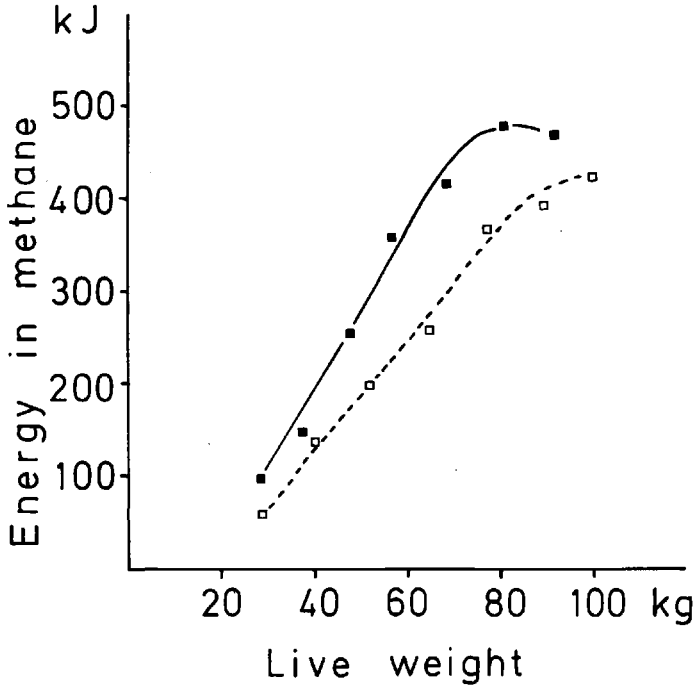

Figure 7.2. Energy loss in methane in pigs (Series B) fed 0.4 (■) or 9.5 (□) energy% linoleate during the growth period

Energitab i methan hos grise (Serie B) fodret med 0.4 (■) eller 9.5 (□) energi% linoleat gennem vækstperioden

concerning energy metabolism are presented in Table 7.2.4, and the statistical evaluation of the results is shown in Table 7.2.5.

As already discussed in Chapter V and shown in Table 7.2.5 the digestibility of GE was significantly lower in Group 2 receiving beef tallow, whereas the loss of energy in urine and methane was identical in the two groups. Thus, the metabolizability (ME/GE,%) was greater for Group 1 than for Group 2, although high (average 92.6%) in both groups as shown in Table 7.2.4.

The loss of energy in urine was greater for sows than for barrows due to a greater nitrogen excretion, but as the energy lost in urine was only about 3%, this did not influence the metabolizability between »sex«. However, the sows dissipated more heat than the barrows due to a greater deposition of energy in protein than in fat resulting in a significantly lower energy retention as evidenced in Table 7.2.5. The interaction observed between groups and »sex« with respect to metabolizability (ME/GE) makes the interpretation of the results

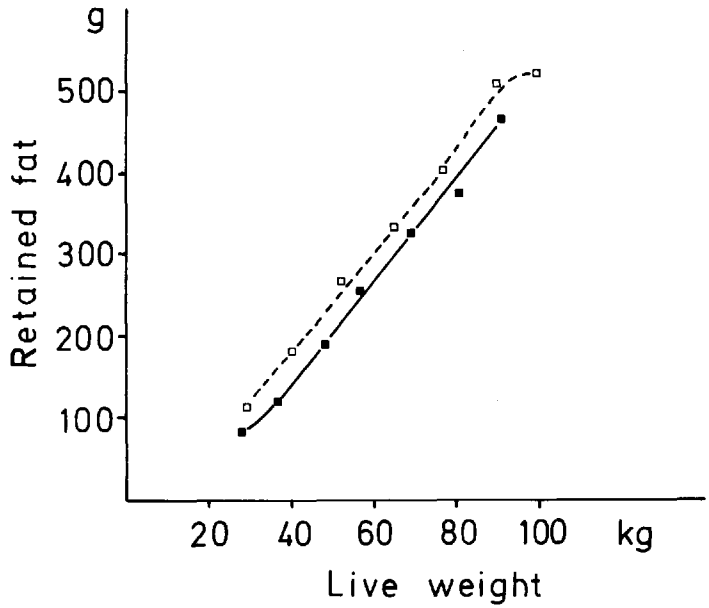

Figure 7.3. Daily retained amount of fat in pigs (Series B) fed 0.4 (■) or 9.5 (□) energy% linoleate during the growth period. The latter group received 11% more GE than the former group

Dagligt aflejret fedtmængde hos grise (Serie B) fodret med 0.4 (■) eller 9.5 (□) energi% linoleat gennem vækstperioden. Sidstnævnte gruppe fik 11% mere bruttoenergi end den førstnævnte

difficult. This interaction may be due to the inclusion of beef tallow to an otherwise »fat free« diet.

Series D was carried out with 4 groups of pigs (one barrow and one sow per group) fed iso-energetically from 15 to 40 kg live weight. The diets were supplied with soya bean oil to provide 0.3, 1.0, 2.0 and 2.7 energy% linoleate to Group 1, 2, 3 and 4, respectively. The results concerning energy metabolism are presented in Table 7.2.6.

Heat production (HE(CN)) was evaluated statistically in relation to metabolic live weight in a regression analysis and showed no significant difference ($P>0.05$) between »sex« or groups. In Table 7.2.6 the results from the four groups have been pooled, whereas the results from barrows and sows are shown separately in order to be able to compare with the results from the other series.

It is obvious from Table 7.2.6 that the metabolizability (ME/GE) of the diets was quite high being about 90%. The barrows apparently received too less

Table 7.2.4 Series C. Energy metabolism. Mean values of gross energy (GE), metabolizable energy (ME heat energy (HE), retained energy (RE) and energy retained in protein (RPE) and fat (RFE) barrows (b) and sows (s) fed 0.04 (Group 1) or 0.2 (Group 2) energy% linoleate added as be tallow

Tabel 7.2.4 Serie C. Energiomsætning. Middelværdier for bruttoenergi (GE), omsættelig energi (ME), v meenergi (HE), aflejret energi (RE) samt energi aflejret i protein (RPE) og fedt (RFE) hos ga (b) og sogrise (s) fodret med 0,04 (Hold 1) eller 0,2 (Hold 2) energi% linoleat tilsat som okseta

Per.	No.	II				III				IV			
Group	No.	1		2		1		2		1		2	
»Sex«		b	s	b	s	b	s	b	s	b	s	b	
LW	kg	29	31	31	31	37	40	39	39	46	50	46	4
Pigs	n	2	2	2	2	2	2	2	2	2	2	1	
GE	kJ	16411	16411	16647	16647	20887	20887	21188	21188	25362	25362	25728	257
ME	kJ	15494	15267	15164	15397	19744	19584	19503	19703	23436	23566	23201	235
SEM		44	40	149	199	52	120	53	22	222	244	–	
ME/GE	%	94.4	93.0	91.1	92.5	94.5	93.8	92.0	93.0	92.4	92.9	90.2	9
HE	kJ	9675	10781	9666	11040	11755	11948	11351	11836	11441	13246	12538	145
SEM		292	28	49	253	73	266	272	520	760	130	–	
HE/ME	%	62.4	70.6	63.7	71.7	59.5	61.0	58.2	60.1	48.8	56.2	54.0	6
RE	kJ	5819	4486	5498	4357	7989	7637	8152	7867	11995	10320	10663	89
SEM		336	68	197	54	21	147	220	498	538	374	–	
CV	%	8.2	2.1	5.1	1.7	0.4	2.7	3.8	8.9	6.3	5.1	–	
RE/ME	%	37.6	29.4	36.3	28.3	40.5	39.0	41.8	39.9	51.2	43.8	46.0	3
RPE	kJ	2440	2408	2287	2807	2884	2835	2695	3292	2795	2968	1786	32
SEM		50	98	29	47	183	57	14	30	36	456	–	
RPE/RE	%	41.9	53.7	41.6	64.4	36.1	37.1	33.1	41.8	23.3	28.8	26.1	3
RFE	kJ	3379	2078	3211	1550	5105	4802	5457	4575	9200	7352	7877	56
SEM		286	30	169	101	163	90	233	528	573	82	–	
RFE/RE	%	58.1	46.3	58.4	35.6	63.9	62.9	66.9	58.2	76.7	71.2	73.9	6

Table 7.2.5 Series C. Results of two way unbalanced analysis of variance on measurements of energy metabolism. F-values and mean square of error (MSE)

Tabel 7.2.5 Serie C. Resultater fra tosidet ubalanceret variansanalyse på målinger af energiomsætningen. F-værdier og residualmiddelkvadratsum (MSE)

Source of variation Degrees of freedom		Group 1	»Sex« 1	Interaction 1	MSE 18
FE/GE	%	54.1***	0.23 ns	2.72 ns	0.55
UE/GE	%	0.51 ns	7.05*	0.60 ns	0.41
CH_4E/GE	%	0.03 ns	0.02 ns	1.43 ns	0.079
ME/GE	%	10.7**	0.23 ns	4.59*	1.16
RE/ME	%	0.95 ns	4.48*	0.001 ns	38.2
RPE/RE	%	1.62 ns	5.37*	0.97 ns	110

Table 7.2.6 Series D. Energy metabolism. Mean values of gross energy (GE), metabolizable energy (ME), heat energy (HE), retained energy (RE) and energy retained in protein (RPE) and fat (RFE) in barrows (b) and sows (s) fed 0.3, 1.0, 2.0 or 2.7 energy% linoleate during 4 balance periods

Tabel 7.2.6 Serie D. Energiomsætning. Middelværdier for bruttoenergi (GE), omsættelig energi (ME), varmeenergi (HE), aflejret energi (RE) samt energi aflejret i protein (RPE) og fedt (RFE) hos galte (b) og sogrise (s) fodret med 0,3, 1,0, 2,0 og 2,7 energi% linoleat gennem 4 balanceperioder

Period	No.	I		II		III		IV	
»Sex«		b	s	b	s	b	s	b	s
LW	kg	16	15	21	21	28	28	36	37
Pigs	n	4	4	4	4	4	4	4	4
GE	kJ	8880	8880	11969	11969	18163	18163	22801	22801
SEM		45	45	26	26	14	14	33	33
ME	kJ	7995	8149	10758	10892	16176	16467	20265	20378
SEM		41	80	69	51	107	50	156	200
ME/GE	%	90.0	91.8	89.9	91.0	89.1	90.7	88.9	89.4
HE	kJ	6568	6326	7944	8433	10259	9943	11178	12263
SEM		143	272	205	217	369	134	288	136
HE/ME	%	82.2	77.6	73.8	77.4	63.4	60.4	55.2	60.2
RE	kJ	1427	1824	2814	2460	5917	6524	9087	8115
SEM		148	308	167	201	443	158	420	256
CV	%	20.8	33.7	11.9	16.3	15.0	4.8	9.2	6.3
RE/ME	%	17.8	22.4	26.2	22.6	36.6	39.6	44.8	39.8
RPE	kJ	1472	1687	1921	2031	2720	3079	3180	3716
SEM		102	97	106	196	135	184	313	255
RPE/RE	%	103.2	92.5	68.3	82.6	46.0	47.2	35.0	45.8
RFE	kJ	–45	137	893	428	3198	3445	5908	4398
SEM		87	271	166	305	551	333	316	483
RFE/RE	%	–3.2	7.5	31.7	17.4	54.0	52.8	65.0	54.2

energy in the first period as they had a negative energy retention in fat. The general trend found in the total material that the sows dissipate more energy as heat and retain more energy in protein than in fat compared to the barrows was also found in this series of experiments.

Series E comprised 4 groups of pigs (one barrow and one sow per group) receiving iso-energetically 0.1, 0.8, 1.5 or 2.2 energy% linoleate during the growth period from 20 to 90 kg live weight. Two sows died. In Period VII one barrow and one sow and in Period VIII one barrow were not subjected to respiration trials because of leg troubles and reduced appetite. The results from the measurements of energy metabolism in the rest of the pigs are shown in Table 7.2.7.

Table 7.2.7 Series E. Energy metabolism. Mean values of gross energy (GE), metabolizable energy (ME), heat energy (HE), retained energy (RE) and energy retained in protein (RPE) and fat (RFE) in barrows (b) and sows (s) fed 0.1, 0.8, 1.5 or 2.2 energy% linoleate during 8 balance periods

Tabel 7.2.7 Serie E. Energiomsætning. Middelværdier for bruttoenergi (GE), omsættelig energi (ME), varmeenergi (HE), aflejret energi (RE) samt energi aflejret i protein (RPE) og fedt (RFE) hos galte (b) og sogrise (s) fodret med 0,1, 0,8, 1,5 eller 2,2 energi% linoleat gennem 8 balanceperioder

Period	No.	I		II		III		IV		V		VI		VII		VIII	
»Sex«		b	s	b	s	b	s	b	s	b	s	b	s	b	s	b	s
LW	kg	20	20	27	27	36	36	45	46	56	57	66	68	77	79	85	90
Pigs	n	4	4	4	4	4	4	4	3	4	3	4	3	3	1	3	2
GE	kJ	12552	12552	17350	17350	22147	22147	26945	26945	31742	31742	36278	36278	39339	39339	42445	42445
SEM		17	17	26	26	59	59	93	93	128	128	143	143	166	166	135	135
ME	kJ	11181	10929	15295	15262	19502	19457	23911	23907	28115	28332	32242	32469	34435	34852	38351	40148
SEM		47	123	63	84	97	210	22	165	61	198	453	136	226	–	2115	2495
ME/GE	%	89.1	87.1	88.2	88.0	88.1	87.9	88.7	88.7	88.6	89.3	88.9	89.5	87.5	88.6	90.4	94.6
HE	kJ	7811	7394	9371	9824	12122	11926	13758	15187	16755	16764	17389	18881	19527	18239	21411	21266
SEM		178	207	66	333	225	313	168	450	227	170	476	306	491	–	1136	148
HE/ME	%	69.9	67.7	61.3	64.4	62.2	61.3	57.5	63.5	59.6	59.2	53.9	58.2	56.7	52.3	55.8	53.0
RE	kJ	3370	3535	5924	5438	7380	7531	10153	8720	11360	11568	14853	13588	14908	16613	16939	18882
SEM		223	182	60	352	295	390	185	429	266	183	882	313	712	–	983	2348
CV	%	13.3	10.3	2.0	12.9	8.0	10.4	3.6	8.5	4.7	2.7	11.9	4.0	8.3	–	10.0	17.6
RE/ME	%	30.1	32.3	38.7	35.6	37.8	38.7	42.5	36.5	40.4	40.8	36.1	41.8	43.3	47.7	44.2	47.0
RPE	kJ	2045	2005	2696	2670	2988	3261	3401	3787	3493	3879	2945	3977	3396	3948	4561	6607
SEM		73	15	160	55	135	116	196	47	168	143	460	126	287	–	2104	2152
RPE/RE	%	60.7	56.7	45.5	49.1	40.5	43.3	33.5	43.4	30.7	33.5	19.8	29.3	22.8	23.8	51.7	35.0
RFE	kJ	1325	1530	3228	2768	4392	4270	6752	4933	7867	7689	11908	9611	11512	12665	12379	12275
SEM		193	169	219	344	410	396	371	413	402	278	495	439	473	–	1134	196
RFE/RE	%	39.3	43.3	54.5	50.9	59.5	56.7	66.5	56.6	69.3	66.5	80.2	70.7	77.2	76.2	48.3	65.0

The material was divided into sows and barrows and regression analyses of HE(CN) in relation to metabolic live weight ($kg^{0.75}$) were performed to test the effect of linoleate level. No statistical significant differences ($P>0.05$) were found between linoleate levels. As shown in Table 7.2.7 the metabolizability of the gross energy (ME/GE) was a little lower (average 89%) than in the previous series of experiments, but still relatively high. The relative loss of heat (HE/ME) and the proportions of energy retained in protein (RPE/RE) and fat (RFE/RE) are comparable to the results obtained at the same live weight in the other series of experiments.

Series G was carried out with three groups of pigs (two barrows and two sows per group) fed iso-energetically 0.2, 1.1 or 2.1 energy% linoleate, respectively, during the growth period from 15 to 90 kg live weight. One barrow was not measured in Period III and IV and two barrows were deleted from Period V because of leg troubles.

Table 7.2.8 Series G. Energy metabolism. Mean values of gross energy (GE), metabolizable energy (ME), heat energy (HE), retained energy (RE) and energy retained in protein (RPE) and fat (RFE) in barrows (b) and sows (s) fed 0.2, 1.1, or 2.1 energy% linoleate during 5 balance periods

Tabel 7.2.8 Serie G. Energiomsætning. Middelværdier for bruttoenergi (GE), omsættelig energi (ME), varmeenergi (HE), aflejret energi (RE) samt energi aflejret i protein (RPE) og fedt (RFE) hos galte (b) og sogrise (s) fodret med 0,2, 1,1, eller 2,1 energi% linoleat gennem 5 balanceperioder

Period	No.	I		II		III		IV		V	
»Sex«	b,s	b	s	b	s	b	s	b	s	b	s
LW	kg	20	21	32	33	48	50	65	68	82	84
Pigs	n	6	6	6	6	5	6	5	6	4	6
GE	kJ	12604	12604	20584	20584	28299	28299	34828	34828	41190	41190
SEM		31	31	7	7	436	436	100	100	135	135
ME	kJ	10837	10819	17857	17849	23132	24446	30013	30265	35440	35687
SEM		25	68	98	119	365	342	170	201	322	397
ME/GE	%	86.0	85.8	86.8	86.7	85.3	86.4	86.2	86.9	86.0	86.6
HE	kJ	7842	7361	10111	11548	13973	13617	15084	17071	17383	18388
SEM		310	329	225	531	387	251	239	526	495	873
HE/ME	%	72.4	68.0	56.6	64.7	57.9	55.7	50.3	56.4	49.0	51.5
RE	kJ	2995	3458	7746	6301	10158	10829	14929	13194	18057	17299
SEM		323	356	317	634	99	270	290	709	735	1207
CV	%	26.4	25.2	10.0	24.6	2.2	6.1	4.3	13.2	8.1	17.1
RE/ME	%	27.6	32.0	43.4	35.3	42.1	44.3	49.7	43.6	51.0	49.5
RPE	kJ	2015	1851	2914	3019	3260	3610	2889	3255	3024	3661
SEM		35	119	65	138	48	72	146	162	212	424
RPE/RE	%	67.3	53.5	37.6	47.9	32.1	33.3	19.4	24.7	16.7	21.2
RFE	kJ	980	1607	4832	3282	6898	7219	12040	9939	15033	13638
SEM		297	264	258	677	133	252	346	750	714	926
RFE/RE	%	32.7	46.5	62.4	52.1	67.9	66.7	80.6	75.3	83.3	78.8

The statistical evaluation of the results is shown in Table 7.2.9. The analysis of variance including the effect of groups and »sex« showed no significant difference between barrows and sows with respect to UE/GE, ME/GE, RE/ME and RPE/RE, and a regression analysis within »sex« evaluating the effect of linoleate level on heat production (HE(CN)) as a function of metabolic live weight also did not show any significant difference between groups. There was a slight significant difference ($P<0.05$) between groups as to UE/GE due to a slightly greater nitrogen excretion in urine of Group 2. As there was no systematic effect of increasing the dietary linoleate level, the data were pooled within »sex« and the results concerning energy metabolism are shown in Table 7.2.8.

The metabolizability of the energy in the feed (ME/GE) used in this series of experiment was lower (average 86%) than in the previous series due to a lower digestibility of the feed components as discussed in Chapter V. HE/GE amounted to 60% at 20 kg live weight decreasing to 43% at 80 kg live weight. The total energy loss in faeces, urine and heat (methane production was not measured) thus amounted to 74% at 20 kg live weight and 57% at 80 kg live weight.

Table 7.2.9 Series G. Results of two way unbalanced analysis of variance on measurements of energy metabolism. F-values and mean square of error (MSE)

Tabel 7.2.9 Serie G. Resultater fra tosidet ubalanceret variansanalyse på målinger af energiomsætningen. F-værdier og residualmiddelkvadratsum (MSE)

Source of variation Degrees of freedom (df):		Group 2	»Sex« 1	Interaction 2	MSE 50
UE/GE	%	3.29*	1.33 ns	0.44 ns	0.073
ME/GE	%	1.62 ns	1.15 ns	2.46 ns	1.44
RE/ME	%	0.30 ns	0.15 ns	0.23 ns	87.3
RPE/RE	%	0.28 ns	0.06 ns	0.19 ns	368

Series H was carried out with three groups of pigs (two barrows and two sows per group) fed the same basal diet as in Series G, but Group 1, 2 and 3 received 0.7, 1.6 and 2.3 energy% linoleate during the growth period from 15 to 80 kg live weight.

The stataistical evaluation of the results is shown in Table 7.2.11. Although no statistical significant effect ($P>0.05$) of linoleate level was found on the apparent digestibility of gross energy (Chapter V) and in UE/GE as evidenced in Table 7.2.11, a significant ($P<0.05$) effect occurred in the metabolizability (ME/GE) both for groups and »sex«. As shown in Table 7.2.10, however, the numerical difference is extremely small between »sex« and this was also the case between groups. There was no systematic effect of increasing linoleate levels on the proportions of metabolizable energy retained and on the proportions of energy retained in protein and fat.

Table 7.2.10 Series H. Energy metabolism. Mean values of gross energy (GE), metabolizable energy (ME), heat energy (HE), retained energy (RE) and energy retained in protein (RPE) and fat (RFE) in barrows (b) and sows (s) fed 0.7, 1.6 or 2.3 energy% linoleate during 5 balance periods

Tabel 7.2.10 Serie H. Energiomsætning. Middelværdier for bruttoenergi (GE), omsættelig energi (ME), varmeenergi (HE), aflejret energi (RE) samt energi aflejret i protein (RPE) og fedt (RFE) hos galte (b) og sogrise (s) fodret med 0,7, 1,6 eller 2,3 energi% linoleat gennem 5 balanceperioder

eriod	No.	I		II		III		IV		V	
Sex«		b	s	b	s	b	s	b	s	b	s
W	kg	18	16	28	27	42	41	57	58	74	73
igs	n	6	6	6	6	6	6	6	6	6	6
GE	kJ	9462	9462	17481	17481	23897	23897	30312	30312	35814	35814
EM		33	33	32	32	72	72	114	114	190	190
ME	kJ	7872	8191	15058	15037	20583	20491	26084	26214	30288	31012
EM		76	88	75	83	114	86	205	152	423	146
ME/GE	%	83.2	86.6	86.1	86.0	86.1	85.7	86.1	86.5	84.6	86.6
HE	kJ	7210	5893	9440	9437	11473	11871	13621	13752	16603	16149
EM		193	550	360	238	165	303	348	163	183	491
HE/ME	%	91.6	71.9	62.7	62.8	55.7	57.9	52.2	52.5	54.8	52.1
RE	kJ	662	2298	5618	5600	9110	8620	12463	12462	13685	14863
EM		211	623	364	207	221	314	422	89	572	436
V	%	78.2	66.5	15.9	9.0	5.9	8.9	8.3	1.8	10.2	7.2
RE/ME	%	8.4	18.1	37.3	37.2	44.3	42.1	47.8	47.5	45.2	47.9
RPE	kJ	1191	1513	2786	2958	3265	3543	3534	3746	3672	4108
EM		69	57	71	77	63	84	117	186	198	94
RPE/RE	%	–	65.8	49.6	52.8	35.8	41.1	28.4	30.0	26.8	27.6
RFE	kJ	–528	785	2832	2642	5845	5077	8929	8716	10013	10755
EM		291	579	369	250	269	362	411	212	389	522
RFE/RE	%	–	34.2	50.4	47.2	64.2	58.9	71.6	70.0	73.2	72.4

Table 7.2.11 Series H. Results of two way balanced analysis of variance on measurements of energy metabolism. F-values and mean square of error (MSE)

Tabel 7.2.11 Serie H. Resultater fra tosidet balanceret variansanalyse på målinger af energiomsætningen. F-værdier og residualmiddelkvadratsum (MSE)

Source of variation Degrees of freedom (df):		Group 2	»Sex« 1	Interaction 2	MSE 54
UE/GE	%	0.65 ns	3.53 ns	0.63 ns	0.10
ME/GE	%	4.25*	7.33**	1.68 ns	2.32
RE/ME	%	0.23 ns	1.24 ns	0.63 ns	181
RPE/RE	%	0.26 ns	0.30 ns	0.13 ns	1743

It is seen that the barrows apparently received too less energy in the first period. As discussed earlier the amount of feed was restricted in the first period to avoid feed residuals and diarrhoea. If this period is excluded from the calculations of RPE/RE and periods included in a three way analysis of variance, the CV% is reduced from 82% to 58%, showing no statistical significant ($P>0.05$) effects of groups and »sex«, but a statistical significant effect ($P<0.001$) of periods, and no statistical significant interactions. Still, the variation in the proportion of retained energy in protein is quite high.

Table 7.3.1 Series B. Mean values of carbondioxide production (CO_2), oxygen consumption (O_2), respiratory quotients (RQ) and methane production (CH_4) in barrows fed 0.4 (Group 1) and 9.5 (Group 2) energy% linoleate during 7 balance periods. Group 2 received about 11% more GE than Group 1

Tabel 7.3.1 Serie B. Middelværdier for kulsyreproduktion (CO_2), iltoptagelse (0_2), respiratoriske kvotienter (RQ) og methanproduktion (CH_4) hos galte fodret med 0,4 (Hold 1) eller 9,5 (Hold 2) energi% linoleat gennem 7 balanceperioder. Hold 2 fik ca. 11% mere bruttoenergi end Hold 1

Period	No.	II		III		IV		V		VI		VII		VIII	
Group	No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2
LW	kg	28	29	37	40	48	52	57	65	69	77	81	90	91	100
Pigs	n	4	4	4	4	4	3	4	3	4	3	3	1	3	2
CO_2	litres	477	497	595	600	692	686	783	794	896	901	1021	956	1033	1087
SEM		10	64	13	9.4	7.6	7.2	18	14	15	5.7	27	16	16	25
O_2	litres	469	506	578	623	642	692	707	751	756	817	871	872	877	976
SEM		13	10	19	12	11	13	21	13	18	12	38	27	31	36
RQ	CO_2/O_2	1.02	0.98	1.03	0.96	1.08	0.99	1.11	1.06	1.19	1.10	1.17	1.10	1.18	1.11
CH_4	litres	2.3	1.3	3.8	3.3	6.8	4.7	9.0	6.3	10.8	9.3	12.3	10.0	11.8	11.0
SEM		0.7	0.3	0.5	0.3	0.8	0.7	0.0	0.3	0.6	1.2	1.2	0.6	0.9	0.0

Table 7.3.2 Series C. Mean values of carbondioxide production (CO_2), oxygen consumption (O_2), respiratory quotients (RQ) and methane production (CH_4) in barrows (b) and sows (s) fed 0.04 (Group 1) or 0.2 (Group 2) energy% linoleate during 3 balance periods

Tabel 7.3.2 Serie C. Middelværdier for kulsyreproduktion (CO_2), iltoptagelse (0_2), respiratoriske kvotienter (RQ) og methanproduktion (CH_4) hos galte (b) og sogrise (s) fodret med 0,04 (Hold 1) eller 0,2 (Hold 2) energi% linoleat gennem 3 balanceperioder

Period	No.	II				III				IV			
Group	No.	1		2		1		2		1		2	
»Sex«		b	s	b	s	b	s	b	s	b	s	b	s
LW	kg	29	31	31	31	37	40	39	39	46	50	46	49
Pigs	n	2	2	2	2	2	2	2	2	2	2	1	1
CO_2	litres	512	535	485	533	605	620	587	602	686	710	667	74
SEM		8.7	1.5	20	10	6.5	10	11	19	18	6.5	–	-
O_2	litres	493	524	468	525	565	575	551	582	628	652	607	70
SEM		12	10	10	0.5	7.6	4.0	21	16	23	6.5	–	-
RQ	CO_2/O_2	1.04	1.02	1.04	1.02	1.07	1.08	1.07	1.03	1.09	1.09	1.10	1.0
CH_4	litres	2.1	2.5	2.0	2.5	4.0	4.5	5.0	3.0	5.5	5.5	6.0	6.(
SEM		0.3	0.5	1.0	0.5	0.5	1.5	0.0	0.0	0.7	2.5	–	-

7.3 Gas exchange and methane production in the individual series of experiments

The carbondioxide (CO_2) production and the oxygen (0_2) consumption together with the ratio ($CO_2/0_2$) called the respiratory quotient (RQ) are shown in Tables 7.3.1, 7.3.2, 7.3.3, 7.3.4, 7.3.5 and 7.3.6 for Series B, C, D, E, G and H, respectively. Generally, the RQ values were below 1.0 in Period 1 showing

Table 7.3.3 Series D. Mean values of carbondioxide production (CO_2), oxygen consumption (O_2) and respiratory quotients (RQ) in barrows (b) and sows (s) fed 0.3, 1.0, 2.0 or 2.7 energy% linoleate during 4 balance periods

Tabel 7.3.3 Serie D. Middelværdier for kulsyreproduktion (CO_2), iltoptagelse (O_2) og respiratoriske kvotienter (RQ) hos galte (b) og sogrise (s) fodret med 0,3, 1,0, 2,0 eller 2,7 energi% linoleat gennem 4 balanceperioder

Period	No.	I		II		III		IV	
»Sex«	b,s	b	s	b	s	b	s	b	s
LW	kg	16	15	21	21	28	28	36	37
Pigs	n	4	4	4	4	4	4	4	4
CO_2	litres	310	302	386	404	519	508	592	629
SEM		5.1	9.4	7.8	8.1	13	4.1	11	5.5
O_2	litres	333	319	387	405	507	498	546	601
SEM		4.5	12	10	6.8	16	9.0	14	1.0
RQ	CO_2/O_2	0.93	0.95	1.00	1.00	1.02	1.02	1.08	1.05

Table 7.3.4 Series E. Mean values of carbondioxide production (CO_2), oxygen consumption (O_2) and respiratory quotients (RQ) in barrows (b) and sows (s) fed 0.1, 0.8, 1.5 or 2.2 energy% linoleate during 8 balance periods

Tabel 7.3.4 Serie E. Middelværdier for kulsyreproduktion (CO_2), iltoptagelse (0_2) og respiratoriske kvotienter (RQ) hos galte (b) og sogrise (s) fodret med 0,1, 0,8, 1,5 eller 2,2 energi% linoleat gennem 8 balanceperioder

Period	No.	I		II		III		IV		V		VI		VII		VIII	
»Sex«		b	s	b	s	b	s	b	s	b	s	b	s	b	s	b	s
LW	kg	20	20	27	27	36	36	45	46	56	57	66	68	77	79	85	90
Pigs	n	4	4	4	4	4	4	4	3	4	3	4	3	3	1	3	2
CO_2	litres	373	356	464	480	600	591	694	744	840	840	930	979	1031	989	1127	1128
SEM		7.0	7.8	2.8	12	7.5	11	4.4	15	7.8	4.1	17	10	17	–	49	15
O_2	litres	379	361	466	484	588	585	663	735	804	810	862	936	958	951	1068	1067
SEM		5.3	16	7.1	17	4.2	14	12	31	13	8.4	24	12	19	–	93	1.5
RQ	CO_2/O_2	0.98	0.99	1.00	0.99	1.02	1.01	1.05	1.01	1.04	1.04	1.08	1.05	1.08	1.04	1.06	1.06

Table 7.3.5 Series G. Mean values of carbondioxide production (CO_2), oxygen consumption (O_2) and respiratory quotients (RQ) in barrows (b) and sows (s) fed 0.2 , 1.0 or 2.1 energy% linoleate during 5 balance periods

Tabel 7.3.5 Serie G. Middelværdier for kulsyreproduktion (CO_2), iltoptagelse (O_2) og respiratoriske kvotienter (RQ) hos galte (b) og sogrise (s) fodret med 0,2 1,0 eller 2,1 energi% linoleat gennem 5 balanceperioder

Period	No.	I		II		III		IV		V	
»Sex«		b	s	b	s	b	s	b	s	b	s
LW	kg	20	21	32	33	48	50	65	68	82	84
Pigs	n	6	6	6	6	5	6	5	6	4	6
CO_2	litres	378	361	523	574	720	709	788	905	987	1024
SEM		11	12	7.5	18	16	12	9.4	23	13	30
O_2	litres	389	369	510	585	699	700	875	905	919	962
SEM		18	16	12	20	23	13	33	23	7.4	22
RQ	CO_2/O_2	0.97	0.98	1.03	0.98	1.03	1.01	0.90	1.00	1.07	1.06

that fat is being oxidized. This is caused by the low feed supply in the first period to avoid diarrhoea and feed residuals during the balance trials. In Series B the group receiving 9.5 energy% linoleate supplied additionally as soya bean oil, had RQ values below 1.0 until Period V and systematically lower values than the RQ values of Group 1 which did not receive dietary fat additionally. It is seen from Tables 7.3.1–7.3.6 that the RQ values increase with increasing live weight reaching values of about 1.06 to 1.18 in barrows and 1.04 to 1.08 in sows at 80–90 kg live weight.

Methane production was only measured in Series B and C as technical problems prevented further measurements. The results are shown in Table 7.3.1 and 7.3.2, respectively. The daily methane production was about 2 litres at about 30

Table 7.3.6 Series H. Mean values of carbondioxide production (CO_2), oxygen consumption (O_2) and respiratory quotients (RQ) in barrows (b) and sows (s) fed 0.7, 1.6 or 2.3 energy% linoleate during balance periods

Tabel 7.3.6 Serie H. Middelværdier for kulsyreproduktion (CO_2), iltoptagelse (O_2) og respiratoriske kvotienter (RQ) hos galte (b) og sogrise (s) fodret med 0,7 1,6 eller 2,3 energi% linoleat gennem 5 balanceperioder

Period	No.	I		II		III		IV		V	
»Sex«	b,s	b	s	b	s	b	s	b	s	b	s
LW	kg	18	16	28	27	42	41	57	58	74	73
Pigs	n	6	6	6	6	6	6	6	6	6	6
CO_2	litres	334	288	477	477	605	615	736	741	891	876
SEM		6.4	19	13	8.8	6.2	11	13	5.7	10	15
O_2	litres	355	312	475	480	581	598	704	727	814	831
SEM		7.8	20	20	11	9.0	18	18	10	12	25
RQ	CO_2/O_2	0.94	0.92	1.00	0.99	1.04	1.03	1.05	1.02	1.09	1.05

kg live weight increasing to about 12 litres at 90 kg live weight. In Series B the high dietary linoleate level corresponding to 90 g soya bean oil per kg feed significantly reduced the methane production as mentioned in the previous section. The inclusion of 2% beef tallow in the diet of Group 2 in Series C did not affect the methane production as evidenced in Table 7.3.2.

7.4 Overall gas exchange and heat production

All individual measurements of gas exchange and heat production (HE(CN)) and (HE(RQ)) comprising 162 balance experiments with barrows and 110 balance experiments with sows were used in regression analyses relating the measured values to metabolic live weight ($kg^{0.75}$). The following equations were found for barrows and sows, respectively:

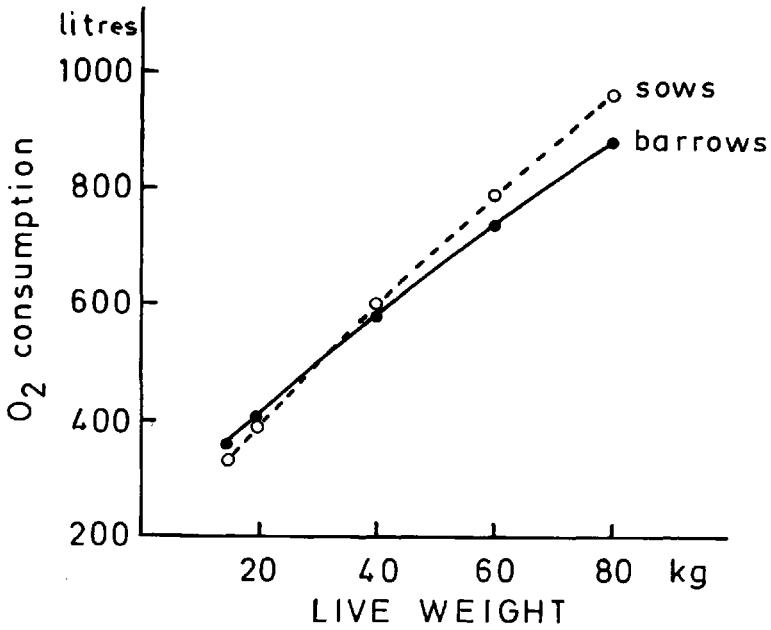

Figure 7.4. Oxygen consumption in barrows (n = 162) and sows (n = 110) fed from 0.04 to 9.5 energy% linoleate during the growth period
Iltoptagelse hos galte (n = 162) og sogrise (n = 110) fodret med 0.04 til 9.5 energi% linoleat gennem vækstperioden

	Barrows (n = 162)	*Sows (= 110)*
(1)	CO_2, litres/24 h = 71.7 + 33.7 $kg^{0.75}$	= 43.7 + 35.9 $kg^{0.75}$
	S_I, S_b 9.9 0.52	12.6 0.72
	RSD = 42.2, CV% = 6.3, R^2 = 0.963	RSD = 45.7, CV% = 7.3, R^2 = 0.958
(2)	O_2, litres/24 h = 143.6 + 27.6 $kg^{0.75}$	= 81.3 + 32.8 $kg^{0.75}$
	S_I, S_b 11.3 0.60	12.9 0.74
	RSD = 48.2, CV% = 7.6, R^2 = 0.930	RSD = 46.8, CV% = 7.5, R^2 = 0.948
(3)	HE(CN), kJ/24 h = 2998 + 545 $kg^{0.75}$	= 2113 + 332 $kg^{0.75}$
	S_I, S_b 254 13.5	332 19.1
	RSD = 1085, CV% = 8.6, R^2 = 0.911	RSD = 1208, CV% = 9.9, R^2 = 0.906
(4)	HE(RQ), kJ/24 h = 2714 + 607 $kg^{0.75}$	= 1562 + 704 $kg^{0.75}$
	S_I, S_b 224 11.9	267 15.4
	RSD = 957, CV% = 7.1, R^2 = 0.942	RSD = 971, CV% = 7.5, R^2 = 0.951

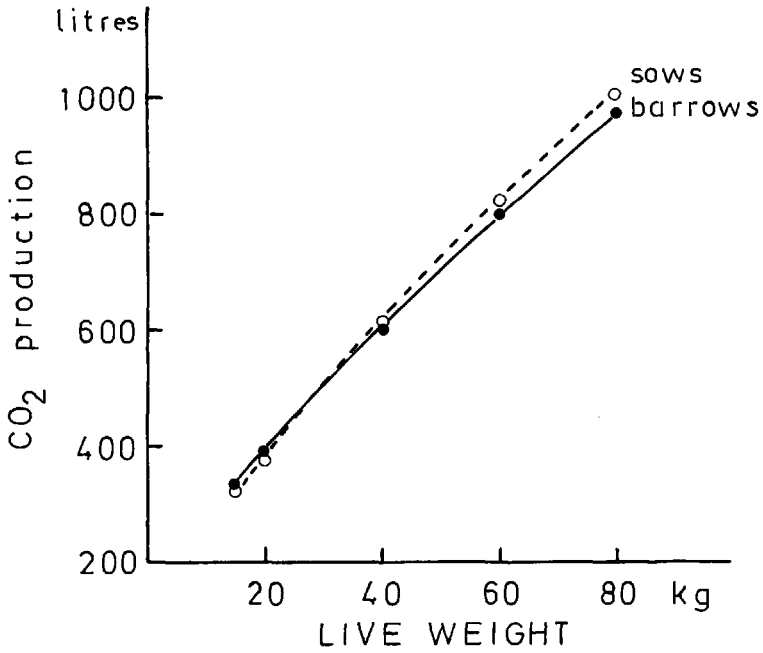

Figure 7.5 Carbondioxide production in barrows (n = 162) and sows (n = 110) fed from 0.04 to 9.5 energy% linoleate during the growth period
Kuldioxid produktion hos galte (n = 162) og sogrise (n = 110) fodret med 0.04 til 9.5 energi% linoleat gennem vækstperioden

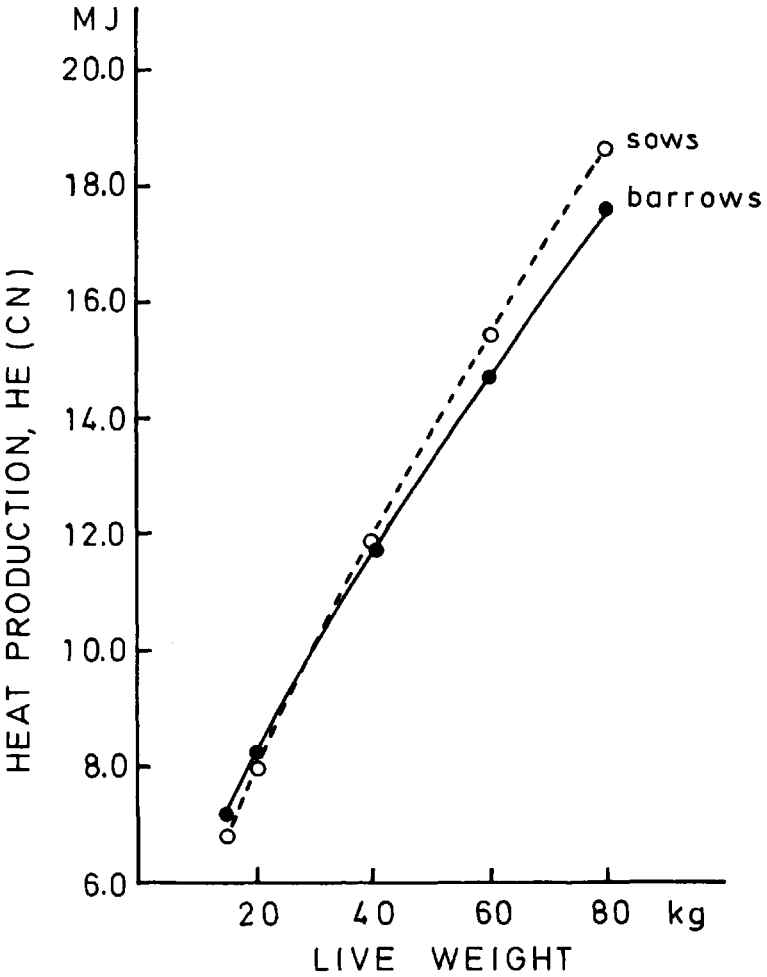

Figure 7.6 Heat production (HE (CN), MJ/24h) in barrows (n = 162) and sows (n = 110) fed from 0.04 to 9.5 energy% linoleate during the growth period
Varmeproduktion (HE (CN), MJ/24t) hos galte (n = 162) og sogrise (n = 110) fodret med 0.04 til 9.5 energi% linoleat gennem vækstperioden

For all equations the differences between barrows and sows were highly significant ($P<0.001$). In all cases also the intercepts were highly significant ($P<0.001$). The set of equations showed a CO_2 production at 20 kg live weight of 391 and 383 litres/24 hours for barrows and sows, respectively, and of 973 and 1004 litres/24 hours, respectively, at 80 kg live weight. Figures 7.4,7.5 and 7.6

Table 7.4.1 Comparison of heat production (kJ/24 h) measured according to the CN and RQ methods in different weight classes

Tabel 7.4.1 Sammenligning af varmeproduktion (kJ/24 h) målt efter CN- og RQ-metoden i forskellige vægtklasser

»Sex«		Barrows				Sows			
		Method		Difference		Method		Difference	
LW kg	$kg^{0.75}$	RQ	CN	kJ	%	RQ	CN	kJ	%
20	9.46	8456	8154	+ 302	+3.7	8222	7959	+ 263	+3.3
40	15.91	12371	11669	+ 702	+6.0	12763	11945	+ 818	+6.8
60	21.56	15801	14748	+1053	+7.1	16740	15437	+1303	+8.4
80	26.75	18951	17577	+1374	+7.8	20394	18645	+1749	+9.4

show graphically the difference in oxygen consumption and carbondioxide and heat (HE,CN) production, in barrows and sows, respectively, during the growth period from 20 to 80 kg.

The heat production calculated according to the CN and RQ method in different weight classes for sows and barrows is shown in Table 7.4.1. It is seen that the difference between the two methods generally is greater for sows than for barrows and that it increases with increasing live weight. In all cases measurements of HE(RQ) give greater values than measurements of HE(CN).

7.5 Overall utilization of GE for energy retention

While the mean values of RE in relation to ME are shown in Tables 7.2.1, 7.2.4, 7.2.6, 7.2.7, 7.2.8 and 7.2.10 for Series B, C, D, E, G and H, respectively, RE is shown graphically in relation to GE during the growth period in question for barrows and sows in Figure 7.7. RE/GE is of practical interest as it describes the percentage of the dietary energy retained in the body.

It is apparent from Figure 7.7 that the variability in RE/GE is greater for barrows than for sows. From this figure the mean values of RE/GE for the whole material may be deduced. For the barrows about 23% of GE is retained at 20 kg live weight increasing to 39% at 40 kg live weight and to about 45% at 80 kg live weight. For the sows the corresponding values were 23, 34 and 42%, respectively. Conversely, Figure 7.7 also describes the total losses of energy in faeces, urine, methane and heat as these constitute the difference between GE and RE. Thus, the total loss of energy in barrows and sows amounted to 77% at 20 kg, but at 40 and 80 kg live weight it was 61 and 55% for barrows, respectively, and 66 and 58% for sows. Thus, for the whole growth period in question, the barrows deposited more energy than the sows, the difference being greatest between 20 and 60 kg live weight. As already described proportionately more of the retained energy was deposited as fat in the barrows than in the sows.

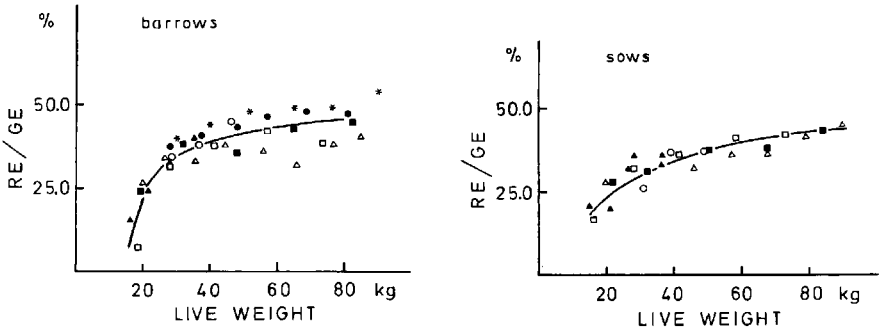

Figure 7.7. Retained energy as a percentage of gross energy (RE/GE, %) in barrows (n = 162) and sows (n = 110) fed from 0.04 to 9.5 energy% linoleate during the growth period. (● Series B Group 1, * Series B Group 2, ○ Series C, ▲ Series D, △ Series E, ■ Series G, and □ Series H)

*Aflejret energi i procent af bruttoenergi (RE/GE, %) hos galte (n = 162) og sogrise (n = 110) fodret med 0.04 til 9.5 energi% linoleat gennem vækstperioden. (● Serie B Hold 1, * Serie B Hold 2, ○ Serie C, ▲ Serie D, △ Serie E, ■ Serie G og □ Serie H)*

7.6 Efficiency of utilization of metabolizable energy for growth and for protein and fat retention

The total material comprising 162 barrows and 110 sows was used to determine the efficiency of utilization of metabolizable energy for growth (k_g) and for protein (k_p) and fat retention (k_f). Retained energy (RE(CN)) was determined as a linear function of metabolizable energy available for growth, i.e.

$$RE(CN)), kJ = b \times ME_g$$

where $ME_g = ME - ME_m$ and $ME_m = 4060 + 210$ LW, $kg^{0.75}$ *(Thorbek and Henckel, 1976).*

The calculations gave the following results:

Barrows (n = 162)	*Sows (n = 110)*
$RE(CN), kJ = 0.694 \times ME_g$	$= 0.641 \times ME_g$
s_b 0.0051	0.0071
$RSD = 1125, CV\% = 10.6, R^2 = 0.965$	$RSD = 1101, CV\% = 13.1, R^2 = 0.943$

The results show that for the purified diets used in the present experiments during the growth period in question (10–100 kg live weight) the mean efficiency of utilization of ME for total energy gain (k_g) was 69% for barrows and 64% for sows, the difference between barrows and sows being highly significant ($P<0.001$).

Anticipating that the total energy gain only consists of fat and protein, the efficiency of the two productions were calculated according to the following equation:

$$ME_g, kJ = b_1 \times RPE, kJ + b_2 \times RFE, kJ$$

where $ME_g = ME - ME_m$ and $ME_m = 4060 + 210\ LW, kg^{0.75}$

By means of all individual figures for ME_g, RPE and RFE the following equations for barrows and sows were obtained:

Barrows (n = 162)

$$ME_g, kJ = 1.83 \times RPE, kJ + 1.30 \times RFE, kJ$$
$$s_b \qquad 0.078 \qquad\qquad 0.027$$

Sows (n = 110)

$$ME_g, kJ = 1.92 \times RPE, kJ + 1.36 \times RFE, kJ$$
$$s_b \qquad 0.105 \qquad\qquad 0.050$$

The difference between barrows and sows was highly significant ($P<0.001$).

The partial efficiencies of utilization of ME for protein and fat retention was calculated as $1/b_1$ and $1/b_2$, respectively. Thus, the efficiency of ME for protein retention (k_p) was found to be 55% in barrows and 52% in sows and for fat retention (k_f) 77% in barrows and 74% in sows. These values correspond to a requirement of 43.6 and 45.7 kJ ME for retention of 1 g protein in barrows and sows, respectively, and 51.6 and 54.0 kJ ME for retention of 1 g fat in barrows and sows, respectively. Both for barrows and sows the regression coefficients for protein retention were determined with a lower precision than those for fat retention indicating a greater variation between animals in their ability to deposit protein than fat.

7.7 Discussion

Specific attention was paid to energy metabolism because disturbance in energy metabolism as indicated by increase in basal oxygen consumption was reported to be an early sign of EFA-deficiency in rats *(Wesson and Burr, 1931; Panos and Finerty, 1953; 1954; Morris et al., 1957; Panos et al., 1956). Wesson and Burr (1931)* also found a higher metabolic rate in EFA deficient rats following a carbohydrate meal. Recently, *Müller (1975)* showed that heat production determined both according to the RQ and CN method increased in rats receiving less than 170 mg linoleic acid per 100 g feed. Increased metabolism measured as energy intake per kg gain in weight was also found in infants fed to satiety with skim milk providing 0.04 energy% linoleic acid compared to infants ingesting a standard milk mixture providing 0.9 energy% linoleate *(Hansen et al., 1955)*. Gain in weight and feed conversion efficiency are, however, not precise indicators of increased metabolic rate. Lower weight gains and higher feed conversion ratios might be due to greater loss of energy in faeces, urine and methane. These factors were not considered in the older studies.

To the author's knowledge no metabolic studies concerning the role of EFAs in energy metabolism have been performed in pigs except my own studies on

mitochondrial activity *(Christensen, 1974a)* indicating some uncoupling of oxidative phosphorylation in EFA deficiency. These observations together with the controversial findings concerning gain in weight and feed conversion efficiency in EFA deficient pigs, encouraged the author to look further into the losses of energy and the utilization of the retained energy for protein and fat deposition.

7.7.1 Metabolizability (ME/GE)

The metabolizability expresses the percentage of energy intake available for metabolic purposes in the body. Thus, the metabolizability depends on the size of the losses of energy in faeces, urine and methane.

The greatest loss of energy occurred in faeces. The loss of energy in faeces has already been described in Chapter V. In all cases the digestibility of the present purified diets was higher than observed for commercial feed mixtures in pigs.

The loss of energy in urine primarily depends on the amount of excreted urea. As described in Chapter VI the sows generally deposited more nitrogen than the barrows and, therefore, excreted less urea than the barrows. The loss of energy in urine is, however, relatively small being about 2–3% of GE during the growth period from 15 to 90 kg. The loss of energy in urine was rather constant because the N intake was reduced from 60 kg live weight, whereby the N intake better covered the requirement for nitrogen.

Methane production was only measured systematically in Series B and C because of technical problems. Methane production amounted to about 2 litres at 30 kg live weight increasing to 12 litres at 90 kg live weight corresponding to an energy loss of about 0.5 and 1% of GE at 30 and 90 kg live weight, respectively. However, the inclusion of soya bean oil in the diet of the pigs of Group 2 in Series B providing 9.5 energy% linoleate corresponding to 90 g soya bean oil per kg diet, significantly ($P<0.001$) reduced the methane production, whereas the inclusion of 2% beef tallow (20 g per kg diet) had no effect on the methane production. The depressive effect of relatively great amounts of unsaturated fat or fatty acids on microbial activity and hence on methane production is well known in ruminants *(Czerkawski et al., 1966; Rohr and Okubo, 1968; Czerkawski, 1976),* but is to the author's knowledge not hitherto described in monogastric animals including the pig. From a quantitative point of view, however, the loss of energy in methane is insignificant and may be neglected in the determination of ME. The methane production in percent of GE on the purified diets used in the present studies was of the same order as found by *Thorbek et al. (1984)* on commercial feed mixtures commonly used to pigs.

Because of a greater digestibility of the purified diets employed in the present experiments compared to that of commercial feed mixtures, the metabolizability of the present rations was greater than for commercial rations. The greatest

metabolizability was found for the mixtures based on glucose, casein and cellulose, ME/GE being about 92%, and the lowest metabolizability for the diets based on tapiocameal, potatomeal, maize starch, casein and beech saw dust, ME/GE being about 86%. *Thorbek et al. (1984)* found a metabolizability of 78% for commercial feed mixtures to pigs.

Because of the sliding feeding schedule used and because of the reduction in N intake at 60 kg live weight, the metabolizability was rather constant during the growth period. ME/GE was generally greater for sows than for barrows due to the greater N retention in the sows, but the differences in numerical values were relatively small.

The precision of the determination of ME was extremely high. Expressed as the coefficient of variation (CV%), the precision varied approximately between 1 and 2%. This precision in the determination of ME was of the same order as found by *Just (1970), Thorbek (1975)* and *Thorbek et al. (1984).*

The various linoleate levels between 0.04 and 2.7 energy% fed iso-nitrogenously and iso-energetically had no effect on the metabolizability. The highest intake of 9.5 energy% linoleate, where the soya bean oil was supplied as an extra energy supply providing 7.4% more ME than the group receiving the basal diet without added oil, however, resulted in a significantly ($P \leq 0.05$) greater metabolizability because of a slightly greater digestibility of energy, a slightly lower loss of energy in faeces and a slightly lower loss of energy in methane.

7.7.2 Gas exchange and heat production

The respiration units were frequently calibrated by means of CO_2 showing an accuracy between 1–1.5% in the determination of the CO_2 production. For all the measurements performed in the present studies the precision of the measurements expressed by the coefficients of variation (CV%) was 6.3 and 7.3% for the CO_2 production for barrows (n = 162) and sows (n = 110), respectively, and 7.6 and 7.5% for the O_2 production for barrows and sows, respectively. Within each series of experiments the variation was greater at 15–20 kg live weight than at 80–90 kg live weight, the CV% sometimes being about 15% at the low live weights and only 2–3% at the heavier live weights. These results indicate a great individual variation in gas exchange especially in smaller pigs. These results are in accordance with former results *(Just, 1970; Thorbek, 1975* and *Thorbek et al., 1984).*

In the present experiments no systematic differences in gas exchange were observed as a consequence of feeding different linoleate levels ranging from 0.1 to 2.7 energy%, whereas increased oxygen consumption was found in the pigs receiving 9.5 energy% linoleate fed hyper-energetically. *Christensen et al. (1980)* compared the results from Series C-D-E and G within the live weight

range of 15 to 50 kg. It was apparent that the pigs in Series C receiving 0.04 and 0.2 energy% linoleate had a lower oxygen consumption and heat production expressed in relation to metabolic live weight than the pigs from the other series. As the pigs from the other series receiving 0.1, 0.2 or 0.3 energy% linoleate had a greater oxygen consumption per kg metabolic live weight being of the same size as for the pigs receiving greater linoleate concentrations up to 2.7 energy%, it was concluded that the lower oxygen consumption and lower heat production in the pigs of Series C might be attributed to the digestive troubles observed in these pigs due to the composition of the diet, and not to the linoleate intake as such. A lower oxygen uptake by the mitochondria isolated from *the longissimus dorsi* muscle was also noticed in Series C compared to that of the other series *(Christensen et al., 1980)*. In any case, the increased metabolic rate observed in EFA deficient rats as described at the beginning of this chapter was not found in the present studies, although the pigs receiving less than 0.8 energy% linoleate had 20:3,n-9/20:4,n-6 ratios indicating EFA deficiency (cf. Figure 3.2).

Significant differences ($P<0.001$) were found in the O_2 consumption and CO_2 production between barrows and sows. As illustrated in Figures 7.4 and 7.5 the O_2 uptake was greater for barrows than for sows and the CO_2 production lower for barrows than for sows from 15 to 30 kg live weight, where the situation was reversed. These observations are in accordance with the findings in heat production as shown in Figure 7.6 and discussed later.

The gas exchange measurements are used in the calculations of the heat production according to the RQ-method, where the measurements of the oxygen consumption are of major importance because of the factor 16.18 per liter O_2 consumed compared to the factor 5.02 per liter CO_2 expired as shown in *7f*. The heat production calculated according to the CN method includes nitrogen and carbon balances and thus the CO_2 production. Both methods involve a set of constants *(Brouwer, 1965)* and as recently discussed in detail by *Thorbek et al. (1984)*, the assumptions on which these constants are based may not always be valid. Generally, the agreement between the results obtained according to the two methods is 2–3%, the RQ method normally giving greater values than the CN method *(Thorbek, 1975; Thorbek et al., 1984)*. The difference between the two methods is usually increasing with live weight *(Thorbek, 1975)*.

In the present experiments, also, the RQ method gave greater heat production than the CN method as shown in Table 7.4.1, and the difference was generally slightly greater for sows than for barrows. However, the difference in heat production determined according to the two methods is increasing from 3.7 to 7.8% for barrows and from 3.3 to 9.4% for sows, which is a greater difference than observed in previous experiments. The main reason for this discrepancy is probably that most of the pigs received unsaturated fatty acids in their diets and

deposited unsaturated fatty acids in their fatty tissues, notably linoleic acid which does not contain 76.7% carbon as assumed in the above-mentioned sets of constants and used for the present calculations, but only 73.0% carbon. If the fat deposited did only contain linoleic acid a factor of 1.370 (100/73.0) should have been used instead of a factor of 1.304 (100/76.7). A mixture of saturated and unsaturated fatty acids is, however, deposited so that the correct factor would lie between 1.304 and 1.370. In any case the factor should be greater, which would augment the heat production calculated according to the CN method and minimize the difference between the two methods. Because relatively more dietary fat is deposited at the heavier live weights than at the lighter live weights, the difference between the two methods naturally increase with increasing live weights. That relatively more dietary fat is deposited with increasing dietary intake of soya bean oil is evidenced in the RQ values of Series B, where Group 2 receiving 90 g soya bean oil per kg diet had RQ values below 1.0 until about 60 kg live weight, and generally lower RQ values than the pigs receiving the basal diet without soya bean oil. RQ values above 1.0 generally indicate synthesis of fat from carbohydrates, and RQ values below 1.0 that fat is being oxidized. In this case the dietary fat apparently is being oxidized and deposited to a greater extent than carbohydrates are converted to fat.

RQ values below 1.0 was found in Series D, E, G and H in the first period, because the pigs were fed restrictedly to avoid diarrhoea and feed residuals during the balance period. In these cases they have not received enough energy for fat deposition which is also apparent from the measurements of energy retained in protein and fat.

Wesson and Burr (1931) and *Burr and Beber (1937)* observed that EFA deficient rats readily synthesized fat from carbohydrates, as the RQ values rapidly increased above 1.0.

The heat production measured according to the CN method is shown in Tables, 7.2.1, 7.2.4, 7.2.6, 7.2.7, 7.2.8 and 7.2.10 for the individual series of experiments both in absolute values and in relation to the intake of ME. Figure 7.6 illustrates the differences in HE(CN) found in the total material between barrows and sows. Greater heat production has been found in sows compared to barrows by *Just (1970), Ludvigsen (1980)* and *Fuller et al. (1980),* and may be due to a greater nitrogen retention as found by *Sundstøl et al. (1979)* comparing genetically lean and fat pigs. It is striking, however, that the barrows in the present studies being littermates to the sows within the individual series of experiments, have a greater heat production until about 30 kg live weights than the sows.

At 15 kg live weight the barrows produced 4.6% more heat than the sows, at 20 kg live weight the difference was 2.4%, at 30 kg live weight they produced similar amounts of heat, and then the sows produced more heat than the bar-

rows, the difference being 6.1% at 80 kg live weight. This trend in heat production has apparently not been described before, which may be due to the fact that only few comparative studies between barrows and sows have been performed. The experiments mentioned above comparing heat production in barrows and sows were started at 20 or 25 kg live weight, and then the difference may not be statistically significant and therefore neglected. Is this difference due to the fact that the castration effect does not manifest itself until 20–30 kg live weight? It might seem a reasonable explanation.

The heat production (HE(CN)) amounted to about 80% of ME at 15 kg live weight, decreased to about 70% at 20 kg live weight and to about 53% at 80–90 kg live weight. The loss of heat energy is highly dependent on the feeding level *(Thorbek et al., 1984),* which was low in the first balance periods in order to minimize the risk for diarrhoea and feed residuals as already described.

The heat production of the barrows in the present experiments was slightly greater than that of the barrows fed the high feeding level in *Thorbek et al.'s (1984)* experiments, which may be due to the different composition of the diets.

7.7.3 Total loss of energy in faeces, urine, methane and heat

The total loss of energy in faeces, urine, methane and heat ranged between 93 and 73% with an average of 82% of ME in barrows at 15–20 kg live weight and between 62 and 51% with an average of 56% of ME at 75–85 kg. For sows the corresponding values were 80 and 72% at 15–20 kg live weight with an average of 75% and 58–55% at 75–85 kg live weight, the average being 57%.

Because of the high metabolizability (92–86%) of the present diets, the total heat loss was found to be approximately 77% of GE at 20 kg live weight both for barrows and sows, whereas it was lower for barrows than for sows both at 40 and 80 kg live weight (61 vs. 66% and 55 vs. 58%, respectively).

Thorbek et al. (1984) found in their experiments including barrows fed at a high feeding level almost comparable to the one used in the present experiments, a total heat loss of 78% of GE at 20–25 kg live weight, the same as found in the present studies, decreasing to about 62% at 80 kg live weight (55% in the present studies). Thus, although the present experimental conditions are not quite comparable to those used by *Thorbek et al. (1984),* it is believed that the main difference in total heat loss between the two studies is primarily due to the composition of the experimental diets. Thus, although a slightly higher heat loss (HE(CN)) was observed for the present purified diets than for the commercial feed mixtures used by *Thorbek et al. (1984),* the digestibility of GE and the metabolizability was so much greater that the total loss of energy was smaller on the purified than on the commercial diets.

7.7.4 Retained energy and the proportions of energy retained in protein and fat

As the total loss of energy in faeces, urine, methane and heat was smaller for

the purified diets used in the present studies than for the commercial mixtures used by *Thorbek et al. (1984)* as discussed in the previous section, it follows that the retention of energy was greater. This further underlines the statement made in Chapter IV on the feed conversion which seemed to be very efficient on the present experimental diets.

The retention of energy varied considerably during the growth period with CV values from 0.4 to 26.4% except in Series H where the CV% was 78% at 15–16 kg live weight. Generally, the precision of the determination of RE was lower at the lower live weight intervals than at the greater live weights.

The proportion of energy retained in the body is dependent upon the proportions of energy retained in protein and fat, as the energy cost is greater at protein than at fat deposition as discussed in the following section.

In Series D and H the barrows deposited more than 100% of RE in protein (RPE) and had a negative retention of energy in fat (RFE) between 15 and 17 kg live weight. In the other series of experiments the barrows deposited 61–68% of RE in protein at 20 kg live weight decreasing to 16–27% at 80 kg live weight. In Series B, the barrows of Group 2 substantially retained 5–10% units less energy in protein and conversely 5–10% units more energy in fat than the barrows of Group 1 due to a greater energy intake. The sows retained 54–83% of RE in protein at 20 kg live weight decreasing to 21–28% at 80 kg live weight.

As shown in Chapter VI nitrogen retention reached maximum at 70 kg live weight in barrows and at 82 kg live weight in sows. Maximum nitrogen retention was 24.0 g corresponding to 150 g protein in barrows and 26.1 g corresponding to 163 g protein in sows. While nitrogen retention is primarily dependent upon the genetic capacity, provided the supply of energy and essential nutrients is optimal, the fat retention is primarily dependent upon the energy intake. Thus, the energy retention in fat was steadily increasing during the growth period and reached a maximum of 20.7 MJ at 100 kg live weight in the barrows of Group 2 in Series B, who received 7% more ME than the barrows of Group 1. The fat retention in g for this series of experiment is shown in Figure 7.4. It is apparent that the barrows of group 1 deposited about 80 g fat at approximately 30 kg live weight linearly increasing to 470 g fat at 90 kg live weight, whereas the barrows of Group 2 deposited 120 g fat at 30 kg live weight increasing to 510 g fat at 90 live weight. In comparison with these values the barrows and sows of Series G which are more representative for the total material deposited 25 and 40 g fat, respectively, at 20 kg live weight increasing to 380 and 340 g fat, respectively, at 80 kg live weight.

In studies with Danish Landrace pigs carried out in 1964–66, *Thorbek (1975)* found a maximum protein deposition of 125 g and a maximum fat deposition of 400 g, whereby RPE/RE fell from 66% at 25 kg live weight to 17% at 80 kg live weight. *Just (1970)* found a maximum retention of protein of about 125 g and

maximum retention of fat of about 300 g using a lower dietary energy level than *Thorbek (1975)*, whereby RPE/RE fell from 54 to 20% during the growth period from 20 to 90 kg live weight. Compared to the latter studies the pigs in the present experiments have had a maximum protein deposition of 25–35 g more and generally a similar fat deposition, whereas the pigs in Group 2 of Series B deposited more fat. As already discussed this fat deposition was due both to a greater fat deposition notably of dietary origin, and to a lower nitrogen retention. *Jentsch and Hoffmann (1977)* found a maximum fat retention of 454 g in barrows of the German landrace at 125 kg live weight fed at a high energy intake but at a low protein level, whereby RPE/RE reached 11%.

Thus, it may be concluded that a relatively high efficiency of utilization of GE for energy retention in the present studies using purified diets is mainly due to a high protein retention, the fat retention being of the same size as found on commercial diets. No effect of varying the dietary linoleate level from 0.2 to 2.7 energy% was found on RPE/RE and RFE/RE, whereas the levels below 0.2 energy% may depress RPE/RE and increase RFE/RE. In case the linoleic acid is not supplied iso-energetically, but added in excess, RPE/RE is also reduced, and RFE/RE is increased.

7.7.5 Efficiency of utilization of metabolizable energy for growth and for protein and fat retention

As described in Section 7.1 and shown in formula *7 g* and *7 h* the efficiency of utilization of metabolizable energy for growth (k_g or k_{pf}) and the partial efficiencies of utilization of metabolizable energy for protein (k_p) and fat (k_f) retention can only be calculated if the maintenance requirement (ME_m) is known. ME_m was not determined in the present studies, but the values found in fasting experiments with barrows of Danish Landrace were used *(Thorbek and Henckel, 1976)*.

For the total material comprising 162 measurements with barrows and 110 measurements with sows from 15 to 100 kg live weight, k_g was found to be 0.69 in barrows and 0.64 in sows, the differences being highly significant ($P<0.001$). *Thorbek (1975)* found a mean k_g of 0.67 for different commercial feed compounds in experiments with barrows ($n = 381$) from 20 to 80 kg live weight and noticed a greater k_g value (0.70) for maize diets than for barley and sorghum diets (0.66), which was attributed to the greater fat content of the maize diets. An examination of the results from Series B comprising barrows fed without or with addition of 9% soya bean oil gave k_g values of 0.73 and 0.74, respectively, the difference being non significant ($P>0.05$). In later studies *Thorbek et al. (1984)* found k_g values between 0.69–0.82 in experiments with barrows ($n = 110$) of Danish Landrace fed commercial feed mixtures from 20 to 125 kg live weight. As recently described in detail by *Thorbek et al. (1984)* k_g values found

by different workers range between 0.62–0.75. Thus, the values found in the present studies lie within this range. Differences in k_g values are likely to occur because different ME_m values are used for the calculations. Thus, *Thorbek et al. (1984)* have shown that ME_m determined in feeding experiments with pigs is 10–25% greater than ME_m determined in fasting experiments. Thus, the present findings tend to give too low k_g values, because the fasting values for ME_m were used for the calculations. Also, the same ME_m was used for barrows as for sows as no values for ME_m in sows was available.

By using the same maintenance requirement for sows as for barrows, the difference observed in heat production (cf. Figure 7.6) is totally attributed to differences in the energy costs of growth. By using multiple regression analysis with the two variables RPE and RFE, the efficiency of utilization of energy for protein retention (k_p) was found to be 0.55 in barrows and 0.52 in sows, and the efficiency of utilization of energy for fat retention (k_f) 0.77 in barrows and 0.74 in sows. These values correspond to a requirement of 43.6 kJ ME/g deposited protein in barrows and 45.7 kJ ME/g deposited protein in sows, and to a requirement for deposition of 1 g fat in barrows and sows of 51.6 and 54.0 kJ ME. Thus, the efficiency of utilization of ME for protein deposition was found to be lower than for fat deposition, a fact which is well established *(Thorbek, 1975; Fowler et al., 1980; Thorbek et al. 1984)*. Both the protein and fat gain was found to be more costly in sows than in barrows, which is in accordance with the theoretical consideration made by *Fuller et al. (1980)*.

From a biochemical point of view it is well recognized that the deposition of dietary fat requires much less ATP than the synthesis of fat *de novo*. The results from Series B comparing a diet without added fat and a diet with 9% soya bean oil gave k_f values of 0.80 and 0.77, respectively, the difference being non significant ($P>0.05$). K_p was slightly greater for the diet supplied with oil (0.63) than for the basal diet without added oil (0.57), but again the differences were not statistically significant ($P>0.05$).

So, for the material in question, the different dietary levels of linoleate ranging from 0.04 to 9.5 energy% did not affect the efficiency of utilization of metabolizable energy for total energy gain or for energy retained in protein and fat.

7.8 Conclusions

1. The various linoleate levels employed ranging from 0.04 to 2.7 energy% fed iso-energetically and iso-nitrogenously had similar effects on *the metabolizability (ME/GE)*.

   The greatest metabolizability was found for the diets based on glucose and

casein, ME/GE being 92%, and the lowest metabolizability for the diets based on tapioca meal, potato meal, maize starch and casein, ME/GE being 86%. The precision of the determination of ME was 1–2%.

FE/GE and UE/GE were rather constant during the growth period in question amounting to 2–11% and 2–3%, respectively. CH_4E was about 0.5% of GE at 30 kg LW, increasing to 1% of GE at 90 kg LW.

The addition of 9% soya bean oil to the basal diet (Series B) significantly reduced the methane production, whereas the inclusion of 2% beef tallow (Series C) had no effect on methane production.

2. No systematic differences in *gas exchange and heat production* were observed as a consequence of feeding different linoleate levels ranging from 0.1 to 2.7 energy % during the growth period.

   Decreased oxygen consumption and decreased heat production per kg metabolic live weight was observed in the pigs of Series C fed 0.04 and 0.2 energy % linoleate compared to the pigs of the other series of experiments receiving similar or greater dietary linoleate levels. This was attributed to the digestive disturbances and the composition of the diets.

   Increased oxygen consumption was observed in the pigs of Series B, Group 2, receiving 9.5 energy % linoleate at a 7% greater ME intake than the pigs of Group 1 fed 0.4 energy % linoleate. The heat production was not significantly ($P>0.05$) affected.

   For comparative purposes all individual measurements of O_2 consumption, CO_2 production and heat production measured both according to the RQ and the CN method were used in regression analyses in relation to metabolic live weight. The folowing equations were obtained:

	Barrows (n = 162)	*Sows (n = 110)*
CO_2,litres/24h:	$71.7 + 33.7 kg^{0.75}$	$43.7 + 35.9 kg^{0.75}$
O_2,litres/24h:	$143.6 + 27.6 kg^{0.75}$	$81.3 + 32.8 kg^{0.75}$
HE(CN),kJ24h:	$2998 + 545 kg^{0.75}$	$2113 + 332 kg^{0.75}$
HE(RQ),kJ/24h:	$2714 + 607 kg^{0.75}$	$1562 + 704 kg^{0.75}$

   For all equations the differences between barrows and sows and the intercepts were highly significant ($P<0.001$).

   The barrows consumed more oxygen, produced more heat and expired less CO_2 than the sows until 30 kg LW, when the situation was reversed. It is believed that this situation was due to the effect of castration.

3. Measurements of HE(RQ) gave systematically greater values than measurements of HE(CN). These results were attributed mainly to the sets of constants used for calculation of HE(CN), where the fat deposited is anticipated to contain 76.7% carbon, while fat containing linoleic acid contain a lower proportion of carbon.

4. The respiratory quotient (RQ) was below 1.0 in the first balance periods of most of the experiments, because the pigs were fed restrictedly to avoid diarrhoea and feed residuals.
   In Series B, Group 2 receiving 90 g soya bean oil per kg diet had RQ values below 1.0 until 60 kg live weight indicating a relatively greater oxidation of dietary fatty acids than synthesis of fatty acids from carbohydrates.
5. Retained energy (RE) was 18 and 25% of ME at 15–20 kg LW for barrows and sows, respectively, and 44 and 43% of ME, respectively, at 75–85 kg LW. RE was greater on the present experimental diets than found for conventional swine rations.
6. On an average the barrows deposited 61–68% of RE in protein at 20 kg LW decreasing to 16–27% at 80 kg LW. The values for sows were 54–83% and 21–28%, respectively.
7. The barrows of Group 2 in Series B fed 7% more ME than the barrows of Group 1, due to the addition of 90 g soya bean oil per kg diet, deposited 40 g more fat during the growth period (25–90 kg LW), which was both due to reduced nitrogen retention and an increased fat retention compared to the barrows of Group 1 receiving the basal diet.
8. The mean efficiency of utilization of ME for total energy gain (k_g) was determined as a linear function of metabolizable energy available for growth (ME_g), where $ME_g = ME - ME_m$ and $ME_m = 4060 + 210LW,kg^{0.75}$. K_g was found to be 69% for barrows (n = 162) and 64% for sows (n = 110), the difference being highly significant ($P<0.001$).
9. Multiple regressions using all data for ME_g, RPE and RFE for barrows (n = 162) and sows (n = 110) gave the following equations: In barrows: $ME_g,kJ = 1.83 \times RPE,kJ + 1.30 \times RFE,kJ$, and in sows: $ME_g,kJ = 1.92 \times RPE,kJ + 1.36 \times RFE,kJ$ corresponding to $k_p = 0.55$ in barrows and 0.52 in sows and $k_f = 0.77$ in barrows and 0.74 in sows. These values corespond to a requirement of 43.6 and 45.6 kJ ME for retention of lg protein in barrows and sows, respectively, and 51.6 and 54.0 kJ ME for retention of lg fat in barrows and sows, respectively. In all cases the same maintenance requirement (ME_m) was used for barrows and sows, the significance of which is being discussed.
10. *In pigs of Danish Landrace weaned at 5 weeks of age the requirement of dietary linoleate for adequate energy metabolism is 0.2 energy%.*

VIII. Overall conclusion concerning the requirement of dietary linoleate

On the basis of 272 digestibility, nitrogen and carbon balances and 272 gas exchange measurements (162 trials with barrows and 110 trials with sows) with a total of 56 pigs of Danish Landrace (32 barrows and 24 sows) fed different levels of linoleic acid ranging from 0.04 to 9.5% of gross energy (energy%) the following conclusions are drawn:

1. The requirement for dietary linoleate to cover maximum levels of daily gain in weight, feed conversion efficiency, digestibility of nutrients, nitrogen and energy metabolism in conventional pigs of Danish Landrace weaned at 5 weeks or more of age and raised until 90–100 kg liveweight is 0.2% of gross energy. With a metabolizability (ME/GE) of 78% as found for commercial swine rations this corresponds to 0.26% of metabolizable energy. This level is likely to be present in all natural feed compounds used for swine, but not in highly refined or purified diets.
2. The fatty acid composition of plasma and bile lipids from some of the experimental animals, however, indicates that the dietary linoleic acid requirement is greater for other biological functions of essential fatty acids. It will therefore be necessary to investigate other biological functions and economically important production traits, before the requirement of dietary linoleate for slaughter pigs is finally settled.

IX. Dansk sammendrag

9.1 Indledning

Behovet for essentielle fedtsyrer (EFAs) til slagtesvin, der danner meget kød, er mangelfuldt belyst og er aldrig blevet fastlagt for svin under danske forhold.

Adskillige danske forsøg har beskæftiget sig med den effekt, foderets fedtsyresammensætning har på fedtdepoternes fedtsyresammensætning og jodtal (se oversigtsartikel af Madsen et al., 1977). Disse forsøg viste, at jo mere umættet fedt, grise indtog, desto blødere var rygspækket, fordi foderets umættede fedtsyrer blev aflejret i fedtdepoterne. Dette medførte en forringet holdbarhed med risiko for oxidationsfejl som misfarvning, harskhed og andre uønskede smagsændringer. Risikoen for kvalitetsfejl er størst ved baconproduktion, fordi både saltlage og røg indeholder stoffer, der fremmer oxidationen. Følgelig forsøger man at begrænse foderets indhold af polyumættede fedtsyrer (PUFAs).

Det traditionelle svinefoder bestående af byg og fedtfri proteinblanding som skummetmælkspulver eller sojaskrå indeholder 1.5–2.5% råfedt, hvoraf ca. 65% er PUFAs. Af disse er både linolsyre (55%) og linolensyre (10%) EFAs, men med forskellige biologiske funktioner.

Egne præliminære undersøgelser med grise, der fik 0.4 eller 6.4% af foderets bruttoenergi (energi%) som linolsyre tilsat i form af sojaolie, viste, at de grise, der fik det lave linolsyreindhold i foderet, manglede linolsyre vurderet ud fra forholdet mellem 20:3,n-9/20:4,n-6 i plasmalipider og fosfolipider isoleret fra skeletmuskel-, lever- og hjertemitokondrier (Christensen, 1973; 1974a). De grise, der blev fodret med det linolsyrefattige foder udviste også PSE (1974b). Andre undersøgelser udført ved Dyrefysiologisk afdeling tydede endvidere på, at EFAs spillede en rolle både for kødmængde (Petersen et al., 1970; Jakobsen, 1972) og kødkvalitet (Christensen, 1970).

På denne baggrund blev det besluttet at udføre en serie undersøgelser over behovet for linolsyre til slagtesvin, idet dette skulle fastlægges som den mængde linolsyre, der skulle være i foderet for at sikre maximal ydelse og produktion målt såvel ved produktionsøkonomiske, fysiologiske som biokemiske parametre.

Denne beretning beskriver og diskuterer de resultater, der vedrører bestemmelse af behovet for linolsyre til sikring af maximal fordøjelighed af foderets næringsstoffer og energi samt til maximal udnyttelse af foderets kvælstof- og energiindhold til køddannelse. Disse faktorer har alle stor betydning for økonomien i slagtesvineproduktionen.

9.2 Litteraturoversigt over essentielle fedtsyrers betydning i ernæringen med særligt henblik på grise

Essentielle fedtsyrers omsætning og funktioner

Burr og Burr (1929; 1930) viste, at rotter ikke trivedes på et fedtfrit foder, men udviklede en karakteristisk mangelsygdom, der viste sig ved skællet hud, nedsat eller manglende tilvækst, nyrelæsioner ofte med blodudskillelse i urinen til følge, abnormt højt vandforbrug og forstyrrelser i ovulation, befrugtning og laktation samt forstyrrelser i de hanlige reproduktionsfunktioner. Som følge af nyrelæsionerne kunne der indtræffe dødsfald. De essentielt fedtsyremanglende rotter kunne imidlertid helbredes ved tilskud af linolsyre givet enten i ren form eller som olie. Burr og Burr (1930) konkluderede, at varmblodede dyr ikke selv kan syntetisere linolsyre og muligvis heller ikke linolensyre og gav betegnelsen »essentiel fedtsyre« til linolsyre.

Linolsyrefamilien (n-6 familien)

Linolsyre (cis,cis-9,12-octadecadiensyre eller 18:2,n-6 eller 18:2,ω-6, se Figur 2.1) er den mest udbredte polyumættede fedtsyre og syntetiseres ligesom linolensyre af planter. Pattedyr mangler det enzym (desaturase), der kan indføre en dobbeltbinding ved det sjette (n-6) eller tredie (n-3) kulstofatom regnet fra metylgruppen i en fedtsyre med 18 kulstofatomer. Senere er det vist, at linolsyre kan omdannes til andre umættede fedtsyrer i kroppen ved skiftevis kædeforlængelse (forøgelse med $-CH_2-CH_2-$) og desaturering (dannelse af en cis-dobbeltbinding -CH=CH-). De derved dannede polyumættede fedtsyrer betegnes n-6 eller ω-6 fedtsyrer. Omdannelsen er vist i 2.1.

(2.1) *18:2,n-6 (linolsyre)* → *18:3,n-6 (*γ-linolensyre) →
(20:3,n-6 (dihomo-γ-linolensyre) → 20:4,n-6 (arakidonsyre)
→ 22:4,n-6 → 22:5,n-6

Af de i 2.1 viste fedtsyrer er linolsyre (Burr og Burr, 1929; 1930) arakidonsyre (Turpeinen, 1938) γ-linolensyre (Thomasson, 1953) og dihomo-γ-linolensyre (Hassam og Crawford, 1978) essentielle, idet de ved tilførsel til EFA manglende dyr kan kurrere mangelsymptomerne.

Linolsyre, γ-linolensyre og arakidonsyre kan tilsyneladende også dannes af mikrober i fordøjelseskanalen (Girard, 1974; Nichols og Appleby, 1969), og muligvis derved bidrage til forsyning med EFAs.

Efter absorption oxideres en del linolsyre, medens en del aflejres i fedtvæv og en del inkorporeres direkte eller efter omdannelse til n-6 familiens fedtsyrer i plasma- og membranlipider. Hos grise findes 60–70% af serum linolsyremængden i sterolestre og 70–75% af serum arakidonsyremængden i fosfolipider (Leat, 1963). Linolsyrefamiliens fedtsyrer har såvel strukturel som funktionel betydning. De er vigtige for opretholdelse af membranernes fysisk kemiske

egenskaber og dermed på mange organel- og enzymfunktioner. Dihomo-γ-linolensyre og/eller arakidonsyre er substrater for dannelse af endoperoxider (PGG,PGH), prostaglandiner (PG), thromboxaner (TX) og prostacyclin (PGI_2) ved reaktion med ilt og enzymet, cyclooxygenase, og for dannelse af hydroperoxy- og hydroxyfedtsyrer (HPETE og HETE) samt leukotriener (LT) ved reaktion med ilt og enzymet, lipoxygenase. Disse reaktionsveje og de dannede produkter er vist for arakidonsyre i Figur 2.2.

Prostaglandiner, endoperoxider, thromboxaner og leukotriener har en lang række fysiologiske og patofysiologiske funktioner i næsten alle organer og væv, hvor de virker i meget små koncentrationer (10^{-12}g) og i meget kort tid (nogle få minutter). Hos grise har især $PGF_{2\alpha}$ interesse, idet det kan anvendes ved igangsættelse af faring og ved abort.

Metaboliske konsekvenser af linolsyremangel viser sig ved, at der ophobes 20:3,n-9 i blod- og vævslipider dannet ud fra oliesyre (18:1,n-9, se Figur 2.3). Samtidig falder koncentrationen af arakidonsyre (20:4,n-6). Forholdet mellem 20:3,n-9 og 20:4,n-6 (trien/tetraensyreforholdet) anvendes i vid udstrækning til vurdering af EFA status. Er forholdet 0.2 eller derunder, er minimumsbehovet dækket, men er det over 0.4, er der tale om EFA mangel (Holman, 1960). EFA mangelsymptomer kan afhænge af dyrearten. Der er ofte tale om nedsat tilvækst og foderudnyttelse, hudlæsioner, forøget vandfordampning gennem huden, sterilitet, reduceret myokardiekontraktilitet (slap hjertemuskulatur), forstyrrelser i blodpladeaggregering og mitokondriefunktion, forøget varmeproduktion m.m. Disse og andre ændringer skyldes formentlig både ændringer i membranstruktur og i produktion af prostaglandin og andre cyclooxygenase- eller lipoxygenaseprodukter. Det er imidlertid fundet, at der ved en daglig indtagelse på 10 g linolsyre kun udskilles 1 mg prostaglandinmetabolitter i urinen pr. døgn (Nugteren, 1975), hvilket tyder på, at forbruget til prostaglandinsyntese og -funktion er relativt lille. Der henvises til oversigtsartikler i litteraturlisten.

Linolensyrefamilien (n-3 familien)

Linolensyre (α-linolensyre, all-cis-9,12,15-octadecatriensyre eller 18:3,n-3 eller 18:3,ω-3) er også en essentiel fedtsyre, da den ikke kan dannes i pattedyrenes organisme *de novo*.

Ved desaturering og kædeforlængelse kan der dannes andre PUFAs, alle tilhørende n-3 familien, idet den første dobbeltbinding findes ved det tredie kulstofatom regnet fra metylgruppen (se Figur 2.4).

(2.2) 18:3,n-3 → 18:4,n-3 → 20:5,n-3 → 22:5,n-3 → 22:6,n-3

Der er ingen enzymer, der kan omdanne en n-3 til en n-6 syre eller omvendt (Mohrhauer og Holman, 1963; Holman, 1964). Linolensyre findes i små mæng-

der i næsten alle frø og olier, men i græs og hørfrø forekommer den i meget høj koncentration. De øvrige n-3 fedtsyrer forekommer først og fremmest i fisk og fiskeolier.

De polyumættede fedtsyrer i n-3 familien inkorporeres i fosfolipider, navnlig i hjernevæv, retina, spermatozoer og testes. Desuden er 20:5,n-3 modersubstrat for n-3 familiens endoperoxider (PGG_3 og PGH_3), prostaglandiner (PG_3), thromboxaner (TX_3) og prostaglandin (I_3) gennem cyclooxygenasens reaktion med ilt og for n-3 familiens hydroperoxy- og hydroxyfedtsyrer samt leukotriener gennem lipoxygenasens reaktion med ilt (sammenlign Figur 2.2).

Linolensyren er snart blevet kaldt essentiel, snart ikke essentiel, hvilket skyldes, at den kan genoprette tilvækst og foderudnyttelse ved tilskud til EFA manglende dyr, hvorimod den ikke kan udbedre skader i hud og reproduktionsorganer. Da en af dens polymere, 20:5,n-3, er modersubstans for prostaglandiner, thromboxaner og leukotriener, er der ingen tvivl om, at den bør medtages som essentiel fedtsyre. Mangel på 20:5,n-3 nedsætter blodpladeaggregering og blodets evne til at koagulere (f.eks. Dyerberg og Bang, 1979), og mangel på 22:6,n-3 medfører ændret adfærd hos rotter (Lamptey og Walker, 1976). Hos de fleste fisk er linolensyren essentiel for vækst og reproduktion (f.eks. Tinoco et al., 1979). Det kan ikke udelukkes, at tilskud af fiskemel til søer, orner og pattegrise, der normalt anses for gunstigt p.g.a. proteinets høje BV, også kan have betydning ved et vis indhold af polyumættede fedtsyrer.

Andre essentielle fedtsyrer

Ifølge Holman (1958) bør betegnelsen »essentiel fedtsyre« begrænses til de fedtsyrer, som kan fremme væksten og hindre udviklingen af hudlæsioner, hvilket vil begrænse betegnelsen til n-6 familien. Da der imidlertid dannes prostaglandiner, thromboxaner, leukotriener m.m., som har biologisk aktivitet, ud fra polyumættede fedtsyrer med 20 kulstofatomer både fra n-6 og n-3 familien, bør begge familier medregnes som essentielle fedtsyrer. Alligevel er der stadig uklarhed m.h.t. betegnelsen »essentiel fedtsyre«, idet der også kan dannes prostaglandiner med biologisk aktivitet ud fra andre fedtsyrer med forskelligt antal kulstofatomer (17-19-20-21-22) (Gurr og James, 1975).

I det følgende anvendes betegnelsen »essentiel fedtsyre« om linolsyrefamiliens fedtsyrer, med mindre andet er nævnt. Det skyldes, at der er anvendt sojaolie som EFA kilde til undersøgelserne. Sojaolie indeholder ca. 55% linolsyre, men det bør huskes, at den også indeholder ca. 7% linolensyre.

Linol- og linolensyre findes ikke som frie syrer i olier og fodermidler, men fortrinsvis som triglycerider eller fosfolipider i animalsk fedt og glysocyl glycerider i plantefedt. Frie fedtsyrer kan forekomme i affaldsfedt og kan udgøre 4.5% af foderet med godt resultat (Mortensen et al., 1983).

I det følgende anvendes ordet linolsyre identisk med linoleat.

EFA mangelsyndromet hos grise

EFA mangelsymptomer udvikles ikke så let hos grise som hos andre dyr, sandsynligvis fordi det er vanskeligt at depletere deres depoter. Den første beskrivelse af EFA mangelsymptomer hos grise stammer fra 1951, hvor Witz og Beeson havde fodret grise fra 16–22 kg levende vægt med et foder bestående af glukose, kasein, cellulose, vitaminer og mineraler indeholdende 0.06 eller 0.12% æterekstraheret fedt. Efter 42 dages fodring fandtes følgende: En skællet dermatitis (hudbetændelse) på hale, ryg og bov. Tørt hårlag samt tab af børster. Et gummiagtigt exudat på nakke og bov. Et utriveligt udseende. Efter 63 dage var de nævnte symptomer mere udtalte, og efter 77 dage døde 2 af de fire grise, der fik 0.06% æterekstraheret fedt i foderet. Disse udviste desuden: Nedsat tilvækst og foderudnyttelse, underudviklet fordøjelseskanal, en lille galdeblære med lidt eller ingen galde, forstørret skjoldbruskkirtel og hæmmet sexualudvikling. Tilsætning af 1.5% majsolie til foderet til de to resterende grise forbedrede tilvækst og i nogen grad, men ikke helt, de ovennævnte lidelser. Indholdet af linolsyre i foderet blev ikke analyseret i denne undersøgelse, men på grundlag af egne erfaringer, skønnes det, at linolsyren i foderet har udgjort 0.01–0.05% af bruttoenergien. De grise, der fik 0.12% æterekstraheret fedt, udviste ingen af de beskrevne ændringer.

Ved anvendelse af pattegrise, der var forløst ved kejsersnit (hysterectomi) og opdrættet uden kolostrum eller somælk på et foder indeholdende 0.14% linolsyre, fandt Hill et al. (1961) en nedsat tilvækst, rastløshed og en dødelighed på 32% (8 ud af 25 grise) ved 8 ugers alderen. Koncentrationen af dien- og tetraenfedtsyrer i hjerte- og leverlipider var reduceret. Der fandtes også andre læsioner, som imidlertid i et senere arbejde blev tilskrevet magnesiummangel (Hill et al., 1961). Senere er udført en del undersøgelser ofte med få grise, der snart har bekræftet, snart afkræftet andres undersøgelser. De forskellige egenskaber, der har været anvendt som mangelkriterium, samt effekten af en linolsyremanglende diæt, er vist i tabel 2.1. Det eneste mangelkriterium, som alle finder ændringer i, er 20:3,n-9/20:4,n-6 forholdet i plasma-, serum- eller vævslipider, der er forøget ved nedsat linolsyretilførsel. Det bør nævnes, at alle undersøgelser vedrørende EFA mangel hos grise er udført med linolsyrefattigt foder.

Kun få undersøgelser omhandler bestemmelse af behov for linolsyre, hvor de anvendte behovskriterier først og fremmest har været: Tilvækst, foderudnyttelse, hudlidelser, 20:3,n-9/20:4,n-6 forhold i plasma- og eller vævslipider. Disse undersøgelser tyder på, at behovet for linolsyre i foderet afhænger af grisenes alder ved fravænning, køn, race og det behovskriterium, der er anvendt. Behovet anføres at ligge mellem 0 og 2% af foderets energiindhold, hvor det dog ikke altid anføres, om det er brutto- eller omsættelig energi.

9.3 Materiale og metoder

Forsøgsdyr

Nærværende undersøgelse blev udført i 6 serier (B-C-D-E-G-H) med i alt 56 grise af dansk landrace, 24 sogrise (s) og 32 galte (b) fordelt som vist i Tabel 3.1. Gennem vækstperioden, som har varieret fra forsøg til forsøg, men totalt set dækker vækstintervallet 10–100 kg, har de fået forskelligt linolsyreindhold i foderet varierende fra 0.04 til 9.5% af bruttoenergien (energi% eller GE%). Gennem vækstperioden er der udført mellem 3 og 8 balanceperioder med hver gris omfattende bestemmelse af fordøjelighed af foderets næringsstoffer, kvælstof- og energibalancer samt luftskifte målt i respirationsforsøg. Som vist i Tabel 3.1 er der således udført i alt 272 balanceforsøg, hvoraf 162 er udført med galte og 110 med sogrise. Særlige studier over galdelipidernes sammensætning blev udført på 3 grise fra en anden forsøgsserie (Serie K), men disse grise har ikke været i balance- og respirationsforsøg.

I det følgende gives en kort beskrivelse af den generelle behandling af dyrene og derefter en kort beskrivelse af de enkelte forsøgsserier.

Generel behandling af forsøgsdyrene

Alle *grise* blev indkøbt i en produktionsbesætning med konventionelle grise, hvori der aldrig har forekommet PSE. Grisene blev udvalgt fra soens tredie eller senere kuld og blandt søer med 12–16 grise i kuldet. Derved sikredes en EFA status, der skønnedes at udgøre et repræsentativt produktionsgennemsnit. Grisene blev fravænnet mellem 5 og 8 uger, hvorefter de blev transporteret til Statens Husdyrbrugsforsøg, hvor forsøgene blev udført på Afdelingen for dyrefysiologi og biokemi. Ved ankomsten fik de kun lov til at drikke en elektrolytopløsning (50 g glukose, 5 g NaCl og 2.5 g $NaHCO_3$ pr. 1). Dagen efter fik de lidt foder bestående af byg, skummetmælkspulver, vitaminer og mineraler og efterhånden vand efter drikkelyst. Hvis der ikke opstod problemer med diarré, blev de vejet, overflyttet til enkeltstier, behandlet mod orm (1 g piperazinfosfat i foderet dagligt i 7 dage) og halothantestet.

Til undersøgelserne er kun anvendt halothannegative grise. Under narkosen blev grisene vasket på ben og bug med en 2% Neguvon® vet. metrifonat opløsning mod skab. De fik samtidig en intramuskulær injektion af 60 mg retinol, 0.5 mg cholecalciferol og 200 mg α-tocopherol, og der blev udtaget en blodprøve fra *vena cava* til fedtsyrebestemmelse. Når grisene vejede ca. 40 kg fik de en tilsvarende vitamininjektion som ovenfor. Grisene blev fordelt på de forskellige hold i henhold til kuld, vægt og køn og blev derefter gradvis tilvænnet forsøgsfoderet.

Vækstperioden blev opdelt i *balanceperioder* på 14 eller 21 døgn med en forperiode på henholdsvis 7 eller 14 dage og en opsamlingsperiode altid på 7 døgn. I opsamlingsperioden stod grisene i afdelingens balancebure, hvor der blev op-

samlet gødning og urin. I opsamlingsperiodens midterste døgn (4' døgn) blev grisene overflyttet til respirationskamre bygget efter det åbne princip. Behandling af foder-, fæces- og urinprøver, udførelse af fordøjeligheds-, balance- og respirationsforsøg var i overensstemmelse med afdelingens procedurer og er detaljeret beskrevet af Thorbek (1969; 1975).

Det var hensigten, at alle grise skulle have samme daglige mængder energi, protein, træstof, vitaminer og mineraler, men forskellige linolsyremængder. Det viste sig meget vanskeligt at få grisene til at æde et fedtfrit foder, hvor det er nødvendigt at anvende raffinerede eller ekstraherede foderkomponenter. Sådant et foder består karakteristisk af sukrose eller glukose, kasein, cellulose, vitaminer og mineraler. Som det kan ses i Tabel 3.2 er der anvendt forskellige komponenter i de forskellige serier. Den blanding, grisene helst åd, og som ikke gav fordøjelighedsforstyrrelser, var den blanding anvendt i Serie G og H bestående af 30% tapiokamel, 20% majsstivelse, 20% kartoffelmel, 20% kasein, 5% savsmuld og 5% vitamin- og mineralblanding. Som linolsyrekilde anvendtes sojaolie, der har et indhold af linol- og linolensyre, der minder meget om bygs indhold (se Tabel 3.4). Foderet indeholdt 14–16% fordøjeligt råprotein indtil ca. 60 kg legemsvægt, hvorefter det reduceredes til 10–12%.

Grisene blev fodret svagt i den første balanceperiode for at forebygge diarré. Derefter blev de fodret efter ædelyst, dog således at de skulle kunne æde op i løbet af 20 minutter. Den mængde, de åd i forperioden, blev brugt som udgangspunkt for fastsættelse af fodermængden i opsamlingsperioden, hvor den daglige fodermængde blev forøget med 20 g dagligt. Grisene blev fodret med hånd kl. 7 og kl. 15. De fik vand efter drikkelyst i forperioden, medens de i opsamlingsperioden fik afvejede vandmængder, der svarede til deres drikkelyst. Ovennævnte procedure anvendtes for at undgå foder- og vandrester i opsamlingsperioden.

De gennemsnitlige daglige foder- og vandmængder samt protein- og energimængder gennem vækstperioden for de enkelte forsøgsserier fremgår af Tabel 3.8–3.13. Det fremgår af disse tabeller samt af Figur 4.1 og 4.2, at alle grise på nær grisene på hold 2 i Serie B stort set har fået samme daglige mængde brutto (GE)- og omsættelig energi (ME) samt protein. Ved en fejl fik hold 2 i Serie B et ekstra tilskud af sojaolie på 90 g pr. kg foder svarende til en forøgelse af energiindtaget på 11% af GE og 7% af ME. Som følge af denne forøgelse fik de relativt mindre protein, hvorved energi/protein forholdet blev lidt større for dette hold end for de øvrige hold.

Den kemiske sammensætning af foderet og energi/proteinforholdet i foderet fremgår af Tabel 3.5 og 3.6. Figur 3.1 viser eksempler på det absolutte linolsyreindtag ved fodring med tre forskellige energikoncentrationer linolsyre gennem vækstperioden.

Den analytiske målesikkerhed på foder, fæces og urin har været af samme

størrelsesorden som fundet i forsøg med konventionelle foderblandinger, dog har træstofbestemmelserne i foder og navnlig i fæces været behæftet med større fejl, hvor der har været anvendt savsmuld.

Den statistiske behandling af materialet har dels omfattet regressionsanalyser udført på A/S Regnecentralen, København, dels varians- og covariansanalyser udført på NEUCC, Lyngby. Materialet er gjort op inden for de enkelte forsøgsserier og totalt.

De enkelte forsøgsserier

Den erfaring, der blev indhentet i én serie, blev brugt ved tilrettelæggelse af den næste serie, hvorfor forsøgsserierne ikke er gentagelser af hinanden.

Det er derfor nødvendigt at give en kort beskrivelse af de enkelte forsøgsserier.

Serie B blev udført med 8 galte fra 2 kuld, begge fra soens fjerde kuld grise. De var fravænnet ved 8 uger. Den første balanceperiode blev gennemført med en kommerciel svinefoderblanding. På grundlag af N-balancer og legemsvægte blev grisene fordelt på to hold. Hold 1 fik et grundfoder som vist i Tabel 3.2 indeholdende 0.4 energi% linolsyre, medens Hold 2 fik et ekstra tilskud på 90 g sojaolie pr. kg foder. Grisene blev fodret 112 dage (8 balanceperioder á 14 dage). I den sidste periode (Periode IX) var appetitten imidlertid stærkt reduceret, hvorfor resultaterne fra denne periode ikke er medtaget. Gris nr. 3 fra Hold 2 døde i forperioden til periode V. Ved obduktionen konstateredes lys, væskedrivende muskulatur (PSE). Disse grise var ikke blevet halothantestet, hvorfor det blev besluttet at teste samtlige forsøgsgrise, før de overgik til forsøgsfoder. Gris nr. 4 i Hold 2 havde foderrester i respirationskammeret i Periode II og VIII og er derfor ikke medtaget i disse perioder. Fodersammensætningen var tilfredsstillende vurderet ud fra grisenes ædelyst og gødningens konsistens. Der blev ikke observeret nogen tegn på EFA mangelsymptomer hos grisene i Hold 1.

Serie C. Da grisene på Hold 1 i Serie B fodret med 0.4 energi% linolsyre ikke viste tegn på EFA mangel og voksede tlfredsstillende på foderet, blev det besluttet at udføre Serie C med et såkaldt delvis syntetisk foder bestående af glukose, kasein, cellulose, vitaminer og mineraler, som vist i Tabel 3.2. Et sådant foder indeholder mindre end 0.05 energi% linolsyre og er oftest anvendt som grundfoder i forsøg over EFA mangel eller – behov både hos grise og rotter. Set ud fra et fysiologisk synspunkt er det imidlertid uheldigt på flere måder: Det indeholder ikke fedt, hvorfor det kan forventes at give en nedsat absorption af fedtopløselige vitaminer; det absorberes hurtigt fra fordøjelseskanalen, hvorved grisene hurtigt bliver sultne igen; det har en kraftig stimulering af insulinkoncentrationen i blodet; grisene bryder sig ikke om det. Det blev derfor besluttet at anvende to hold grise, Hold 1, der skulle fodres med det fedtfri grund-

foder, og Hold 2, der skulle have et tilskud af fedt som ikke indeholdt linolsyre. Oksetalg, som indeholder meget lidt linolsyre, blev anvendt i en mængde på 2.5%, der blev erstattet iso-energetisk med glukose. Hold 1 fik 0.04 og Hold 2 0.2 energi% linolsyre i foderet. Forsøget blev udført med 4 galte og 4 sogrise fra samme hold (soens 4'kuld) fravænnet ved 8 uger.

Der blev udført 3 balanceperioder á 14 dage (Per. II-IV) med grisene. I periode IV havde 2 grise på Hold 2 diarré og opspilet bug og måtte behandles medikamentelt. De blev derfor ikke sat i opsamlingsbure og udgik derfor af opgørelsen i denne periode. Da flere af grisene viste lignende symptomer, blev forsøget standset. Det viste sig, at cellulosens fordøjelighed varierede mellem 66 og 92%.

Da tilsætning af oksetalg ikke forbedrede ædelysten og bevirkede, at fæces klæbede fast til burene, så det var vanskeligt at opsamle fæces kvantitativt, blev det besluttet at udelade oksetalg i senere forsøg. Forholdet mellem 20:3,n-9 og 20:4,n-6 i plasmalipiderne fra disse grise viste klart, at der var tale om EFA mangel hos begge hold (se Figur 3.2), men der var ingen synlige tegn på mangel.

Serie D blev gennemført som et pilotforsøg med det formål at fodre tidligt fravænnede grise med fire forskellige linolsyreniveauer (0–3 energi%) indtil slagtevægt. Der blev anvendt 8 kuldsøskende, 4 galte og 4 sogrise, fra soens 3' kuld, fravænnet ved 6 uger (9.6–10.9 kg legemsvægt). Efter en uges forberedelse blev de fordelt på fire hold (0.3 – 1.0 – 2.0 – 2.7 energi% linolsyre). Grundfoderet var glukose og kasein som vist i Tabel 3.2, men cellulose blev erstattet med bøgesavsmuld. Efter fire balanceperioder (á 14 dage) begyndte en af grisene på Hold 4 at kaste op, og en gris på Hold 2 havde diarré. Grisene var meget ophidsede før fodring og var tilsyneladende sultne, men de kunne ikke æde op. Det blev derfor besluttet at standse forsøget. Det besluttedes at undlade et sådant ensidigt grundfoder i de kommende forsøg. Plasmalipidernes 20:3,n-9/20:4,n-6 forhold fra de fire hold er vist i Figur 3.2. Disse viser klart, at behovet for linolsyre med dette forhold som kriterium ligger på 0.8 energi%. De linolsyreniveauer, der skulle undersøges gennem hele vækstperioden, fra fravænning til slagtning, burde følgelig ligge mellem 0 og 3 energi%.

Serie E blev gennemført som et pilotforsøg til afprøvning af et foder bestående af tapiokamel, delvis hydrolyseret stivelse, glukose, kasein, bøgesavsmuld, vitaminer og mineraler, som vist i Tabel 3.2. Der blev anvendt 8 kuldsøskende, 4 galte og 4 sogrise fra soens 3' kuld fravænnet ved 6 uger. De blev fordelt på 4 hold, der fik henholdsvis 0.1, 0.8, 1.5 og 2.2 energi% linolsyre i ialt 8 balanceperioder á 14 dage (ialt 112 dage). Efter 47 dage på forsøgsfoderet døde sogrisen fra Hold 1 pludselig af tarmslyng. Da fordøjeligheden af foderets tørstof var 91%, fik samtlige grise 30 g pektin i foderet dagligt fra periode IV. Dette forbedrede gødningens konsistens. Efter 94 dage på forsøgsfoderet døde sogrisen i Hold 3. Ved obduktionen viste den tegn på PSE, men der var ingen

umiddelbar forklaring på dette fund. Grisen var halothannegativ og foderet indeholdt 48 mg α-tocopherylacetat pr. kg, hvilket var forventet og af samme størrelsesorden som hos de øvrige hold (36, 41 og 44 mg/kg). De to grise på Hold 4 havde beskadigede klove og kunne ikke sættes i balancebure i periode VII og VIII, men luftskiftet blev målt. Galten på Hold 3 havde slået sit venstre forben og kunne ikke stå i balanceburet i periode VIII. På grund af disse vanskeligheder med klove og ben var appetitten ikke så stor hos grisene. Der var ingen synlige tegn på EFA mangel.

Serie G. De tidligere forsøg viste klart, at foderets fordøjelighed var for høj (91–96%). De viste også, at linolsyreniveauerne skulle ligge mellem 0 og 3 energi%. Dermed var det givet, at forsøgsfoderet skulle bestå af meget fedtfattige eller linolsyrefattige fodermidler. En fodersammensætning på 30% tapiokamel, 20% majsstivelse, 20% kartoffelmel, 20% kasein, 5% bøgesavsmuld og 5% vitaminer og mineralblanding viste sig at have en fordøjelighed på 88% og et linolsyreindhold svarende til 0.2 energi%. Grisene åd foderet omend noget langsomt, især efter 60 kg levendevægt.

Serie G blev gennemført med 12 grise, 6 sogrise og 6 galte, fra to kuld. P.g.a. diarré var det nødvendigt at udskifte galtene fra det ene kuld med galte fra et andet kuld. Alle grise var fra soens 3' kuld fravænnet ved 5 uger. Grisene blev fordelt efter køn og kuld på tre hold, der fik henholdsvis 0.2, 1.1 og 2.1 energi% linolsyre, i ialt 5 balanceperioder (á 3 uger). Af tekniske årsager måtte opsamlingen udskydes 1 uge i periode III og IV for nogle af grisene. Gris nr. 9 (galt) i Hold 2 slog sit ben i respirationskammeret i periode III og kunne ikke måles hverken i denne periode eller i periode IV og V. Den anden galt i Hold 2 slog uheldigvis sit forben i periode V og måtte udgå af målingerne i denne periode. Efter 60–70 dage på forsøgsfoderet tabte den ene galt på Hold 1 en del børster på ryggen og havde en tør, »flækket« hud. Efter ca. 100 dage på forsøgsfoderet skete det samme hos de to sogrise på Hold 1. Der var intet at bemærke på de andre grise. Disse ændringer kan muligvis tilskrives det lave linolsyreindhold i foderet.

Serie H blev gennemført med samme grundfoder i Serie G og med 12 grise, 6 sogrise og 6 galte, fordelt på tre hold, der fik henholdsvis 0.7, 1.6 og 2.3 energi% linolsyre gennem 5 balanceperioder (á 3 uger). P.g.a. diarré blev der anvendt 3 galte og 3 sogrise fra et kuld (soens 5'kuld), 3 galte fra et andet kuld (soens 4' kuld) og 3 sogrise fra et tredie kuld (soens 4' kuld). Alle grise blev fravænnet ved 5–6 uger. Dette forsøg blev gennemført uden komplikationer. Appetitten svigtede lidt, da grisene vejede ca. 60 kg, men den forbedredes, da foderets proteinindhold blev reduceret.

Serie K blev udført med 3 kuldsøskende fravænnet ved 5 uger. De fik samme grundfoder som grisene i Serie G og H, men med henholdsvis 0.2, 1.2 og 2.3 energi% linolsyre. De blev aflivet efter 65 dage på dette forsøgsfoder. Galde-

blære med galde blev udtaget til bestemmelse af galdelipidmængde og -fedtsyresammensætning. Grisene havde ikke været i balance- eller respirationsforsøg.

9.4 Daglig tilvækst og foderudnyttelse

Figur 4.1 og 4.2 viser, at grisene i de forskellige serier stort set har fået samme daglige mængder brutto- (GE) og omsættelig (ME) energi i relation til legemsvægten, hvilket også var tilstræbt. Som nævnt fik Hold 2 i Serie B 90 g sojaolie ekstra svarende til et ekstra energiindtag på 11% bruttoenergi og 7% omsættelig energi i forhold til Hold 1. Tabel 4.1 viser, at den daglige foderoptagelse har ligget 0.1–0.2 FE_s over de danske normer for moderat fodring undtagen ved 20 kg, hvor foderoptagelsen har svaret til normen for moderat fodring.

Daglig tilvækst og foderudnyttelse (MJ, ME eller FE_s/kg tilvækst) blev korrigeret til samme vægt ved begyndelse og slutning af den pågældende vækstperiode i de forskellige serier. Disse resultater er vist i Tabel 4.2–4.7, medens de gennemsnitlige vækstkurver for de enkelte serier er vist i Figur 4.3. Middelværdier for daglig tilvækst og foderudnyttelse i de forskellige vægtklasser mellem 20 og 90 kg er beregnet for sogrise og galte fra samtlige forsøgsserier og vist i Tabel 4.8.

Resultater og konklusioner

1. De forskellige linolsyreniveauer fodret isoenergetisk og isonitrogent har ikke haft nogen systematisk indflydelse på tilvækst og foderudnyttelse.
2. Generelt har galtene haft en lidt lavere tilvækst og et lidt større foderforbrug pr. kg tilvækst end sogrisene.
3. I Serie G og H, hvor foderet bestod af tapiokamel, majsstivelse, kartoffelmel, kasein og bøgesavsmuld, voksede grisene (n = 22) gennemsnitligt 650 g om dagen beregnet for vækstperioden 15–80 kg. Det gennemsnitlige daglige foderforbrug var 32 MJ ME (ca. 2.6 FE_s) pr. kg tilvækst, hvilket tyder på en effektiv udnyttelse af foderet.
4. Grisene i Serie B, der fik henholdsvis 0.4 (Hold 1) og 9.5 (Hold 2) energi% linolsyre, hvor Hold 2 fik 7% mere omsættelig energi daglig gennem vækstperioden 20–90 kg, havde en gennemsnitlig daglig tilvækst på henholdsvis 756 og 860 g, hvor forskellen var signifikant ($P<0.01$). Der var imidlertid ikke signifikant forskel ($P>0.05$) i foderudnyttelse, der var på henholdsvis 35.4 og 33.8 MJ ME (2.9 og 2.8 FE_s) pr. kg tilvækst.
5. Variationen i daglig tilvækst og foderudnyttelse for hele materialet udtrykt ved variationskoefficienten (CV%) var henholdsvis 4.5 og 5% og ens for galte og sogrise.
6. Da de grise, der fik 0.04 og 2.7 energi% linolsyre i foderet, blev aflivet ved ca. 50 kg levendevægt, og der kun var én gris, der fik 0.1 energi% linolsyre,

som gennemførte hele vækstperioden til 90 kg, konkluderes det, at *grise af Dansk Landrace fravænnet ved 5 uger kan forventes at have maximal tilvækst og foderudnyttelse, hvis foderet blot indeholder 0.2 energi% linolsyre.*
Det er sandsynligt, at behovet er mindre, men sådanne lave linolsyrekoncentrationer forekommer kun i raffinerede eller stærkt fedtekstraherede fodermidler, som ofte vil have en negativ indflydelse på appetit og fordøjelse og dermed indirekte en negativ effekt på tilvækst og foderudnyttelse.

9.5 Fordøjelighed af næringsstoffer og energi

Fordøjeligheden af tørstof (DM), organisk tørstof (OM), kvælstof (N), N-frit ekstraktstof (NFE), råfedt (HCl + EE, dvs. Stoldt fedt), træstof (CF), bruttoenergi (GE) og fedtsyrer blev bestemt som foder-fæces differencer og er derfor i alle tilfælde udtryk for den tilsyneladende fordøjelighed.

Resultater og konklusioner

1. De forskellige linolsyreniveauer havde ingen signifikant ($P>0.05$) indflydelse på fordøjeligheden af DM, OM, N, NFE og GE. Fordøjeligheden blev heller ikke påvirket af »køn« og perioder (alder, vægt). Derimod havde basalfoderets sammensætning afgørende indflydelse på fordøjeligheden, som vist i Tabel 5.1 og 5.2. Fordøjelighedskoefficienterne lå mellem 88 og 98% bestemt med en relativ spredning på 0.7–2%. I alle tilfælde er de fundne fordøjelighedskoefficienter højere for forsøgsfoderet end for svinefoderblandinger i almindelighed.
2. Anvendelse af 2% oksetalg i foderet (Hold 2, Serie C) gav en signifikant lavere fordøjelighed af DM, OM og GE, en signifikant højere fordøjelighed af råfedt, men påvirkede ikke fordøjeligheden af N, CF og NFE. Resultaterne er vist i Tabel 5.2.
3. Fordøjeligheden af træstof varierede fra serie til serie afhængig af den anvendte træstofkilde.
   I Serie G og H, hvor der anvendtes bøgesavsmuld, blev der i 24 ud af 116 bestemmelser fundet mere træstof i fæces, end der havde været i foderet. Fordøjeligheden af træstof var 18% i de resterende tilfælde, men med så stor en variationskoefficient som 67%.
   I Serie B og C, hvor der blev anvendt cellulose, var fordøjeligheden af træstof henholdsvis 79 og 84% bestemt med en variationskoefficient på henholdsvis 9.6 og 11.9%. I begge tilfælde var fordøjeligheden større end forventet.
4. Indtag og fordøjelighed af råfedt bestemt ved æterekstraktion efter forudgående saltsyrehydrolyse (HCl + EE) er vist for de enkelte forsøgsserier i Tabel 5.3–5.7.
   Såvel fordøjeligheden som sikkerheden på bestemmelsen blev stærkt påvir-

ket af mængden af foderfedt. Generelt medførte et lille fedtindtag lavere fordøjelighedskoefficienter og højere variationskoefficienter end et højt fedtindtag. Dette tilskrives den endogene fedtudskillelse. I de forsøg, hvor foderet næsten har været fedtfrit, er der ikke fundet over 2 g fedt i fæces, hvilket svarer til en endogen fedtudskillelse på ca. 2 g pr. kg fodertørstof. I litteraturen anføres den endogene fedtudskillelse til 10–12 g pr. dag.

5. Fedtsyresammensætningen af fæceslipid og fordøjeligheden af fedtsyrer blev bestemt hos de grise, der fik 0.04, 0.4 og 9.5 energi% linolsyre i foderet (Tabel 5.8 og 5.9). Fæceslipid indeholdt en større mængde fedtsyrer ved det høje end ved det lave linolsyreindtag (52 vs. 34 mg/100 mg total lipid) og ligeledes mere linolsyre. Det er bemærkelsesværdigt, at fæceslipid også indeholdt linolsyre fra de grise, der kun fik 0.04 energi% linolsyre i foderet, men ikke palmitolsyre (16:1) og oliesyre (18:1). Det skyldes sandsynligvis, at linolsyre var inkorporeret i mikrober og derved havde undgået hydrogenering, hvorimod linolensyre, palmitolsyre og oliesyre er blevet hydrogeneret til stearinsyre (18:0) og palmitinsyre (16:0). Der fandtes ingen umættede fedtsyrer med 20 eller flere kulstofatomer i fæceslipid, heller ikke fra de grise, der fik det høje linolsyreindhold i foderet. Der fandtes fedtsyrer med et ulige antal kulstofatomer (15, 17 og 19) i fæceslipid fra alle ovennævnte grise, hvilket vidner om mikrobiel aktivitet ved alle linolsyreniveauer. Det forhold, at der udskilles mere linolsyre ved det høje linolsyreindtag, tyder dog på, at mere linolsyre undslipper hydrogenering ved et højt linolsyreniveau i foderet. Målingerne på metanproduktionen på de grise, der fik 0.4 og 9.5 energi% linolsyre, viste, at metanproduktionen var halveret hos de grise, der fik 9.5 energi% linolsyre i forhold til de grise, der fik 0.4 energi% linolsyre (se 9.7).
6. Alle grise havde galde i galdeblæren ved aflivning, hvilket dermed afkræfter de første fund på grise med EFA mangel beskrevet af Witz og Beeson (1951).

   Da grise ikke koncentrerer galden under opbevaring i galdeblæren (Kolb, 1967), er galdeblæregalden opsamlet til bestemmelse af galdelipidernes fedtsyreindhold og -sammensætning. På grundlag af galdesekretionens størrelse fundet af Sambrook (1978) i forsøg med grise fodret med et foder svarende til det her anvendte, er der foretaget beregninger over sekretion af galdelipid og galdefedtsyrer hos grise fodret med 0.2, 1.2 og 2.3 energy% linolsyre (Serie K). Resultaterne er vist i Tabel 5.10–5.12 og sammenholdt med fedtsyresammensætningen af plasmalipiderne fra de samme grise. Fedtsyrerne: 12:0, 20:3,n-6 og 22:4,n-6 forekom ikke i galdelipiderne. Forholdet 20:3,n-9/20:4,n-6 var af samme størrelsesorden eller større for galdelipider end for plasmalipider og viste klart, at de grise, der fik 0.2 energi% linolsyre var EFA deficiente, medens de grise, der fik 1.2 energi% linolsyre,

akkurat havde dækket behovet. Resultaterne viser også, at grisene på det lave linolsyreindtag udskiller ca. 8 g total lipid i galden dagligt, og til trods for at både plasma- og galdelipidernes 20:3,n-9/20:4,n-6 forhold indikerer EFA mangelstatus i kroppen, udskilles 249 mg linolsyre og 154 mg arakidonsyre med galden dagligt. Da der maximalt forekom 2 g fedt i fæces, og da arakidonsyre ikke blev fundet i fæceslipiderne, og disse kun indeholdt ca. 40 mg linolsyre, antages det, at en stor del af dette fedt og disse fedtsyrer er blevet reabsorberet og/eller anvendt som energikilde for mikroberne i blind- og tyktarm.

Resultaterne viser, at med stigende linolsyreniveau i foderet, stiger udskillelsen af fedt og fedtsyrer i galden, herunder også udskillelsen af de essentielle fedtsyrer, linolsyre og arakidonsyre.

7. Det konkluderes, at *grise af Dansk Landrace fravænnet ved 5 uger kan forventes at fordøje foderets næringsstoffer og energi tilfredsstillende, når foderet indeholder 0.2 energi% linolsyre i vækstperioden 10–100 kg.*

9.6 Kvælstofomsætningen

Kvælstofomsætningen blev målt i balanceforsøg gennem vækstperioden som beskrevet i 9.3. Kvælstofretentionen (RN) angiver forskellen mellem kvælstofindtag (IN) og kvælstof udskilt i fæces (FN) og urin (UN). Som omtalt i 9.5 havde de forskellige linolsyreniveauer ikke nogen signifikant effekt på fordøjeligheden af kvælstof, men fordøjeligheden af kvælstof varierede mellem serierne afhængig af basalfoderets sammensætning. Kvælstofudnyttelsen er derfor sat i relation til fordøjet kvælstof (DN) i stedet for kvælstofindtag. Effektiviteten af kvælstofudnyttelsen er udtrykt i procent (RN/DN × 100) og betegnet RN/DN,% eller blot RN/DN. Resultaterne er vist for de enkelte serier i Tabel 6.1–6.6. Kvælstofretentionen er også sat i relation til metabolisk legemsvægt.

Resultater og konklusioner

1. RN nåede et plateau ved 39 kg legemsvægt både for sogrise og galte i Serie C, hvor de to hold fik henholdsvis 0.04 og 0.2 energi% linolsyre i et såkaldt syntetisk foder bestående af glukose, kasein, cellulose, vitaminer og mineraler ± tilsætning af 2% oksetalg. P.g.a. fordøjelsesforstyrrelser blev dette forsøg standset ved ca. 50 kg levendevægt.
2. De forskellige linolsyreniveauer (0.2 – 0.7 – 1.1 – 1.6 – 2.1 – 2.3 energi%) fodret isoenergetisk og isonitrogent fra 15–80 kg levendevægt i Serie G og H (n = 116) havde ingen signifikant (P>0.05) effekt på RN/DN.
3. I Serie B, der kun omfattede galte, fik Hold 2 (9.5 energi% linolsyre) et ekstra tilskud af sojaolie svarende til 90 g pr. kg foder i forhold til Hold 1 (0.4 energi% linolsyre), der kun fik basalfoderet. Begge hold fik samme fordøjelige mængder kvælstof. Hold 2 aflejrede 1–3 g mindre kvælstof dagligt gen-

nem vækstperioden, hvilket dels tilskrives et højere energi/proteinindhold i foderet, dels tilskrives den relativt store sojaoliemængde i foderet, idet der er nyere undersøgelser, der viser, at $PGF_{2\alpha}$ stimulerer proteinsyntesen i muskelvæv, medens PGE_2 stimulerer proteolysen. De to prostaglandiner, der begge dannes ud fra arakidonsyre, kan derfor have forskellig effekt på proteinbalancen afhængig af, hvilken af dem der dannes mest af.

4. Sogrisene aflejrede signifikant ($P<0.001$) mere kvælstof end galtene gennem vækstperioden.
5. Der blev ikke fundet signifikant ($P>0.05$) vekselvirkning mellem perioder (tid på forsøgsfoder) og hold (linolsyreniveauer) eller mellem hold og »køn«.
6. De individuelt målte værdier for RN og de tilhørende metaboliske legemsvægte ($kg^{0.75}$) beskrev en kvadratisk funktion, hvorfra den maximale kvælstofaflejring blev beregnet. For galtenes vedkommende omfattede beregningerne dels alle serier (n = 162) og dels alle serier undtagen Serie B (n = 112). For hele materialet fandtes følgende funktioner:

Galte (n = 162):	$RN, g/d = 1.982\,kg^{0.75} - 0.0409\,kg^{1.50}$ med $RN_{max.}$ på 24.0 g ved 70.1 kg levendevægt (CV% = 16.6)
Galte (n = 112):	$RN, g/d = 1.904\,kg^{0.75} - 0.0409\,kg^{1.50}$ med $RN_{max.}$ på 22.6 g ved 66.5 kg levendevægt (CV% = 16.0)
Sogrise (n = 110):	$RN, g/d = 1.916\,kg^{0.75} - 0.0351\,kg^{1.50}$ med $RN_{max.}$ på 26.1 g ved 82.2 kg levendevægt (CV% = 15.4)

Den maximale kvælstofaflejring var 2.1–3.5 g større for sogrise end for galte, og sogrisene nåede maximum senere (ved 82.2 kg) end galtene (66–70 kg). Funktionerne er vist grafisk i Figur 6.1.

7. RN/DN var 55–71% hos galte og 58–69% hos sogrise ved 20–30 kg levendevægt og faldt til 36–48% hos galte og 43–52% hos sogrise ved 80 kg levendevægt. Disse værdier er lidt højere end fundet i forsøg med grise af Dansk Landrace fodret med traditionelle svinefoderblandinger.
8. *Behovet for linolsyre til maximal kvælstofaflejring til svin af Dansk Landrace fravænnet ved 5 uger er 0.2 energi% i vækstperioden 15–90 kg.* Mindre koncentrationer i foderet vil sandsynligvis hæmme kvælstofaflejringen. Høje linolsyrekoncentrationer i foderet, svarende til 9.5 energi% (90 g sojaolie pr. kg foder) kan tilsyneladende også hæmme kvælstofaflejringen. Det ser derfor ud til, at der er et optimalt linolsyreniveau m.h.t. kvælstofaflejring, der på grundlag af nærværende undersøgelser anslås til at ligge mellem 0.2 og 9.5 energi%.

9.7 Energiomsætningen

Energiomsætningen blev målt i balance- og respirationsforsøg som beskrevet i 9.3. De enkelte led i energibalancen fremgår af Figur 7.1. Foderets omsættelighed (ME/GE) og udnyttelsen af omsættelig energi til total energiaflejring (RE) og energi aflejret i protein (RPE) og fedt (RFE) samt varmeproduktionen bestemt på grundlag af kvælstof- og kulstofbalancerne (HE,CN) er vist for de enkelte serier i Tabel 7.2.1 – 7.2.11. Luftskiftet (liter ilt optaget og liter kuldioxid produceret) samt metanproduktionen i de enkelte forsøgsserier fremgår af Tabel 7.3.1 – 7.3.6. Varmeproduktionen målt på grundlag af luftskiftet (HE/RQ) blev beregnet for hele materialet og sammenlignet med varmeproduktionen bestemt efter CN-metoden. Disse resultater er vist i Tabel 7.4.1. Resultaterne fra energimålingerne er beregnet ved hjælp af regressionsanalyser udført på A/S Regnecentralen som beskrevet af Henckel (1973) og i overensstemmelse med den procedure, der normalt anvendes ved Dyrefysiologisk Afdeling. Desuden er resultaterne behandlet i variansanalyser på NEUCC, Lyngby, ved hjælp af ANOVA og GLM procedurer som beskrevet af Freund og Littell (1981) til vurdering af effekten af linolsyreniveau (hold), »køn« og vekselvirkning mellem linolsyreniveau og »køn«.

Resultater og konklusioner

1. De forskellige linolsyreniveauer mellem 0.04 og 2.7 energi% fodret isoenergetisk og isonitrogent medførte samme omsættelighed af foderets bruttoenergi udtrykt ved ME/GE. ME/GE var højest (92%) for foderet baseret på glukose og kasein og lavest (86%) for foderet baseret på tapiokamel, majsstivelse, kartoffelmel og kasein. ME blev bestemt med en relativ spredning (CV%) på 1–2%.
   Energi i fæces (FE) og urin (UE) udgjorde ret konstant henholdsvis 2–11% og 2–3% af foderets bruttoenergi gennem vækstperioden.
   Energitabet i metan (CH_4E) udgjorde ca. 0.5% af GE ved 30 kg levendevægt stigende til ca. 1% ved 90 kg levendevægt. Tilsætning af 90 g sojaolie til basalfoderet (Serie B) reducerede metanproduktionen signifikant ($P<0.001$), hvorimod 20 g oksetalg pr. kg foder ikke havde nogen effekt på metanproduktionen. Der er således fundet samme depressive effekt af polyumættede fedtsyrer på den mikrobielle aktivitet i fordøjelseskanalen hos grise som er kendt fra drøvtyggere.
2. De forskellige linolsyreniveauer mellem 0.1 og 2.7 energi% havde samme effekt på luftskiftet og varmeproduktionen.
   I Serie C, hvor grisene fik 0.04 og 0.2 energi% linolsyre, var iltoptagelsen pr. kg metabolisk legemsvægt lavere end i de andre serier, hvor grisene fik samme eller større linolsyreniveauer. Dette tilskrives de fordøjelsesforstyrrelser, som forekom i dette forsøg.

I Serie B havde de grise, der fik 9.5 energi% linolsyre (Hold 2), en højere iltoptagelse end de grise, der fik 0.4 energi% (Hold 1), men varmeproduktionen var ikke signifikant forskellig (P>0.05).

For at kunne sammenligne de opnåede resultater med resultater fra andre forsøg blev iltoptagelse, kuldioxidproduktion samt varmeproduktion både efter CN-metoden og RQ-metoden beregnet i relation til metabolisk legemsvægt. Følgende sammenhænge blev fundet:

	Galte (n = 162)	*Sogrise (n = 110)*
CO_2,liter/24h:	$71.7 + 33.7kg^{0.75}$	$43.7 + 35.9kg^{0.75}$
O_2,liter/24h:	$143.6 + 27.6kg^{0.75}$	$81.3 + 32.8kg^{0.75}$
HE(CN),kJ24h:	$2998 + 545kg^{0.75}$	$2113 + 332kg^{0.75}$
HE(RQ),kJ/24h:	$2714 + 607kg^{0.75}$	$1562 + 704kg^{0.75}$

For alle ligningerne var forskellen mellem galte og sogrise stærkt signifikant (P<0.001), og intercepterne var signifikant forskellige fra nul (P<0.001).

Galtene brugte mere ilt, producerede mindre kuldioxid og producerede mere varme end sogrisene indtil 30 kg levendevægt, hvorefter situationen var omvendt. Disse resultater er vist grafisk i Figur 7.4, 7.5 og 7.6. Det antages, at forskellene skyldes, at kastrationseffekten først slår igennem ved ca. 30 kg.

3. Målinger af HE (RQ) gav systematisk større værdier end målinger af HE (CN). Ved 20 kg var forskellen 3.7% for galte og 3.3% for sogrise, men ved 80 kg var forskellene henholdsvis 7.8 og 9.4%. Disse forskelle tilskrives primært foderets linolsyreindhold, idet linolsyren, der i vid udstrækning aflejres i fedtdepoterne ikke indeholder 76.7% kulstof som forudsat i de fastlagte beregninger af HE (CN), men kun 73% kulstof.
4. Den respiratoriske kvotient (RQ = 1 CO_2/1 O_2) var mindre end 1.0 i første balanceperiode i næsten alle forsøgsserier, hvilket fortrinsvis skyldes, at grisene blev fodret restriktivt i denne periode for at nedsætte risikoen for diarré.

   I Serie B var RQ for de grise, der fik 90 g sojaolie pr. kg foder (Hold 2), mindre end 1.0 indtil ca. 60 kg levendevægt, hvilket tyder på en relativt større oxidation af foderfedt end syntese af fedt ud fra kulhydrat.
5. Aflejret energi (RE) udgjorde 18 og 25% af ME for henholdsvis galte og sogrise ved 15–20 kg levendevægt og 44 henholdsvis 43% af ME ved 75–85 kg levendevægt. Der blev således aflejret procentvis mere energi ved anvendelse af forsøgsfoderet end ved anvendelse af traditionelt svinefoder.
6. Galtene aflejrede 61–68% af RE i protein ved 20 kg levendevægt faldende til 16–27% ved 80 kg. De tilsvarende værdier for sogrisene var henholdsvis 54–83% og 21–28%.

7. Galtene i Hold 2, Serie B, der fik 90 g sojaolie pr. kg foder ekstra i forhold til galtene i Hold 1, aflejrede 40 g mere fedt dagligt gennem vækstperioden 25–90 kg, hvilket både skyldes en lavere kvælstofaflejring og en højere fedtaflejring.
8. Den gennemsnitlige udnyttelsesgrad af ME til energiaflejring (k_g) blev bestemt som en lineær funktion af omsættelig energi til rådighed for vækst (ME_g), hvor $ME_g = ME - ME_m$ og ME_m (ME til vedligehold) = 4060 + 210 $kg^{0.75}$ (Thorbek og Henckel, 1976). K_g var 69% for galte (n = 162) og 64% for sogrise (N = 110) og forskellen var stærkt signifikant ($P<0.001$).
9. Multiple regressioner omfattende alle målinger af ME_g, RPE og RFE for galte (n = 162) og sogrise (n = 110) viste følgende sammenhænge: For galte: ME_g,kJ = 1.83 RPE,kJ + 1.30 RFE,kJ og for sogrise: ME_g,kJ = 1.92 RPE,kJ + 1.36 RFE,kJ, hvilket viser, at udnyttelsesgraden af ME til proteinaflejring (k_p) var 55% for galte og 52% for sogrise, medens udnyttelsesgraden af ME til fedtaflejring (k_f) var 77% for galte og 74% for sogrise. Disse værdier svarer til et behov på 43.6 og 45.5 kJ ME til aflejring af 1 g protein hos henholdsvis galte og sogrise og 51.6 og 54.0 kJ ME til aflejring af 1 g fedt hos henholdsvis galte og sogrise. Disse beregninger er dog baseret på samme ME_m for galte og sogrise, hvilket diskuteres.
   Fra et biokemisk synspunkt koster det mindre energi i form af ATP at syntetisere fedt *de novo* på grundlag af kulhydrat. K_p og k_f blev beregnet for Serie B, hvor Hold 1 fik basalfoder uden fedttilskud, medens Hold 2 fik et tilskud på 90 g sojaolie pr. kg foder, for at se, om der var forskelle i udnyttelsesgraden af den omsættelige energi. For Hold 1 var k_f 80%, medens den for Hold 2 var 77%, og k_p var henholdsvis 57 og 63%, men forskellene var ikke statistisk sikre ($P>0.05$).
10. *Hos grise af Dansk Landrace fravænnet ved 5 uger er behovet for linolsyre til opretholdelse af normal energiomsætning gennem vækstperioden dækket, hvis foderet indeholder 0.2 energi% linolsyre.*

9.8 Sammenfattende konklusion vedrørende behovet for linolsyre

På grundlag af i alt 272 fordøjeligheds-, kvælstof- og kulstofbalanceforsøg samt 272 luftskiftemålinger udført i respirationskamre (162 målinger på galte og 110 målinger på sogrise) med i alt 56 grise af Dansk Landrace (32 galte og 24 sogrise), der er fodret med forskellige linolsyreniveauer fra 0.04 til 9.5% af foderets bruttoenergiindhold (energi%) konkluderes følgende:

1. Behovet for linolsyre til sikring af maximale niveauer for daglig tilvækst, foderudnyttelse, fordøjelighed af næringsstoffer, protein- og energiomsætning hos svin af Dansk Landrace fra fravænning ved 5 uger eller mere og til slagtning ved 90–100 kg levendevægt er 0.2% af foderets bruttoenergi. Med et indhold af omsættelig energi på 78% som fundet i gennemsnit for kom-

mercielle svinefoderblandinger, svarer behovet til 0.26% af foderets omsættelige energi. Denne linolsyrekoncentration vil sandsynligvis forefindes i alle naturligt forekommende fodermidler til svin, men ikke i raffinerede eller stærkt fedtekstraherede fodermidler.

2. Fedtsyresammensætningen af plasma- og galdelipider viser imidlertid, at behovet for linolsyre til andre biologiske funktioner er større end 0.2 energi%. Det er derfor nødvendigt at undersøge andre biologiske og produktionsøkonomiske parametre, før det endelige linolsyrebehov kan fastlægges.

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