PROTEIN AND FAT DEPOSITION IN PIGS IN RELATION TO BODYWEIGHT GAIN AND FEEDING LEVEL

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(with a summary in Dutch)

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN
DE LANDBOUWWETENSCHAPPEN, OP GEZAG VAN DE
RECTOR MAGNIFICUS, PROF. DR. IR. H. A. LENIGER,
HOOGLERAAR IN DE TECHNOLOGIE,
IN HET OPENBAAR TE VERDEDIGEN OP WOENSDAG
11 DECEMBER 1974 DES NAMIDDAGS TE VIER UUR
IN DE AULA VAN DE LANDBOUWHOGESCHOOL
TE WAGENINGEN

H. VEENMAN & ZONEN B.V. - WAGENINGEN - 1974

STELLINGEN

I

Bij de vergelijking van groei, voederverbruik en slachtkwaliteit wordt vooral door genetici te weinig rekening gehouden met verschillen in voeropname.

Dit proefschrift

II

Indien de selectie op vleesproductiegeschiktheid bij varkens wordt gebaseerd op groeiresultaten over een constant gewichtstraject, verdient het geen aanbeveling de dieren onbeperkt voer te verstrekken.

Dit proefschrift

III

Door voorlichtingsdiensten, werkzaam op het gebied van de varkenshouderij, wordt het gescheiden mesten van borgen en gelten onvoldoende gepropageerd.

Dit proefschrift

IV

Verhoging van het vleespercentage bij varkens kan wellicht zonder ernstige, nadelige gevolgen voor de vleeskwaliteit geschieden door vermindering van de spekdikte.

V

Het is noodzakelijk dat strenger wordt toegezien op de behandeling van slachtvarkens vòòr het bedwelmen, en op het correct doorvoeren van de bedwelming.

HOENDERKEN, R. : Electrische bedwelming van slachtvarkens.
I. V. D. O. -Rapport H 743 (1974).

VI

Het ontwikkelen van technieken om in de Nederlandse varkenshouderij op practijkschaal gebruik te kunnen maken van diepvriessperma, is te kostbaar.

VII

Bij de discussies over een beperking van de vleeskalverenproductie wordt te weinig aandacht besteed aan alternatieven voor de bij deze productietak betrokken partijen.

VIII

De voorlichting over de mogelijkheden om etensresten te voeren aan honden en katten, is onvoldoende.

IX

In publicaties over de relaties tussen bloedgroepen en productiekenmerken bij landbouwhuisdieren wordt vaak onvoldoende aandacht besteed aan de geringe verwachtingswaarde van dergelijke relaties ten aanzien van de toepasbaarheid voor de fokkerij.

X

De afstammingscontrole van varkens levert geen positieve bijdrage aan de fokkerij.

XI

Het aantal nascholingscursussen voor zoötechnici moet aanzienlijk worden uitgebreid.

W. A. G. Cöp
Wageningen, 11 december 1974

VOORWOORD

Het onderzoek dat in deze dissertatie is beschreven werd uitgevoerd in het Laboratorium voor Veeteeltwetenschappen van de Landbouwhogeschool te Wageningen, met financiële steun van de Researchgroep voor Vlees en Vleeswaren T.N.O.

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DR. A. JUST NIELSEN, Laboratory of Physiology in Copenhagen, provided additional data, that were used for the computation of bodyweight gain, feed intake, energy and N balances, and chemical composition of the empty body of each pig. These data gave an essential contribution to this investigation.

De heren J. STELWAGEN, P. N. DE GROOT, J. H. WALLINGA en W. J. KOOPS wil ik in het bijzonder danken voor hun enthousiaste medewerking bij het verzamelen en verwerken van de gegevens.

Het typewerk werd verricht door Mevr. P. ROZENDAAL-PENNINGS van de afdeling Tekstverwerking van de Landbouwhogeschool en door Mej. M. A. VAN GINKEL.

De figuren zijn verzorgd door de heer W. HEIJE.

De Engelse tekst is gecorrigeerd door Mevr. E. BROUNS-MURRAY.

CONTENTS

USED ABBREVIATIONS / LIJST MET AFKORTINGEN

A	ash / *as*
c	metabolizable energy (kcal) for 1 g protein deposition / *beschikbare energie (kcal) nodig voor de aanzet van 1 g eiwit*
cm	castrated males/*borgen*
d	metabolizable energy (kcal) for 1 g fat deposition / *beschikbare energie (kcal) nodig voor de aanzet van 1 g vet*
Δ	change in a trait during a certain weight range or a time interval / *verandering van een kenmerk over een bepaald gewichts- of tijdstrajekt*
D	gut fill / *darminhoud*
DE	digested energy / *verteerde energie*
EB	energy balance, energy retention, net energy for production / *energiebalans*
f	females/*gelten*
F	fat / *vet*
GE	gross energy / *bruto energie*
H	water / *water*
K	ratio *LBM* to protein / *LBM-eiwit verhouding*
$kg^{3/4} = W^{3/4}$	metabolic weight / *metabolisch gewicht*
LBM	lean body mass (bodyweight minus gut fill and fat) / *levend gewicht min darminhoud en vet*
L_E	empty bodyweight (bodyweight minus gut fill) / *levend gewicht min darminhoud*
m	males/*beren*
M	protein + water / *eiwit + water*
ME	metabolizable energy / *beschikbare energie*
ME_M	metabolizable energy for maintenance / *beschikbare energie nodig voor onderhoud*
ME_P	metabolizable energy for production / *beschikbare energie voor productie*
N	nitrogen / *stikstof*
P	protein / *eiwit*
P/PW	ratio protein to protein + water / *eiwit-eiwit + water verhouding*
PWF	protein + fat + water / *eiwit + vet + water*
t	age (days) / *leeftijd (dagen)*
W	bodyweight / *levend gewicht*

1. INTRODUCTION

The main aim of pig breeding is to produce meat with the difference between returns and costs as great as possible. The factors which determine this difference occur in three stages: costs of producing pigs for fattening, costs during the fattening period and the price received for the fattened pigs.

The cost price of weaned pigs is determined mainly by the number of pigs weaned per litter. The suitability of these pigs for fattening is mainly determined by the factors bodyweight gain, feed conversion and carcase traits. With index selection all three factors can be improved simultanously (STANDAL, 1970; WHITE, 1970). HAZEL (1943) described the theoretical background needed to construct such an index. HAZEL and LUSH (1942) have shown that generally a simultaneous selection for various traits is most efficient when index selection is used. When using an index it is assumed that the genetic and phenotypic parameters are determined or known without error (cf. CUNNINGHAM, 1969; FOWLER et al., 1973). However the value of the phenotypic correlation coefficient between daily bodyweight gain and feed conversion ranges between –0.4 and –0.9, according to OWEN and MORTON (1969). Also the values of the phenotypic correlation coefficient which are found between daily gain and carcase traits and between feed conversion and carcase traits range between –0.2 and 0.2. These values have been found by FLOCK (1968), METZ and POLITIEK (1969) and WALSTRA (1974).

It is obvious that the variation in the values found for these correlation coefficients is caused by genetic differences or differences in feeding level. Moreover it has been pointed out that the effects of housing and microclimate can be mainly related to differences in feeding level (KLEIBER, 1961; VERSTEGEN and VAN DER HEL, 1974). Furthermore these values of the phenotypic correlation may differ because the chemical composition of prime cuts of the carcase may be different at the same weight of these cuts (VAN LOGTESTIJN, 1969).

The significance of this chemical composition for the values of the correlation coefficients between daily gain, feed conversion and carcase traits becomes clear when fatty tissue and muscle tissue are considered. Deposition of fat will cost about 3 times more energy per gram than deposition of 1 g muscle tissue (mainly protein + water). Therefore if feeding level and chemical composition of the carcase are taken into account, there should be less variation in the values of correlation coefficients between the parameters connected with gain, feed conversion and carcase traits.

KIELANOWSKI (1968) and FOWLER et al. (1973) concluded that the main aim of pig breeding is that from a given amount of feed the maximum of protein and the minimum of fat should be deposited. However also other traits should be included in the aim of breeding. Protein should not only be efficiently produced but should deposited in certain parts of the carcase and its relation to fat should be optimum.

The amount of protein deposited is important because of its relation to bodyweight gain on the one hand and the economics of bodyweight gain and amount of muscle tissue on the other. Fat deposition is of great importance because the correlation coefficient between intermuscular and intramuscular fat and backfat thickness is small (DUNIEC et al., 1961; SCHIERBAUM, 1961; JUST NIELSEN, 1973). An unfavourable correlation exists between economics of daily bodyweight gain and fat deposition. KOTARBINSKA (1968) and VAN ES (1970) found that 1 g protein deposited increased the bodyweight by 4.3 and 3.6 g, respectively. Bodyweight gain increased by 0.6 g when 1 g fat was deposited, according to VAN ES (1970). KIELANOWSKI (1966) investigated the change in feed conversion of the Danish Landrace pig between 1926 and 1963. He found that 75–80% of the change in feed conversion was caused by the increase of daily protein deposition. OSLAGE (1965) concluded from his experiments that protein deposition is directly related to the increase in weight of active body tissues e.g. muscle tissue.

If protein and fat deposition are to be included in the aim of breeding then data about these traits must be collected by routine or simply calculated. Investigations by KIELANOWSKI (1966), KOTARBINSKA (1969) and CLOSE (1970) with pigs and by VAN ES (1970) with veal calves showed that protein and fat deposition can be computed from daily bodyweight gain, bodyweight and feed intake.

The purpose of this investigation was:

- to find out how precisely protein and fat can be predicted from bodyweight gain, bodyweight and feed intake;
- to study the variation in protein and fat deposition at restricted and ad libitum feeding and the relation between these traits, growth and carcase traits.

These investigations were part of a project that was set up to study the relationship of gain, feed conversion and carcase traits with various slaughter weights of pigs fed ad libitum.

2. LITERATURE

In the literature there are many reports on protein and fat deposition in pigs. Some of the studies are based on data from chemical analysis of the empty body. But most of the studies deal with protein and fat deposition determined from energy and N balances. The calculation of the protein and fat from the gain and feeding level is in fact based on energy balance data. Therefore in this chapter aspects of the following topics will be reviewed:

- energy metabolism in pigs;
- the course in protein and fat deposition in relation to bodyweight;
- methods to calculate protein and fat deposition.

2.1. ENERGY METABOLISM IN THE PIG

The feed given to a pig (gross energy = *GE*) is digested in the intestinal tract. The energy remaining after subtracting energy in the faeces is called apparently digested energy (*DE*). A small part of *DE* leaves the body with the urine or gases (about 3% in pigs). The remainder is called metabolizable energy (*ME*). This *ME* is retained partly as protein and fat stored in the body and partly dissipated as heat. Energy stored in protein and fat is called net energy for production, energy retained or energy balance (= *EB*). Part of the energy produced as heat originates from maintenance (maintaining homoiothermia, activity etc.) and from the production of protein and fat. The ratio between energy balance and metabolizable energy used for production is called efficiency.

The partial efficiency for protein and fat deposition can be defined in the same way as the efficiency for *EB*.

In Figure 2.1 the use of metabolizable energy as parameter of feed intake for a growing pig is given (cf. KIELANOWSKI, 1972).

The data in this figure are given for a pig weighing 50 kg and gaining 700 g a day. Deposition of protein, fat and water are 120 g, 200 g and 380 g, respectively. According to KOTARBINSKA (1969), the maintenance requirement is assumed to be 100 kcal *ME* per $kg^{3/4}$ and per g protein and per g fat 16 and 13 kcal *ME*, respectively, are needed.

VAN ES (1972) extensively reviewed about maintenance requirement in farm animals. Maintenance is defined as the amount of *ME* needed at zero level of production, when the animal is in energy equilibrium. In the literature the maintenance requirement in the zone of thermoneutrality has been estimated at 70–120 kcal $ME/kg^{3/4}$ (VAN ES, 1972)[1]. Maintenance requirement seems to decrease with increasing bodyweight. The estimations of maintenance in some investigations were in kcal $ME/kg^{3/4}$, 108 (BREIREM, 1935), 123 (LUND, 1938),

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[1] Energy will be expressed in kcal. When converting into kJ: 1 kcal is 4.184 kJ.

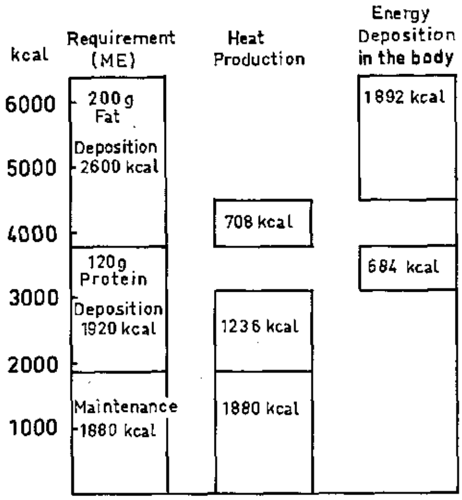

FIG. 2.1. Energy balance of a growing pig.

104 (LUDVIGSEN and THORBEK, 1955), 123 (VERSTEGEN, 1971) (cit. VERSTEGEN et al., 1973), 109 (VERSTEGEN et al., 1973) and 103 to 112 (VERSTEGEN and VAN DER HEL, 1974). To calculate these maintenance requirements, the conversion of metabolizable energy for production (ME_P) into production (EB) was assumed to be 0.7. The efficiency for protein synthesis is considered to be less than that for fat synthesis. This is probably partly caused by protein turn-over in growing animals (VAN ES, 1974). According to BREIREM and HOMB (1972), the mean of the efficiency for protein synthesis is 0.44 and for fat synthesis 0.74. In growing animals, 60–85% of the energy balance (EB) is fat and therefore according to BREIREM and HOMB (1972) it is justifiable to use one efficiency figure for energy deposition. When animals are housed *below* thermoneutrality, the partial efficiency of extra ME is 1 (VERSTEGEN et al., 1973). From their investigations they found the following equation for pigs housed at 8 °C (below thermoneutrality)

$$EB/kg^{3/4} = 0.994\ (\pm\ 0.04)\ ME/kg^{3/4} - 186.2\ (\pm\ 12.4).$$

2.2. DEPOSITION OF PROTEIN AND FAT IN GROWING PIGS

2.2.1. *Daily protein and fat deposition*

HÖRNICKE (1960) has extensively reviewed the studies on the relation between chemical composition and bodyweight published before 1960. After 1959 some more investigations on chemical composition of the carcase were done. The aim of these studies was to find suitable parameters for selection in pigs and to describe the functional relationships between carcase composition and change in bodyweight (HÖRNICKE, 1960; KOTARBINSKA, 1969). In addition the carcases of pigs were analysed chemically so that the results of energy and N balances could be better interpreted (e.g. OSLAGE 1962, 1963a, b, 1964; SCHIEMANN et al., 1962; KOTARBINSKA and KIELANOWSKI, 1969; JUST NIELSEN, 1970). Also data about protein and fat deposition in growing pigs during respiration trials were collected by JUST NIELSEN (1970), THORBEK (1969), FARRIES et al. (1968) and others.

In Figure 2.2 (HÖRNICKE, 1960) the changes in chemical composition in relation to bodyweight are given. This figure shows that the content of ash and protein hardly change with bodyweight. The changes in chemical composition with increasing bodyweight seem to be brought about mainly by the replacement of water by fat.

According to investigations made by LUND (1938), SMITH (cited by OSLAGE, 1962), JESPERSEN (1952), FARRIES et al. (1968) and FULLER and BOYNE (1971), daily protein deposition increases in the first half of the fattening period and decreases in the second half. The first 3 authors mentioned found most daily protein deposited at 60–80 kg, while FARRIES et al. (1968) found that the highest protein was retained at 40–60 kg bodyweight. In the investigations reported by OSLAGE and FLIEGEL (1965), THORBEK (1969), HOMB (1972) and WENK and SCHÜRCH (1974), the protein synthesis is maximum at 40–60 kg. The deposition is then about constant up to 100–120 kg bodyweight. OSLAGE (1962) and PIATKOWSKI and JUNG (1966) found a continuous increase in protein deposition between 30 and 110 kg bodyweight. LUDVIGSEN and THORBEK (1955) and JUST NIELSEN (1970) found a constant increase in protein deposition in females, and FARRIES and KALLWEIT (1969) showed the same in males. OSLAGE (1962), FARRIES et al. (1968) and GÄDEKEN (1971) state that the change in protein deposition over the last decades has been caused by selection for increase in bodyweight and muscle gain. According to OSLAGE (1965), this selection has led to a pig which matures later so that the decrease of growth-intensity is reduced and therefore the decrease in protein deposition occurs at a higher bodyweight. This theory can also explain the results obtained by FARRIES et al. (1968) with the Piétrain pigs. This breed matures earlier than the breeds used in the other

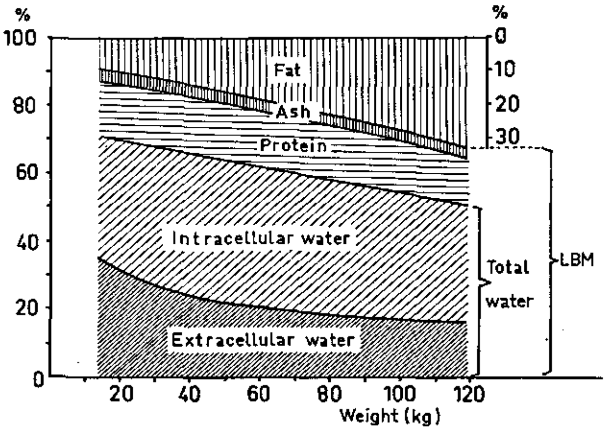

FIG. 2.2. Chemical composition of pigs at different weights.

studies. The Piétrain is a meat-type pig whose daily bodyweight gain decreases from about 60 kg onwards because of a low feed intake. The moment, at which the daily protein deposition is highest also depends on sex. This point is reached at a lower weight in castrated males than in females. Daily protein deposition is highest in males and goes on to a higher bodyweight (LUDVIGSEN and THORBEK, 1955; FARRIES and KALLWEIT, 1969; JUST NIELSEN, 1970; PEDERSEN, 1973).

Fat deposition continues to increase from 100 g at 20–25 kg bodyweight, to 300–400 g at 100–120 kg bodyweight (OSLAGE, 1962; OSLAGE and FLIEGEL, 1965; KOTARBINSKA, 1968; THORBEK, 1969; JUST NIELSEN, 1970). The increase in fat deposition depends on feeding level. The relation between the protein and fat deposition, and bodyweight for data found in the literature is given in Figure 2.3.

The differences in the protein and fat deposition in relation to bodyweight

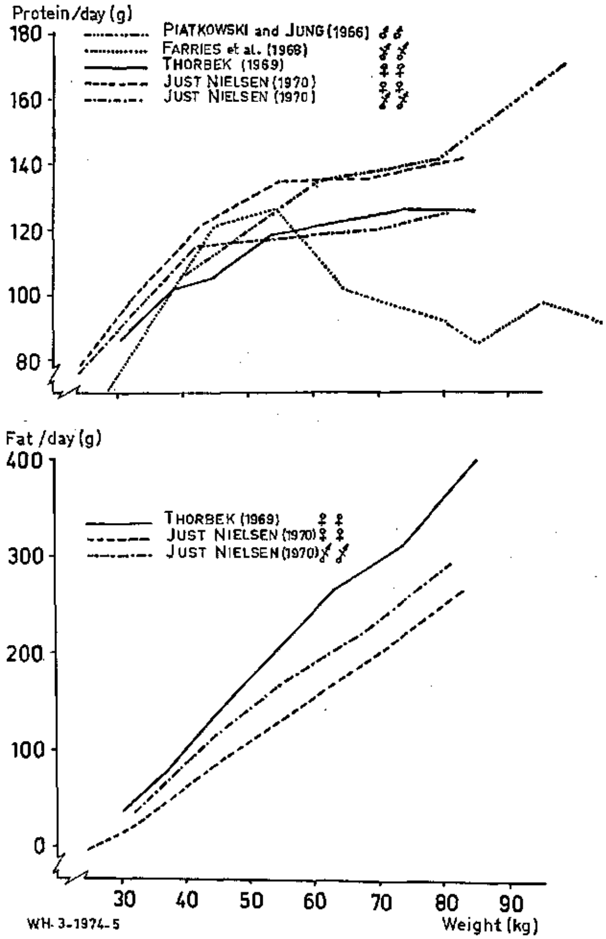

FIG. 2.3. Daily protein and fat deposition in relation to weight.

are clearly illustrated by the increase of the energy balance during the fattening period. From the results of energy and N balances, it is clear that the increase in energy balance from 500–1000 kcal at 25 kg to 3000–4000 kcal at 100 kg can almost completely be attributed to the increase in fat deposition (THORBEK, 1969; JUST NIELSEN, 1970; WENK and SCHÜRCH, 1974).

2.2.2. *Factors influencing protein and fat deposition*

2.2.2.1. Breed

A number of investigators have studied the differences in protein and fat deposition between breeds, and especially at about 100 kg bodyweight (SCHMIDT et al., 1933; PIATKOWSKI and JUNG, 1966; FARRIES et al., 1968; FARRIES and ANGELOWA, 1968),

SCHMIDT et al. (1933) found that pigs at 100 kg and 150 kg bodyweight and belonging to Improved German Landrace and German Yorkshire, had a highter N content then Berkshire and 'Weideschwein' pigs. Fat deposition increased for every 2 breeds by 2–3% in the order: Improved German Landrace, German Yorkshire, Berkshire and 'Weideschwein'. Fat content at 100 kg bodyweight ranged between 33.7% in Improved German Landrace and 50.3% in the 'Weideschwein' pigs. PIATKOWSKI and JUNG (1966) investigated Improved German Landrace, British Landrace and crosses between German and Swedish Landraces and did not find differences in protein deposition.

In Piétrains, FARRIES and ANGELOWA (1968) found a different pattern of daily protein deposition than in other breeds. According to FARRIES et al. (1968), Piétrain pigs have a higher protein deposition in the first part of the fattening period than Landrace pigs, and a lower protein deposition in the second part of the fattening period. FARRIES and ANGELOWA (1968) studied wild pigs (males), Improved German Landrace (castrated males) and crosses between these two breeds (castrated males). They found that at 40 kg bodyweight the N retention for the three genotypes was 0.27, 0.35 and 0.34 g per kg bodyweight, respectively.

As a result of all investigations mentioned in this section GÄDEKEN (1971) concluded that hardly any differences in N retention exist between white-skinned meat-type pigs.

2.2.2.2. Sex

It is generally known that the daily protein and fat deposition of males, castrated males, and females differ (LUDVIGSEN and THORBEK, 1955; PIATKOWSKI and JUNG, 1966; KOTARBINSKA, 1968; JUST NIELSEN, 1970; PEDERSEN, 1973). LUDVIGSEN and THORBEK (1955) found that the N balance in females was on average 4 g higher than in castrated males in the weight range 20–90 kg. JUST NIELSEN (1970) did not find significant differences in N balances between castrated males and females up to 40 kg liveweight. From 40 kg onwards he noticed a higher increase in N balance in females than in castrated males. At 85 kg liveweight the females retained 4 g more N per day than the castrated males.

This result agrees with those obtained with males and castrated males by FARRIES and KALLWEIT (1969). Up to 50 kg only small differences were found between males and castrated males. At 95 kg the males retained 185 g protein and the castrated males about 120 g. PIATKOWSKI and JUNG (1966), however, found that the differences between males, females and castrated males with respect to *N* balnces were equidistant during the whole fattening period.

On the basis of these investigations, GÄDEKEN (1971) concluded that males retain about 28% more protein per day than castrated males and that males retain 15% more protein per day than females. The fat deposition was highest in castrated males, then in females and then in males. According to PALLSON (1955) (cited by PIATKOWSKI and JUNG, 1966), these differences exist because castrated males and females are somatically mature at a younger age than males, so that gain in muscle and bone tissue starts to decrease at an earlier age. Consequently fat gain will increase more and earlier in these pigs.

2.2.2.3. Individual variation

Pigs of the same age and the same feeding level show differences in daily protein deposition, e.g. 95 to 140 g per day (THORBEK, 1969). OSLAGE et al. (1966) working with 7 pigs of 90–100 kg, found a protein deposition range between 93 and 117 g. In the weight range 100–110 kg these pigs deposited 89 to 122 g protein. There is some indication that the variation in *N* balance increases with increasing bodyweight. JUST NIELSEN (1970) measured protein retention in 40 females and 40 castrated males from 25 to 85 kg bodyweight onwards. It was computed that in females the standard deviation in daily protein deposition (g/day) increased from 5.76 to 18.99, whereas in castrated males this standard deviation increased from 6.19 to 16.85. Especially from 50 kg onwards the standard deviation increased. When based on the chemical composition of the empty body, the standard deviation of protein deposition was 7.14 g at 85 kg bodyweight (mean deposition of protein 95.98 g). Fat deposition determined from chemical analysis of the empty body was 131.13 g per day (standard deviation 22.53 g).

No data on heritability of protein and fat deposition in pigs are known.

2.2.2.4. Feeding level

KIELANOWSKI (1972) reviewed protein requirements of growing pigs. He concluded that protein deposition will increase with feeding to a certain level. Above that feeding level protein deposition does not increase. Therefore the feed above this level will be used only for fat deposition. This conclusion of KIELANOWSKI is supported by WENK and SCHÜRCH (1974) and also by JUST NIELSEN (1973), who found that differences in feeding level did not influence muscle content of the carcase at the same weight. However FULLER and BOYNE (1971) found an increase in *N* balance with increasing feeding level at different environmental temperatures. About the same increase in *N* balance with increase of feeding level was found by VERSTEGEN et al. (1973), i.e. 9.95 mg *N*/g feed when the feeding level was 39, 45 or 52 g/kg bodyweight per day. Also

OSLAGE (1963b) found that N balance varied with feeding level. In his investigation feeding was decreased by 10 or 20% when 60 kg liveweight was reached. In the weight range 90–110 kg, N balance was parallel with feeding level. PEDERSEN (1973) compared the effect of feed restriction and protein level in 5 groups of pigs. One control group was fed according to weight up to 120 kg (slaughter weight). The other 4 groups received the same diet up to 80 kg liveweight. Then they received one of two protein levels in the diet: two groups were fed 18% less energy than the control and two groups 29% less than the control. In the control group there was no decrease in protein deposition. All four experimental groups deposited less protein in the weight range 110–120 kg than the control group, 10 and 20 g (= 25%) less, respectively. Variation of protein level in the diet had no influence.

The effects of feeding level on fat deposition are very clear. All investigations showed an increase in fat deposition with increasing feeding level. When pigs of 60 kg received 10 or 20% less feed, the fat deposition in the weight range 90–110 kg was 294 and 262 g/day, respectively, compared with 308 in the control group (OSLAGE, 1963b). In the previously mentioned study of PEDERSEN, the restrictedly fed pigs deposited 204 or 159 g fat compard with 270 g in the controls in the weight range 110–120 kg. These results agree with those reported by BREIREM (1935), JUST NIELSEN (1973), VERSTEGEN et al. (1973) and WENK and SCHÜRCH (1974). JUST NIELSEN (1970) and VERSTEGEN (1970) reported that young growing pigs may still have positive N balances when body fat is mobilized for maintenance.

In feeding experiments, DAVIES and LUCAS (1972a, b) found that the relation between feed above maintenance and bodyweight gain was non-linear, also the relation between that feed and lean-tissue was non-linear. ELSLEY et al. (1964) concluded from the literature and from analysis of the results of MCMEEKAN (1940), that there is no evidence for the influence of feeding level on the ratio of muscle to bone in the carcase. This also shows that fat deposition is much more related to feeding level than protein deposition.

2.2.2.5. Ambient temperature and housing conditions

From the previous section and from a review of FOWLER and LIVINGSTONE (1972), it can be expected that temperatures below the zone of thermoneutrality cause a reduction in fat deposition. Part of the metabolizable energy used for production will then be used for extra thermoregulatory heat production and this will cause a rise in maintenance requirement. Results from energy and N balances showed that at least during a relatively short time of exposure to cold (less than 3 weeks), protein deposition was not influenced (VERSTEGEN, 1970; VERSTEGEN et al., 1973). Also GRAY and MCCRACKEN (1974) demonstrated that protein deposition did not vary with temperature. In all these studies, fat gain varied proportionally with the metabolizable energy available for production after subtraction of extra thermoregulatory heat production. A small reduction in protein deposition together with a much greater reduction of fat deposition in the cold were found by PIATKOWSKI (1958), CLOSE (1970) and FULLER and

BOYNE (1971). SØRENSEN (1962) pointed out that pigs in the cold were fatter than pigs at normal temperatures. This conclusion was based on measurement of backfat thickness. Low temperatures can influence the carcase measurements and they may also cause a 'shift' of fat to the outer tissues of the body (VAN DER HEL and VERSTEGEN, 1969; TEN BRINKE, 1971; KUIPERS et al., 1973). According to VERSTEGEN (1972), the differences in effects of cold on protein deposition might be explained by differences in length of exposure to low temperatures. The studies which showed a clear reduction in protein deposition had relatively longer treatment periods (SØRENSEN, 1962).

The type of housing may also influence the thermoneutral zone and thus protein deposition and carcase measurements (VERSTEGEN et al., 1973 and 1974). VERSTEGEN et al. (1974) found that pigs of about 40 kg liveweight, restrictedly fed according to bodyweight (about 75% of ad libitum, CVB, 1965) and housed in groups on straw, asphalt or concrete slats had different effective critical temperatures (lower border of thermoneutrality). On straw, asphalt and concrete slats 11.7°C, 14.8°C and 19.2°C were the respective, effective critical temperatures. Thus the effective critical temperature is determined by feeding level, bodyweight and housing conditions.

When the temperature rises above a destinate value, feed intake at ad libitum conditions will decrease and thus also the metabolizable energy available for production (KLEIBER, 1961; HOLMES, 1973; GRAY and MCCRACKEN, 1974). Apart from the reduction in fat and protein due to the lower feed intake, there was also found a reduction in energy balance; HOLMES (1973) and GRAY and MCCRACKEN (1974) found that heat production was higher at 29°C than at 25°C. This result means that 29°C is above the zone of thermoneutrality. GRAY and MCCRACKEN (1974) found a reduction of protein deposition at 29°C compared with 25°C. The same effects were noticed by HOLMES (1973), who reported that at 33°–35°C compared with 25°C fat deposition had increased and protein deposition decreased.

2.3. METHODS TO CALCULATE PROTEIN AND FAT DEPOSITION

Various authors (KIELANOWSKI, 1966; KOTARBINSKA, 1969; CLOSE, 1970) have constructed models with which protein and fat deposition can be calculated from bodyweight gain, bodyweight and feed intake. The models are based on the use of all metabolizable energy for maintenance, and protein and fat deposition. It has been assumed that maintenance requirement does not change with bodyweight gain, also that the cost of synthesis of protein and fat are constant throughout the growth period.

2.3.1. *Method of* KIELANOWSKI *and* KOTARBINSKA (MEK *model*)

This method defines bodyweight gain as gain in liveweight minus gut fill. Metabolizable energy is used for maintenance, protein and fat deposition according to

$$ME = ME_M + c\,\Delta P + d\,\Delta F \qquad 2.1$$

Fat gain is defined as

$$\Delta F = \Delta L_E - \Delta LBM \qquad 2.2$$

The coefficients c and d were computed by regression of ME intake on protein (P) and fat (F) in the carcase. The last components were obtained from chemical analysis of the empty body. KIELANOWSKI (1966) assumed furthermore that the relation between lean body-mass (LBM) and protein (P) was linear ($LBM = K \times P$). KOTARBINSKA (1969), however, estimated ΔLBM from a non-linear relation between LBM and P ($LBM = K \times P^h$). ΔL_E is found from the relation between L_E and bodyweight (W). By substituting Eqn. 2.2 in Eqn. 2.1 and replacing ΔP by P–P_o KIELANOWSKI obtained the equation

$$ME = ME_M + c\,(P - P_o) + d\,\{\Delta L_E - K(P - P_o)\} \qquad 2.3$$

and

$$P = \frac{d\,\Delta L_E + (dK - c)P_o - (ME - ME_M)}{(dK - c)} \qquad 2.4$$

In these equations P is the amount of protein in the empty body. Protein deposition in the experimental period ($P - P_o$) then equals

$$\Delta P = \frac{d\,\Delta L_E - (ME - ME_M)}{(dK - c)} \qquad 2.5$$

Substituting KOTARBINSKA's equation, $LBM = K \times P^h$ into Eqn. 2.1 gives

$$ME = ME_M + c\,(P - P_o) + d\,(\Delta L_E - KP^h + KP_o^h) \qquad 2.6$$

and

$$dKP^h - cP = (d\Delta L_E + dKP_o^h - cP_o) - (ME - ME_M) \qquad 2.7$$

In Eqn. 2.7, P is the only unknown and KOTARBINSKA proposed to substitute A' for the therms on the right. By substituting all reasonable values for P at a certain weight of the pig, A' can be solved. Then one can find an equation which describes $ln\ P$ as a function of A'. In a general sense the solution of Eqn. 2.7 is

$$ln\ P = b \ln \{(d\Delta L_E + dKP_o^h - cP_o) - (ME - ME_M)\} + \text{constant} \qquad 2.8$$

As c, d, h, K and P_o are constant, the amount of protein (P) can be considered as a function of ΔL_E and metabolizable energy for production ($ME - ME_M$). Protein deposition can then be calculated from Eqn. 2.8 as $P - P_o$ and expressed either per day or per experimental period. If P is known, then fat deposition (ΔF) can be derived from Eqn. 2.1. It is also possible to calculate ΔF by substituting $(\Delta L_E - \Delta F)/K$ for $P - P_o$ (KIELANOWSKI, 1966). This gives

$$ME = ME_M + c\,\{(\Delta L_E - \Delta F)/K\} + d\Delta F \qquad 2.9$$

and it follows that

$$\Delta F = \frac{K(ME - ME_M) - c\Delta L_E}{dK - c} \qquad 2.10$$

2.3.2. *Method of* CLOSE (EBC *model*)

CLOSE (1970) calculated protein and fat deposition from bodyweight gain and energy balance. He defined bodyweight gain as

$$\Delta W = \Delta H + \Delta P + \Delta F + \Delta A + \Delta D \qquad 2.11$$

and

$$EB = 5.7\,\Delta P + 9.46\,\Delta F \qquad 2.12$$

Furthermore, he assumed on the basis of literature data that ΔA (ash) and ΔD (gut fill) together were 10% of bodyweight gain. He also assumed that the value of $\Delta P/(\Delta P + \Delta H)$ (= protein to protein + water) is 0.21. If protein and water are replaced by ΔM, then $\Delta P + \Delta H = \Delta M$.

Hence protein and fat deposition can be calculated from Eqns. 2.11 and 2.12 as

$$\Delta F = 0.9\,\Delta W - \Delta M \qquad 2.13$$

Moreover

$$EB = 5.7 \times 0.21\,\Delta M + 9.46\,(0.9\,\Delta W - \Delta M) \qquad 2.14$$

and

$$\Delta M = (-EB + 8.514\,\Delta W)/8.263 \qquad 2.15$$

then

$$\Delta P = 0.21\,\Delta M \qquad 2.16$$

and substituting ΔP in Eqn. 2.12 gives ΔF.

2.3.3. *Method of* KIELANOWSKI *and* KOTARBINSKA *on the basis of EB* (EBK *model*)

When the method of KIELANOWSKI (1966) and KOTARBINSKA (1969) is used, the fat and protein deposition can be calculated from Eqns. 2.12 and 2.2 by using net energy.

ΔLBM can be replaced by $K\,\Delta P$ and Eqn. 2.2 substituted in Eqn. 2.12 gives

$$\Delta P = 5.7\,\Delta P + 9.46\,(\Delta L_E - K\Delta P) \qquad 2.17$$

It follows that

$$\Delta P = (EB - 9.46\,\Delta L_E)/(5.7 - 9.46\,K) \qquad 2.18$$

From ΔP and Eqn. 2.12 fat deposition can be derived.

2.3.4. *Differences between the three methods*

With the methods of KIELANOWSKI (1966) and KOTARBINSKA (1969), the metabolizable energy eaten by the pigs is used, while CLOSE (1970) used net energy or energy balance (*EB*). Moreover the bodyweight gain is described in a different way. CLOSE (1970) used live bodyweight gain (ΔW) as parameter and the Polish research workers used empty bodyweight gain (ΔL_E). All three methods of calculations relate protein to ΔM (= protein + water) or protein to *LBM*. CLOSE (1970) and KIELANOWSKI (1966) considered this ratio as a constant. KOTARBINSKA (1969) considered the ratio protein to *LBM* to decrease with increasing bodyweight.

3. PRECISON OF THE CALCULATION OF DAILY PROTEIN AND FAT DEPOSITION

3.1. MATERIAL AND METHODS

3.1.1. *Material*

In the literature some investigators have given detailed reports of studies on protein and fat deposition in pigs. Their data were compared with daily protein and fat deposition calculated from their results for bodyweight gain and feed intake. The data which were used to study the precision of the prediction of protein and fat deposition, consisted of:
- data on chemical composition of homogenized pigs;
- data from energy and N balance trials.

3.1.1.1. Data on chemical composition of homogenized pigs

Data of SCHMIDT et al. (1931 and 1933), OSLAGE (1962, 1963a, b, 1964), KOTARBINSKA (1969) and JUST NIELSEN (1970) were used to calculate the relation between protein, water, fat, ash and gut fill and the bodyweight.

SCHMIDT et al. (1931 and 1933) used pigs of 6 breeds or crossbreds (Table 3.1). The pigs were fed according to liveweight and the amount of feed was adjusted per day. The housing and management conditions were the same for all pigs. The pigs were slaughtered at 30 kg, 100 kg or 150 kg bodyweight. The aim of the study was to find a reliable reference for comparison of dissection results and judgement of carcases. Weight and slaughtering were done after 36 h of fasting. After slaughtering, a sample, each of 17 fractions of the empty body was analysed chemically, i.e. blood, bristles, viscera, leaf fat, offal, bones, subcutaneous fat, skin, feet and ears, and meat or bonemeat in ham, shoulder and belly, eye muscle and head.

OSLAGE (1962, 1963a, b, 1964) used 162 Improved German Landrace pigs in an extensive study on the change of carcase composition with increasing

TABLE 3.1. Numbers of pigs per breed and per slaughter weight after the data of SCHMIDT et al. (1931 and 1933).

Breed	Weight at slaughter (kg)		
	30	100	150
German Yorkshire	2	13	4
Improved German Landrace	2	9	6
Berkshire	2	10	4
'Weideschwein'	2	4	5
Middle White	–	2	–
Berkshire × Middle White	–	4	–

bodyweight. The influence of feeding on carcase composition was also part of this study. The pigs were slaughtered before the morning feed at a liveweight of 25 kg, 40 kg, 60 kg, 90 kg or 110 kg, respectively, and 18, 18, 22, 30 and 74 pigs were analysed at each slaughter weight. 119 pigs were fed to appetite during the whole fattening period. All the other pigs in this study were fed to appetite during one part of the fattening period, and during the other the amount of feed was restricted. 13 pigs were fed 10% less and 12 20% less from 60 kg onwards. Moreover 10 pigs received 10% less in the weight range 20–40 kg and 8 20% less in the weight range 20–60 kg. Before the analyses the empty body of the pigs was divided in: meat, bones, viscera, bristles, blood and offal.

KOTARBINSKA (1969) collected data from 317 Polish Large White pigs ranging from 2.5 to 98.2 kg. The pigs had been previously used for balance trials. The feeding scheme was according to days on test (KIELAOWSKI, 1968). Pigs of 30 kg liveweight or less were homogenized completely after bleeding and then analysed for chemical composition. If the pigs were heavier than 30 kg, the empty body was analysed in three sections, i.e. bristles, blood and viscera, and one half of the carcase. This last part was sometimes divided into edible and non-edible parts.

JUST NIELSEN (1970) collected data from 80 Danish Landrace pigs (40 castrated males and 40 females). He used these pigs to study the feeding value of U.S.A. barley in concentrates for growing pigs. The pigs were fed individually according to liveweight and the amount of feed was adjusted daily. When the pigs weighed about 90 kg they were slaughtered. The empty body of the pigs was divided into: meat, subcutaneous fat, skin, bones, blood, bristles, and viscera. The variation in chemical composition of blood and bristles between the pigs was very small. Therefore these parts were only analysed in 16 pigs. For the other pigs he used constant values.

3.1.1.2. Data from energy and *N* balances

Besides the data on composition of the empty body, data from energy and *N* balances were used for the calculation of protein and fat gain. The data obtained from *ME* intake, bodyweight and bodyweight gain from these trials were used to compare predicted protein and fat deposition with protein and fat gain found. The data were analysed from trials published by BREIREM (1935), LUND (1938), LUDVIGSEN and THORBEK (1955), JUST NIELSEN (1970), VERSTEGEN (1971) and VERSTEGEN et al. (1973). All investigations, apart from the last two, were done at the Laboratory of Physiology in Copenhagen. With JUST NIELSEN's data, both methods – chemical analyses (comparative slaughter technique) and energy and *N* balances – could be compared. The *ME* contents collected by BREIREM (1935), LUND (1938) and LUDVIGSEN and THORBEK (1955) were corrected for an assumed methane production (VERSTEGEN, 1971). It was assumed that in pigs of 20 kg methane was 0.5% of gross energy and that this percentage increased linearly to 1% of gross energy in pigs of 100 kg or more.

BREIREM's investigations (1935) were done in two series in which diets with a high and a low protein content were compared. The aim of his study was to find standards for the feed requirements (on energy basis) of bacon pigs. He used in total 11 pigs, and they were fed from 20 to 100 kg. During the fattening period a number of balance experiments were done. Each experiment consisted of a preliminary period of 10–19 days and a collecting period of 8–10 days. The pigs were fed twice a day and weighed twice a week before the morning feed. Feed intake was according to weight. For each pig, 1 to 6 energy balance experiments were done, and altogether 43 balance experiments were reported. The weight of the pigs was determined from the two weighings by linear interpolation.

LUND (1938) collected data in a study about the influence of avitaminose A on the energy balances of pigs. 44 pigs were used in the trial and with 21 of these pigs 1 to 4 balance experiments were done. The system of feeding and housing was the same as in BREIREM's (1935) investigations. From LUND's results data of 57 experiments were used. Vitamin A had no influence on protein deposition, energy metabolism and use of energy. Feed intake, however, was depressed in the group with low Vitamin A intake. The bodyweight gain in that group was not as regular as in the group with normal Vitamin A.

LUDVIGSEN and THORBEK (1955) carried out some energy balances to study the effect of Aureomycin in the feed. N balance was not influenced by Aureomycin. Digestability of dry matter, and C and N balances were determined in 6 main periods per pig. The preliminary period was 9 days and the main period lasted 7 days. Gaseous exchange was determined during the second and the last days of the main period. In the same way as in the previous studies from Copenhagen, the weight was estimated by linear interpolation between the two weighings. All 8 pigs were fed individually according to the scheme of BREIREM (1935) and LUND (1938). In the preliminary period and also in the main period the amount of feed was constant. In the periods between the trials (5 days) the amount of feed was adjusted. Data of 44 energy and N balances could be used. One pig had to be discarded and another one could no longer be used after the 4th experimental period.

JUST NIELSEN (1970) used the 80 pigs, that were used for chemical analysis of the empty body, for the energy and N balance trials as well.

All pigs were fed individually and the amount of feed was adjusted daily. The weight range from 20 to 90 kg was split up into 6 periods of 18 or 19 days. In each period the total collecting period lasted 7 days. Gaseous exchange was determined on the 4th collection day. In the same way as in the other Danish investigations, weight was determined from the weighings of bodyweight and linear interpolations in between. Thus 480 energy and N balances were done. From data supplied by JUST NIELSEN in 1973 (personal communication), the feed intake on each day of the trials could be calculated. From all weights (including that collected in the preliminary periods) a curvilinear growth curve has been computed (cubic curve). The bodyweight at each day was computed from interpolation with this curve.

VERSTEGEN (1971) published data from a study about the influence of ambient temperature on energy metabolism of pigs housed individually and in groups. Only data obtained in the zone of thermoneutrality have been used for the present investigations. The pigs (Dutch Landrace) were fed restricted according to standards of CENTRAAL VEEVOEDERBUREAU (1965). The amount of feed was adjusted according to expected liveweight. The pigs were weighed once a week at a fixed time of the day. If this was not possible the weight was corrected accordingly. Energy and N balances were determined for two related pigs placed in one respiration chamber; each pig was placed in a metabolism cage. Balance experiments lasted 5–7 days. The shortest period for the heaviest pigs. Heat production was obtained from gaseous exchange, which was measured every two days. Total heat production was divided between the two pigs in one respiration chamber according to metabolic weight. Data of 37 pigs were used for the present study. The weight of the pigs ranged from 19.5 to 98.0 kg.

VERSTEGEN et al. (1973) also studied the influence of ambient temperature on heat loss, energy and N balance in pigs fed at various feeding levels. Only data obtained at 20 °C were used for the present investigation. The pigs used were 4 groups of 4 castrated males (Large White). The pigs were put in the calorimeter 3 weeks. The feeding level was 39 or 45 g of feed/kg liveweight per day. The pigs weighed 25 to 30 kg at the start of the experiments. Feed was adjusted according to expected liveweight. The bodyweight was determined 3 times a week. Each experiment consisted of 7 collection periods of two or three days. Heat loss was measured directly in a heat sink calorimeter. In this way data of 28 energy and N balances from a group of 4 pigs were available.

3.1.2. *Methods*

3.1.2.1. Estimation of ME_P and energy balance (EB)

From the literature it has been assumed that the efficiency of conversion of ME_P into energy balance was 0.7 (BLAXTER, 1968; VERSTEGEN, 1971; BREIREM and HOMB, 1972). Then energy balance was computed according tot the following equation

$$EB = 0.7\,(ME - ME_M) \qquad 3.1$$

The precision of the estimation of EB and ME_P was tested by analysing the data of BREIREM (1935), LUND (1938), LUDVIGSEN and THORBEK (1955), JUST NIELSEN (1970), VERSTEGEN (1971) and VERSTEGEN et al. (1973). In the analysis the maintenance requirement was varied stepwise from 70 to 140 kcal $ME/kg^{3/4}$ in steps of 10. Moreover the possible influence of bodyweight on maintenance requirement was tested by decreasing the maintenance requirement by 0, 0.1, 0.2, 0.3, 0.4 or 0.5 kcal $ME/kg^{3/4}$ per kg liveweight increase.

The maximum differences in the values of correlation coefficients between found EB and estimated ME_P per set of data are given in Table 3.2. Table 3.2 shows that independent of the assumed maintenance requirement, there is a good agreement between energy balances given by the authors and estimated ME_P. Of course, these values of correlation coefficients would be identical with those obtained from EB and the estimated net energy for production. The

TABLE 3.2. Values of correlation coefficients between *EB* (found) and ME_P (calculated).

Data	$r_{EB.ME_P}$
BREIREM (1935)	0.971–0.984
LUND (1938)	0.947–0.963
LUDVIGSEN and THORBEK (1955)	0.984–0.988
JUST NIELSEN (1970)	0.982–0.984
VERSTEGEN (1971)	0.932–0.962
VERSTEGEN et al. (1973)	0.949–0.955

analysis showed that reducing the maintenance per $kg^{3/4}$ by increasing bodyweight decreased the values of correlation coefficients when the maintenance was assumed to be lower than 110 to 120 kcal $ME/kg^{3/4}$. If maintenance was assumed to be 130 or 140 kcal $ME/kg^{3/4}$ then subtracting a factor for increasing bodyweight increased the values of correlation coefficients.

3.1.2.2. Relation between protein, water, fat, ash, gut fill, and bodyweight

To study the relation between protein, water, fat, ash and gut fill (y) with bodyweight (x), some data given in the literature were analysed. These data were given by SCHMIDT et al. (1931 and 1933), OSLAGE (1962, 1963a, b, 1964), KOTARBINSKA (1969) and JUST NIELSEN (1970). For the analysis two types of equations were used:

- linear equation: $y = a'x + b'$
- allometric equation: $y = c'x^{d'}$

According to HUXLEY (1932), the allometric equation is very suitable for the description of growth of tissues or parts of the animal body in relation to bodyweight. The allometric equation can be rewritten as:

$$ln\, y = ln\, c' + d'\, ln\, x$$

The data according to these equations were analysed for each investigation and for the 4 investigations together.

Table 3.3 shows the goodness of fit of these equations when protein, water, fat, ash and gut fill were related to bodyweight or *ln* bodyweight. Except for JUST NIELSEN's data, the allometric equation gave a better goodness of fit than the linear equation. Probably the goodness of fit in JUST NIELSEN's data is lower, because in his data the variation in bodyweight is less than in the other investigations. The residual variation in the data of SCHMIDT et al. (1931 and 1933) was higher than in OSLAGE's and KOTARBINSKA's data. The data, however, are obtained from different breeds, each with a different growth curve, so that in the analysis of all data this may have increased the residual variation. The magnitude of the residual variation in the data of all 4 investigations shows that the different components of the growth vary much more with time than the variation among animals of the same weight.

To test the models derived in Section 2.3, the equations were computed from 4 sets of data because the weight range of the total data was wider than for a

TABLE 3.3. Equations and residual variance (%) for the linear and allometric relations between protein, water, ash, gut fill and fat, and bodyweight.

	Data	Total	Schmidt et al.	Oslage	Kotarbinska	Just Nielsen
	Number of pigs	622	69	156	317	80
	Weight range (kg)	2–150	30–150	25–120	2–99	85–95
	Equations					
1	Protein $= 1.049 + 0.129 \times W$	7.29	9.14	2.13	1.04	57.72
2	Protein $= 0.176 \times W^{0.954}$	1.94	4.79	1.27	0.50	56.90
3	Water $= 6.177 + 0.415 \times W$	5.42	12.39	2.63	1.28	62.24
4	Water $= 1.030 \times W^{0.836}$	1.39	6.19	1.37	0.47	61.74
5	Ash $= 0.238 + 0.023 \times W$	19.10	11.98	39.15	5.12	93.05
6	Ash $= 0.037 \times W^{0.921}$	7.84	6.91	27.99	1.88	93.18
7	Gut fill $= 0.916 + 0.049 \times W$	67.12	73.73	44.58	25.47	27.80
8	Gut fill $= 0.060 \times W^{0.984}$	31.97	57.79	33.99	15.42	27.81
9	Fat $= -8.380 + 0.385 \times W$	17.57	7.95	4.43	5.75	88.65
10	Fat $= 0.021 \times W^{1.565}$	4.71	3.27	2.30	4.12	89.64

single set of data. Moreover the results of the 4 sets together are influenced less by the specific conditions under which each of the four studies is done. Also the results of all data together are less influenced by one breed.

3.1.2.3. Tested factors[1] and sets of data

The precision with which protein and fat deposition can be predicted was tested with the energy and N balance data given by Breirem (1935), Lund (1938), Ludvigsen and Thorbek (1955), Just Nielsen (1970), Verstegen (1971) and Verstegen et al. (1973). Also the data on the chemical composition of the empty body of pigs given by Just Nielsen (1970) were used.

In the equations tested the factors were varied in the range of data given in the literature. In this way the sensitivity of the models for various values (a range as high as possible) of the factors was tested. In Section 3.1.2.2, the relations between protein, fat, water, ash, gut fill and bodyweight were computed. Linear and allometric relations and constants were used, to arrive at equations which fit best the growth of the various components of the body (see Table 3.3). Data on bodyweight and bodyweight gain were used as they have been given by the investigators.

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[1] In the rest of this chapter the word 'factor' is used for the parameters, which are modified in the models, thus: Maintenance requirement, efficiency, *LBM*/protein or protein/protein + water, and ΔL_E or ΔPWF. The word 'trait' is used for the characteristics, for which the precision is estimated: protein and fat deposition and the values of correlation coefficients between calculated protein deposition and protein deposition found by the various authors and between calculated fat deposition and fat deposition found by the various authors. In the rest of this chapter the description of the last two traits will be abbreviated as: the values of correlation coefficients between calculated and found protein and fat deposition.

Besides these data a non-linear relationship between bodyweight and time (cubic equation) was used in the data of BREIREM (1935), LUDVIGSEN and THORBEK (1955) and JUST NIELSEN (1970) to predict the bodyweight and thus bodyweight gain on the day on which the energy balance had been measured. Table 4.6 shows that the bodyweight and the bodyweight gain could be predicted better with the cubic equation than with other equations. 3 sets of data with a cubic formula for bodyweight gain were available.

Together with the 6 investigations on energy and N balances (linear weight gain) and the data of chemical analysis of the empty body, collected by JUST NIELSEN (1970), 10 sets of data were available to analyse the goodness of fit of various sets of equations and constants, and to test the precision of various ways of prediction of protein and fat deposition.

It is assumed that the dependency between sets of data, which arose in this manner, has not influenced too strongly the computations, described in Section 3.2.

As derived in Section 2.3 three models were used (Table 3.3) to test the prediction of protein and fat deposition. The models tested are:

- Model according to CLOSE: EBC model (Equations 2.11 to 2.16).
- *EB* model according to KIELANOWSKI: EBK model (Equations 2.2, 2.12, 2.17 and 2.18).
- *ME* model according to KIELANOWSKI and KOTARBINSKA: MEK model (Equations 2.1 to 2.10).

Table 3.4. gives a survey of the factors tested per model. For each model 36 different combinations of factors have been tested.

3.1.2.4. Computations

Mean values of the protein and fat deposition and values of correlation coefficients between calculated and found protein and fat deposition were used for the computations. The values for the four traits were computed for each set of data, for each combination of factors and for each model.

In order to quantify the influence of the 3 models and the four factors on the values of the correlation coefficients between calculated and found protein and fat deposition, these correlations were transformed by means of the Z transformation of FISHER (DE JONGE, 1964).

First of all each model was tested by difference between sets of data. For each of the four factors the uniformity of reaction in the different sets of data was investigated, and also the difference of the level of the four traits. For this investigation the following statistical model was used:

$$\begin{aligned} y_{ij} = \mu + ma_i + \bar{b}_o(X_o) + \bar{b}_e(X_e) + \bar{b}_l(X_l) + \bar{b}_a(X_a) + \\ + b_{io}(X_{io} - \bar{X}_{io}) + b_{ie}(X_{ie} - \bar{X}_{ie}) + b_{il}(X_{il} - \bar{X}_{il}) + \\ + b_{ia}(X_{ia} - \bar{X}_{ia}) \qquad \text{Model 3.1} \end{aligned}$$

In this model

y_{ij} = jth value of a trait in ith set of data ($j = 1, 36$)

μ = total mean

TABLE 3.4. Values of the different factors in the three models.

Factors	EBC model	EBK model	MEK model
Maintenance requirement (kcal $ME/kg^{3/4}$)	80, 100, 120	80, 100, 120	80, 100, 120
Efficiency (EB/ME_P)	0.55, 0.65, 0.75	0.55, 0.65, 0.75	
or: ME per g P and F, respectively (kcal)			16 and 13, 13 and 13, 11.4 and 12.6
Ratio protein to protein + water	0.21, (2)/{(2)+(4)}		
or: LBM to protein		4.6838, {W–(8)–(10)}/(2)	4.6838, {W–(8)–(10)}/(2)
PWF gain	W–(5)–(7), W–(6)–(8)		
or: gain of empty body		W–(7), W–(8)	W–(7), W–(8)

The figures within brackets concern the equations mentioned in Table 3.3.

ma_i = influence of the *i*th set of data ($i = 1, 10$)

$\bar{b}_o$, $\bar{b}_e$, $\bar{b}_l$ and $\bar{b}_a$ = the mean regression coefficient of each of the four traits (level of protein and fat deposition, and correlation coefficient between calculated and found protein and fat deposition), on the four factors: maintenance (X_o), efficiency (X_e), *LBM*/protein or protein/protein + water (X_l) and empty body or *PWF* gain (X_a)

b_{io}, b_{ie}, b_{il} and b_{ia} = deviations of the line regression of the traits on the four factors, within sets of data

e_{ij} = random error.

Moreover for each set of data the regression coefficients were calculated of the four traits on the factors for each model. To get an impression of the difference of the four traits per set of data, also the total mean of four traits for each model was calculated per set of data. From the calculations it turned out that the various sets of data did not react uniformly to changes in the four factors. For later investigations the common effect and the component of interaction between factors and sets of data were added together.

It was calculated which part of the variance was due to differences between sets of data and which part was due to the influence of the four factors. The differences between the three models (EBC, EBK and MEK models) were tested by means of *F* values, obtained for each pair of two models, of the mean squares between sets of data, between factors (summed) and random errors.

3.2. RESULTS

3.2.1. *Differences between sets of data*

The differences in the level of the four traits and in uniformity of reaction, when changing the four factors: maintenance, efficiency of synthesizing fat and protein, *LBM*/protein or protein/protein + water and weight gain of empty body or weight gain of *PWF*, have been tested with the statistical Model 3.1. The *F* values for the differences between sets of data and between reaction to the changes in the four factors are given in Table 3.5. This table shows that the *F* values for differences between sets of data, maintenance and efficiency are all significant ($p < 0.005$). Non-significant values for the fat level in the EBC and EBK models were found with respect to the factor: protein/protein + water or *LBM*/protein. For the factor: gain of *PWF* or empty body no *F* values were significant for the level of fat deposition and the values of the correlation between calculated and found fat deposition.

Also the differences in regression coefficients of the values of the traits on the four factors for all sets of data together and within sets of data show, that the sets of data did not give consistent results. In Table 3.6 the mean regression coefficients have been given for the levels of protein and fat deposition and for the values of the correlation coefficients between calculated and found protein and fat deposition on the four factors. Also the highest and the lowest value of these regression coefficients per set of data have been given in this table. These

TABLE 3.5. *F* values for differences between sets of data and reaction on changing of the factors.

			EBC model			
			Level		Correlation coefficients	
	Effect	df.	Protein	Fat	Protein	Fat
Sets of data	Ma*	9	10908.49	4368.43	16900.40	89556.52
Maintenance	O*	9	36.02	28.52	40.32	51.15
Efficiency	E*	9	87.44	69.45	165.98	155.46
Protein/protein+water or: *LBM*/protein	L*	9	35.14	0.53	27.32	4.61
PWF gain or: gain of empty body	A*	9	4.38	0.06	2.73	1.46

$F^{9}_{310} \geqslant 1.88 \quad p \leqslant 0.05$
$F^{9}_{310} \geqslant 2.41 \quad p \leqslant 0.01$
$F^{9}_{310} \geqslant 2.62 \quad p \leqslant 0.005$

differences are in agreement with the *F* values given in Table 3.5.

The mean protein and fat deposition and the mean values of correlation coefficients between calculated and found protein and fat deposition were calculated per set of data in the three models. These values have been given in Table 3.7. A comparison of the results of the first 6 sets of data in this table, where the bodyweight gain is the figure given by the investigator, shows that there are considerable differences in protein and fat deposition between sets of

TABLE 3.7. Daily protein and fat deposition and the mean value of correlation coefficients between calculated and found protein and fat deposition.

Data	Level		Correlation coefficients	
	Protein (g)	Fat (g)	Protein	Fat
Daily gain, as given by the authors				
BREIREM (1935)	58.92	185.66	0.841	0.956
LUND (1938)	54.92	184.67	0.242	0.905
LUDVIGSEN and THORBEK (1955)	73.48	214.82	0.069	0.985
JUST NIELSEN (1970)	66.47	192.02	0.353	0.959
VERSTEGEN (1971)	80.73	130.25	0.194	0.814
VERSTEGEN et al. (1973)	71.83	118.34	0.370	0.656
Daily gain, calculated from the cubic curve				
BREIREM (1935)	54.16	192.02	0.555	0.922
LUDVIGSEN and THORBEK (1955)	76.42	212.58	0.046	0.985
JUST NIELSEN (1970)	84.76	177.94	0.761	0.970
Chemical analysis of empty body				
JUST NIELSEN (1970)	81.89	178.06	0.716	0.257

EBK model				MEK model			
Level		Correlation coefficients		Level		Correlation coefficients	
Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat
8287.50	3012.71	16732.90	98497.40	16613.30	13351.69	70486.49	25818.17
24.56	23.83	37.03	53.17	63.51	122.29	277.70	59.27
59.44	62.09	154.83	176.44	21.69	47.52	13.48	64.58
47.40	0.81	36.49	40.00	113.83	11.77	196.57	13.31
4.23	0.05	1.55	1.43	4.01	0.48	8.39	0.46

data. These differences are partly caused by differences in feeding level, bodyweight and experimental conditions. The values of correlation coefficients between calculated and found protein deposition also vary considerably. The highest value was 0.841 (BREIREM, 1935) and the lowest 0.069 (LUDVIGSEN and THORBEK, 1955). The values for the correlation coefficients between calculated and found fat deposition were much more constant, i.e. the highest value was 0.985 (LUDVIGSEN and THORBEK, 1955) and the lowest value 0.656 (VERSTEGEN et al., 1973).

In balance and respiration trials the bodyweight gain was estimated for a short experimental period (about 10–14 days). Therefore the error is relatively important (cf. CÖP et al., 1970). To reduce this error the bodyweight gain was, if possible, calculated from a cubic growth curve. When using this method for JUST NIELSEN's (1970) data, the value of the correlation coefficient between calculated and found protein deposition was double that found when protein was calculated from bodyweight gain derived from linear interpolation between two weighings. Also the level of protein deposition increased by 18 g/day, when the bodyweight gain was derived from the cubic curve. According to the data of BREIREM (1935), the value for the correlation coefficient between calculated and found protein deposition decreased when using a cubic growth curve, and according to the data of LUDVIGSEN and THORBEK (1955), the value for the correlation coefficient hardly changed by calculating bodyweight gain from a cubic curve.

The precision of the three models was also tested with JUST NIELSEN's data obtained from chemical analysis of the empty body. Comparison of the level of protein and fat deposition calculated from energy and N balances (using bodyweight gain data derived from a cubic growth curve), with levels for the traits from total feed intake and bodyweight gain shows, that the levels are nearly the same. Also the value of the correlation coefficients between calcu-

Table 3.6. Values of regression coefficients of the four traits on the different factors.

Factor	Value regression coefficients	EBC model				EBK model				MEK model			
		Level		Correlation coefficients[1]		Level		Correlation coefficients[1]		Level		Correlation coefficients[1]	
		Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat
Maintenance	mean	6.07	-28.62	4.14	-3.01	5.86	-28.49	3.89	-2.96	7.41	-36.01	5.24	-6.00
	highest	6.74	-20.63	6.97	-0.61	6.51	-20.54	6.65	-0.63	8.23	-25.88	9.26	-0.73
	lowest	4.27	-31.57	0.01	-6.23	4.13	-31.44	-0.01	-6.27	5.21	-39.76	0.01	-14.01
Efficiency	mean	-8.31	39.16	-7.57	4.21	-8.02	38.98	-7.12	4.06	-4.10	19.96	-1.07	9.34
	highest	-6.03	45.70	0.21	11.21	-5.83	45.50	0.32	11.10	-3.34	23.40	0.03	15.07
	lowest	-9.77	29.08	-14.94	0.93	-9.43	28.96	-14.18	0.76	-4.82	16.35	-2.13	2.37
Protein/protein+water	mean	0.82	-0.49	4.75	-1.12	-6.96	4.20	4.38	1.58	-7.95	8.39	5.56	2.58
or: *LBM*/protein	highest	1.79	1.31	8.43	1.29	-4.57	6.04	9.39	8.38	-5.02	12.24	12.07	10.11
	lowest	-2.17	-1.07	-1.00	-2.17	-10.02	2.75	-1.33	-1.31	-11.59	5.31	-1.47	-0.24
PWF gain	mean	1.61	-0.97	-1.78	-0.07	1.74	-1.05	-1.28	-0.13	1.94	-2.04	-1.48	-0.12
or: gain of empty body	highest	2.65	-0.72	0.21	0.80	2.55	-0.80	0.22	0.58	2.84	-1.56	0.22	0.70
	lowest	1.18	-1.60	-2.96	-1.39	1.33	-1.54	-2.23	-1.37	1.48	-2.98	-2.56	-1.50

[1] The regression coefficients are computed from Z transformed correlation coefficients multiplied by 100.

TABLE 3.8. Relative contribution (%) to the different factors of the total SS.

		EBC model				EBK model				MEK model			
		Level		Correlation coefficients		Level		Correlation coefficients		Level		Correlation coefficients	
	df.	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat
Sets of data	9	59.24	32.91	94.95	99.30	56.75	32.94	95.29	99.25	66.44	49.25	97.61	97.59
Maintenance	10	13.84	23.18	0.95	0.20	12.41	23.08	0.87	0.19	18.74	38.04	1.49	0.73
Efficiency	10	26.06	43.55	3.34	0.45	23.36	43.40	3.09	0.43	5.75	11.72	0.07	1.46
Protein/protein+water or: *LBM*/protein	10	0.28	0.01	0.51	0.01	6.80	0.19	0.52	0.05	8.44	0.81	0.74	0.09
PWF gain or: gain of empty body	10	0.38	0.01	0.07	0.00	0.43	0.01	0.04	0.00	0.49	0.05	0.04	0.00
Error	310	0.19	0.34	0.19	0.04	0.24	0.38	0.20	0.03	0.14	0.13	0.05	0.13

TABLE 3.9. *F* values for the tested factors.

Factors	EBC model				EBK model				MEK model			
	Level		Correlation coefficients		Level		Correlation coefficients		Level		Correlation coefficients	
	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat	Protein	Fat
Maintenance	2294.07	2099.82	151.44	161.27	1631.13	1905.49	137.09	169.26	4217.67	9280.74	969.67	173.17
Efficiency	431.92	3945.41	534.35	364.40	3069.66	3582.63	487.59	388.33	1294.18	2859.69	42.28	348.41
Protein/protein+water or: *LBM*/protein	49.78	0.71	81.24	10.11	894.12	16.04	82.35	48.93	1898.59	197.45	480.58	20.32
PWF gain or: gain of empty body	63.66	0.95	10.44	1.34	56.83	1.00	5.59	1.38	110.43	11.42	29.07	0.43

$F^{10}_{310} \geqslant 1.83$ $p \leqslant 0.05$　$F^{10}_{310} \geqslant 2.32$ $p \leqslant 0.01$　$F^{10}_{310} \geqslant 2.52$ $p \leqslant 0.005$

lated and found protein deposition were nearly the same. The value of the correlation coefficients between calculated fat deposition and fat deposition found by chemical analysis of the empty body was 0.257 compared with 0.970 obtained from energy and N balance data.

3.2.2. *Differences between factors and between models*

The relative contribution of the total sum of squares of the traits to the four factors and to the differences between sets of data are given in Table 3.8. The data in this table show that the relative contribution to the four factors of the traits, protein and fat deposition, is 35% to 70%. The total sum of squares for the values of the correlation coefficients between calculated and found protein and fat deposition is mostly (95 to 99%) caused by differences between sets of data. Of the factors, efficiency contributed most in the EBC and EBK models, whereas in the MEK model, maintenance gave the highest contribution. The relative influence of the four factors on the value of the correlation coefficient between calculated and found protein deposition always was higher than for the value of the correlation coefficient between calculated and found fat deposition. With respect to the level of protein and fat deposition the factors, maintenance and efficiency, contributed more to the sum of squares in fat deposition, whereas the other two factors contributed more to protein deposition.

Table 3.9 shows that in nearly all cases the influence of change in any of the four factors on the four traits was significant. Only 6 F values connected with fat deposition or with the values of the correlation coefficient between calculated and found fat deposition were not significant.

Analysing the data on level of protein and fat deposition showed that 4.6838 as value for LBM/protein, which was used in the EBK and MEK models was lower than might be expected from the mean bodyweight of the pigs in the various sets of data. However the value of 0.21 used for the ratio protein to protein + water fitted well for the mean bodyweight. Because of the ratio LBM to protein in the EBK and MEK models was underestimated, the level of protein deposition was higher whereas the level of fat deposition was found lower (cf. Equations 2.18 and 2.5 and Table 3.10). Therefore after comparing the three models, the sum of squares caused by the factor protein/protein + water in the EBC model and LBM/protein in the EBK and MEK models were added to the error.

The results about the mean squares for the sets of data and the influence of the three remaining factors, and the error have been summarized per model in Table 3.11. The differences between the models have been given in Table 3.12. From these tables it can be stated that the mean squares for the various sets of data did not differ significantly in the three models. In the MEK model, the variance in the values of the correlation coefficient between the calculated and found protein and fat deposition which was caused by maintenance, efficiency and PWF gain or empty bodyweight gain was higher than in the EBK and EBC models. The lowest residual sum of squares was found in the EBC model and the highest in the MEK model. Except for the differences of the values of the

TABLE 3.10. Mean protein and fat deposition and mean values of correlation coefficients between calculated and found protein and fat deposition for the three models.

Trait	Value used for the factor: Protein/protein+water or: *LBM*/protein	EBC model	EBK model	MEK model
Protein (g)	constant	68.80	74.09	75.22
	allometric equation	69.62	67.13	67.28
Fat (g)	constant	180.51	177.33	172.01
	allometric equation	180.02	181.52	180.41
Correlation coefficient	constant	0.459	0.468	0.415
protein	allometric equation	0.496	0.501	0.461
Correlation coefficient	constant	0.935	0.933	0.907
fat	allometric equation	0.933	0.935	0.912

TABLE 3.11. Mean squares for sets of data, factors and error within models.

			Level		Correlation coefficients	
Effect	Model	df.	Protein	Fat	Protein	Fat
Sets of data	EBC	9	4267.02	41403.55	60438.73	169291.82
	EBK	9	4243.20	31249.15	58406.72	169989.96
	MEK	9	5258.64	45310.38	64581.98	186123.91
Factors within sets of data	EBC	30	870.60	19101.69	829.30	332.07
	EBK	30	812.16	18922.04	733.33	321.56
	MEK	30	593.21	13746.19	317.94	1254.41
Error	EBC	320	0.95	9.39	12.54	2.43
	EBK	320	14.81	15.20	12.36	4.31
	MEK	320	19.09	24.23	14.65	11.56

TABLE 3.12. *F* values for differences between the models EBC, EBK and MEK.

Effect	Models	Level		Correlation coefficients	
		Protein	Fat	Protein	Fat
Sets of data[1]	EBC–EBK	1.01	1.32	1.03	1.10
	EBC–MEK	1.23	1.09	1.07	1.00
	EBK–MEK	1.24	1.45	1.11	1.09
Factors within sets of data[2]	EBC–EBK	1.07	1.01	1.13	1.03
	EBC–MEK	1.47	1.39	2.61	3.78
	EBK–MEK	1.37	1.38	2.31	3.90
Error[3]	EBC–EBK	15.54	1.62	1.01	1.78
	EBC–MEK	20.03	2.58	1.17	4.76
	EBK–MEK	1.29	1.59	1.17	2.68

[1] $F_9^9 \geqslant 3.18$ $p \leqslant 0.05$

[2] $F_{30}^{30} \geqslant 1.84$ $p \leqslant 0.05$
$F_{30}^{30} \geqslant 2.39$ $p \leqslant 0.01$
$F_{30}^{30} \geqslant 2.63$ $p \leqslant 0.005$

[3] $F_{320}^{320} \geqslant 1.15$ $p \leqslant 0.05$
$F_{320}^{320} \geqslant 1.20$ $p \leqslant 0.01$
$F_{320}^{320} \geqslant 1.22$ $p \leqslant 0.005$
(*F* values have been extrapolated)

correlation coefficient between calculated and found fat deposition, the EBC model always had significantly lower residual variances than the MEK and EBK models. Table 3.10 shows that, if the underestimated ratio of *LBM* to protein is taken into account, none of the three models differed significantly in the level of protein and fat deposition. However the values of the correlation coefficients between the calculated and found protein and fat deposition were lower in the MEK model than in the EBC and EBK models.

3.3 DISCUSSION

Feeding values and also energy and protein requirements in farm animals are mainly based on energy and *N* balances (cf. NEHRING, 1969; JUST NIELSEN, 1970; KIELANOWSKI, 1972; BREIREM and HOMB, 1972). In addition, these data have been used frequently to find the most desirable housing conditions for farm animals and the optimum climate in stables for feed utilization (CLOSE, 1970; VERSTEGEN, 1971). In pig breeding, energy and *N* balances have been seldom used until now. However these data may be very useful in this field, because both bodyweight gain and efficiency of bodyweight gain of farm animals are mainly determined by feed intake and feed utilization (maintenance, protein and fat deposition).

In the introduction, it has been argued that protein and fat deposition are important traits for efficiency of meat production. Using information from the literature, three models (EBC, EBK and MEK models) were obtained, with which protein and fat deposition could be calculated from bodyweight gain and feeding level. These models were mainly based on wellknown and accepted physiological data connected with bodyweight gain and feed utilization. HOUSEMAN and MCDONALD (1973) computed protein and fat deposition from bodyweight gain and feeding level using multiple regression, whereas HUXLEY (1932) showed that allometric equations, were very useful to estimate protein and fat. Their methods may give better results with the data, in which the equations were computed, compared with the method used in this investigation. However the aim of this investigation was to find how useful energy and *N* balances could be as parameters in pig breeding. Furthermore, by using physiological data connected with bodyweight gain and feed utilization it is possible to correct for some differences in environmental factors between groups of animals, if the relationships between feed utilization, and feeding level and that between feed utilization and climatic and housing conditions are known.

To judge the precision, with which protein and fat deposition could be predicted from bodyweight gain and feeding level, the protein and fat deposition and also the values of correlation coefficients between calculated and found protein and fat deposition were computed for each model, for each set of data and for each combination of the four factors. The differences in results between the 10 sets of data used, between the 4 factors and between the 3 models were analysed.

Differences between sets of data

The relative contribution of the variance in protein and fat deposition to differences between sets of data was in the three models 60 to 70% and 30 to 50%, respectively. The relative contribution to this effect of the variance in the values of correlation coefficients between calculated and found protein and fat deposition was about 95% and 99%, respectively (Table 3.8).

The differences in the level of protein and fat deposition between sets of data are partly caused by differences in feeding level, feed composition, sex and breed. The influence of these points of the level op protein and fat deposition is reviewed in Section 2.2.2, and as such these points should not be used to judge, how precise protein and fat deposition can be predicted from bodyweight gain and feeding level.

Differences in the precision of the prediction of protein and fat deposition in the various sets of data may be concluded both from differences between calculated and found protein deposition and between calculated and found fat deposition. It may also be concluded from differences in the ratios calculated to found protein and fat deposition, respectively (Table 3.13). Furthermore the differences in precision for the various data are illustrated by the great differences in the values of correlation coefficients between calculated and found protein and fat deposition.

The differences between the values given in Table 3.13 may be partly explained by systematic differences in the experimental procedures applied.

These differences might have been caused by

TABLE 3.13. Difference between calculated and found protein and fat deposition and the ratio calculated to found protein and fat deposition (EBK model; $ME_M/kg^{3/4} = 100$ kcal; $EB/ME_P = 0.65$).

Data	Difference		Ratio	
	Protein (g)	Fat (g)	Protein (%)	Fat (%)
Daily gain, as given by the authors				
Breirem (1935)	-33.15	2.94	63	102
Lund (1938)	-40.22	4.76	56	103
Ludvigsen and Thorbek (1955)	-39.54	-2.69	64	99
Just Nielsen (1970)	-50.34	69.00	56	155
Verstegen (1971)	-19.43	27.59	79	125
Verstegen et al. (1973)	-31.39	15.55	67	114
Daily gain, calculated from the cubic curve				
Breirem (1935)	-36.17	3.95	59	102
Ludvigsen and Thorbek (1955)	-36.81	-4.32	66	98
Just Nielsen (1970)	-33.49	58.72	70	147
Chemical analysis of empty body				
Just Nielsen (1970)	-18.91	52.25	80	140

- the method used for the estimation of the traits, bodyweight, daily gain and energy balances
- the management of the pigs
- differences between management and housing conditions during the balance periods and the rest of the fattening period.

All points mentioned will influence the ratio ME_p to bodyweight gain, and as a consequence also the differences between sets of data in calculated and found protein and fat deposition. Systematic differences between experimental procedures applied by the research workers and also the already mentioned differences in feeding level, feed composition, breed and sex probably influence the level of protein and fat deposition more than the values of correlation coefficient between calculated and found protein and fat deposition. These values of correlation coefficients may be influenced by various interactions between experimental procedures and breed, sex, individual variation of pigs, feeding level or feed composition. However, it is impossible to quantify the various causes of interaction and their influence on the values of correlation coefficients.

The highest and the lowest value of the correlation coefficient between calculated and found protein deposition were 0.841 and 0.046, respectively, and between calculated and found fat deposition 0.985 and 0.257 (see Table 3.7). Especially the low value of the correlation coefficient between calculated and found protein deposition in LUDVIGSEN and THORBEK's data could not be explained satisfactorily. VERSTEGEN (1971) mentioned that their data, especially in young pigs, may have been influenced seriously, because heat production measurements started immediately after arrival in the respiration chamber. Very low values for bodyweight gain in combination with a quite normal feed intake were observed in the data of LUND (1938). The values of correlation coefficients between calculated and found protein and fat are surely influenced disadvantageously by this fact, because a feeding schedule according to liveweight was applied. The value of the correlation coefficient between calculated and found protein and fat deposition in JUST NIELSEN's data doubled when bodyweight gain was derived from the cubic curve compared with that found, when bodyweight gain was derived from linear interpolation between two weighings. Probably this increase can be explained because using a cubic curve the error in the estimation of bodyweight gain is lower and also because the influence of the environmental conditions during the balance period on this estimation is lower. This increase in the values of correlation coefficients between calculated and found protein deposition, using a cubic curve to derive bodyweight gain, did not occur in the data of BREIREM (1955) and LUDVIGSEN and THORBEK (1955). Possibly there was no increase because of an irregular growth curve of their pigs (for instance due to adaptation of feed quantity to bodyweight, feed composition or housing conditions). In addition, small numbers of pigs have been used in these investigations.

The values of correlation coefficients between calculated and found fat deposition are higher than those between calculated and found protein deposition (Table 3.8). This result is mainly caused by protein deposition being rather constant during the fattening period, whereas the fat deposition nearly linearly increases with increasing feed intake above maintenance (JUST NIELSEN, 1970; GRAY and MCCRACKEN, 1974). Hence the order of the pigs for fat deposition will be influenced less by errors in the parameters used in the models, than would occur for protein deposition. The constancy in protein deposition in the data used for this investigation has also occurred because all pigs were fed according to liveweight, and thus only a small variation in feeding level occurred. *ME* intake can be estimated with an error of about 1–2% (VERSTEGEN, 1971). This means that the standard deviation due to error in the estimation of *EB* will be higher in the larger pigs receiving more feed. Therefore the values of correlation coefficients between calculated and found protein deposition might be more variable. Probably a better fit of calculated to found protein deposition would be found if the quantity of feed, given to pigs of a certain weight varied as much as possible.

The value of the correlation coefficient between the calculated and found fat deposition in JUST NIELSEN's data, calculated from energy and *N* balances was 0.970 compared with a value of 0.257, when calculated from the data of chemical analysis of the empty body. JUST NIELSEN (1970) extensively discussed the possible differences between balance experiments and slaughter investigations. Most of the investigations he mentioned were comparisons between *N* balances and protein deposition, as could be calculated from chemical analysis of the empty body. JUST NIELSEN (1970) concluded that complete agreement between the results of balance experiments, and slaughter investigations had seldom been obtained. Especially the difference between balance experiment and slaughter investigation for the individual animal varied considerably. JUST NIELSEN (1970), however, could not explain the cause or causes responsible for the differences between methods. On the basis of the difference in the value of the correlation coefficient between calculated and found fat deposition in both methods, one might conclude that the estimation of the fat deposition by means of energy and *N* balances is not very precise, also because fat deposition calculated from balances is a rest factor. There fore more research should be done about this subject.

Table 3.5 shows that the reaction of the various sets of data to the factors, maintenance, efficiency, protein/protein + water or *LBM*/protein and gain of *PWF* or gain of empty body was not consistent.

Differences between sets of data in this respect may increase if there exist systematic differences in bodyweight or feeding level. Therefore the average weight of the pigs is given for the various sets of data in Table 3.14. From Equation 2.18 it can be concluded that ΔP increases linearly per kcal of decrease of *EB*. From the Equations 2.18 and 2.12 together it can be seen that the dereverse is true for the fat deposition. Because at a higher bodyweight the decrease of *EB* is greater through an increase in the factor maintenance requirement, the increase of protein deposition will be greater in data with a higher average bodyweight. The order of the values of regression coefficients of calculated protein and fat deposition on maintenance was similar to that for the

TABLE 3.14. The average bodyweight of the pigs used for the computations of the precision of protein and fat deposition.

Data	Weight (kg)
BREIREM (1935)	52.79 (± 23.75)
LUND (1938)	45.70 (± 17.93)
LUDVIGSEN and THORBEK (1955)	55.57 (± 23.18)
JUST NIELSEN (1970) (balances)	50.58 (± 20.22)
VERSTEGEN (1971)	43.75 (± 19.75)
VERSTEGEN et al. (1973)	31.02 (± 2.51)
JUST NIELSEN (1970) (Chemical analysis of empty body)	90.86 (± 4.02)

coefficients of variation for the weights of pigs in the various data. This similarity can also be explained by the relations between *EB*, and protein and fat deposition at different bodyweight.

An inconsistent increase of protein or fat deposition for various sets of data will be found together with an equal change of efficiency for synthesizing protein or fat, if ME_P differs systematically per set of data. This is true, because proportional changes of the efficiency were only taken into account for the three models. Thus if ME_P differs per set of data, the amount of kcal, with which *EB* changes, when changing the efficiency, are unequal for the different sets of data. Because all pigs were fed according to liveweight, and because there were systematic differences between average liveweights of the pigs in the different sets of data, it is clear, that ME_P also differed between data systematically.

A constant value for the ratio protein to protein + water or the ratio *LBM* to protein and equations that described the relation between this ratio and bodyweight were used. Also these alternatives have influenced the change in protein and fat deposition between data, because of the differences in average bodyweight between sets of data.

The two equations used in the three models for the factor *PWF* gain or gain of empty body did not cause inconsistency in the reaction to calculated fat deposition for the various sets of data. The different reaction of the sets of data to calculated protein deposition may also be caused by differences in average bodyweights.

The values of correlation coefficients between calculated and found protein and fat deposition also did not react consistently to changes of the values of the four factors. Again this can be partly explained by differences in average bodyweight and feeding level above maintenance in the various sets of data. This change of the values of correlation coefficients between calculated and found protein and fat deposition will be discussed later.

It could not be analysed to what extent the inconsistent change in the protein and fat deposition and in the values of correlation coefficients between calculated and found protein and fat deposition for the various sets of data was caused by systematical differences in genotype, bodyweight, feeding level, or experimental procedures, and to what extent it was caused by the assumptions made in the three models.

Differences between factors and between the three models

The relative contribution to the four factors of the total sum of squares of the traits, protein and fat deposition and values of the correlation coefficients between calculated and found protein and fat deposition are given in Table 3.8. The influence of the four factors on the four traits nearly always was significant (Table 3.9). Table 3.8 shows, that the factors, maintenance and efficiency, contribute much more to the total sum of squares of the protein and fat deposition than the factors, protein/protein + water or *LBM*/protein and *PWF* gain or gain of empty body. These differences may not be mutually compared. When choosing the models and the different values or equations of the four factors, the intention was only to test alternatives for each factor.

As mentioned before an increase of maintenance requirement and a decrease of efficiency both increase calculated protein deposition and lower calculated fat deposition. A decrease of the ratio *LBM* to protein and an increase of the ratio protein to protein + water rise calculated protein deposition and lower calculated fat deposition. This cannot only be concluded from the equations for protein and fat deposition in Section 2.3, but also from the lower energy content in protein compared with fat. Therefore if a given amount of bodyweight gain is found a decrease of *EB* will cause a shift to protein and an increase a shift to fat; less water in the gain will also give a shift to protein for the same reason.

The increase of the values of the correlation coefficients between calculated and found protein deposition by increasing maintenance and decreasing efficiency may be explained by assuming a non-linear relationship between calculated and found protein deposition. Computations about this relationship were done with the data collected by BREIREM (1935) and by LUDVIGSEN and THORBEK (1955).

At a higher found protein deposition the difference between calculated and found protein deposition was relatively lower. Moreover, the values of the correlation coefficient between found protein deposition and bodyweight were positive (0.579 in BREIREM's data and 0.371 in LUDVIGSEN and THORBEK's data). Therefore by increasing maintenance or by decreasing efficiency the relation of calculated protein deposition to found protein deposition will become more linear, and the value of the correlation coefficient will increase. On the basis of this theory there might be a certain *EB*, which gives the maximum value of the correlation coefficient. But, it is questionable whether the highest value of the correlation coefficient also gives the best prediction of the protein deposition. The reason for this may be that the relation of the difference between calculated and found protein deposition and this value of the correlation coefficient change in the same direction. Therefore the point of *EB* that gives the highest value of correlation coefficients has not been investigated so far in the various sets of data. The reverse was found for the values of correlation coefficients between calculated and found fat deposition. For this trait lower values were obtained by decreasing *EB*.

In JUST NIELSEN's data, however, the four factors hardly influenced the values of correlation coefficients between protein and fat deposition, when calculated protein and fat deposition were related to the data of the chemical analysis of the empty body. This can be explained by the fact, that all pigs were fed according to liveweight and all were fattened over nearly the same weight range. Hence changes in the four factors influenced mainly the level of protein and fat deposition by an equal amount. Thus, differences between pigs only changed slightly, and therefore also the values of correlation coefficients.

Assuming that feed intake and bodyweight gain can be estimated quite well, the precision of the models to calculate protein and fat deposition could be increased by taking into account the variation in *LBM*/protein or protein/protein + water between pigs. The increase of precision that might occur, was investigated with the data collected by JUST NIELSEN (1970). The course of the *LBM*/protein was related to the value, that was calculated from the chemical analysis of each pig. By doing so the values of correlation coefficients between calculated and found protein and fat deposition were hardly influenced. With a maintenance requirement of 100 kcal *ME* per $kg^{3/4}$ and an efficiency of 0.55, the value of the correlation coefficient between calculated and found protein deposition increased from 0.710 to 0.720, whereas the value for fat decreased from 0.258 to 0.251.

With regard to the differences between the three models in Section 3.2.2 it has already been mentioned that the constant value of 4.6838 used in the EBK and MEK models for the factor *LBM*/protein, was lower than might be expected from the average bodyweight of the pigs. Hence it can be explained, that the relative contribution to this factor in the EBK and MEK models of the total sum of squares for protein and fat deposition was significantly higher than it was in the EBC model to the factor, protein/protein + water (see Table 3.8). Furthermore the contribution of the total sum of squares of the values of correlation coefficients between calculated and found protein and fat deposition to the factors, maintenance, efficiency and *LBM* gain or gain of empty body, differed significantly between the MEK model on one hand and the EBC and EBK models on the other. The difference between the MEK model and the EBK and EBC models can also be seen from the values of correlation coefficients between calculated and found protein and fat deposition (see Table 3.10). One would have expected that taking into account the difference between efficiency for synthesizing protein and that for fat, would increase the precision of the prediction of the protein and fat deposition. Further the differences between the three models were very small. This is in agreement with the points that were stated in Section 2.3.4.

3.4. CHOICE OF THE MODEL AND THE COMBINATION OF FACTORS USED FOR THE FURTHER COMPUTATIONS

Tables 3.10 and 3.12 show that the differences between the calculated protein deposition and those between the calculated fat deposition using the EBC model, the EBK model or the MEK model were very small. The values of correlation coefficients between calculated and found protein and fat deposition were significantly lower for the MEK model than those for the EBC and EBK models. For the EBK model the value of the correlation coefficient between calculated and found protein deposition was slightly higher than in the EBC model, and the calculated protein deposition was slightly lower in the EBK model. Table 3.6 showed that the value of the correlation coefficient between calculated and found protein deposition and the level of the calculated protein deposition changed in the same direction. Because in the EBK model a slightly lower protein deposition and a slightly higher value of the correlation coefficient between calculated and found protein deposition were found compared with those data for the EBC model, the first of these two models was chosen.

Tables 3.6 and 3.15 show that the change of the protein deposition and the values of correlation coefficients between calculated and found protein deposition were opposite to these for fat when changing maintenance or efficiency. Furthermore, even when the maintenance requirement was assumed to be 120 kcal ME per $kg^{3/4}$ and the efficiency was assumed to be 0.55 the calculated protein deposition was 21 g lower than that found in N balances. Therefore to make a choice between the different combinations of factors within the EBK model the following assumptions have been made:

- the maintenance requirement is 100 kcal ME per $kg^{3/4}$

TABLE 3.15. Effect of the different values of the factors on the traits in the EBK model

Factor	Value/equation	Level: Protein (g)	Level: Fat (g)	Correlation coefficients: Protein	Correlation coefficients: Fat
(Maintenance ($ME/kg^{3/4}$)	80	64.75	207.92	0.453	0.937
	100	70.61	179.43	0.487	0.935
	120	76.47	150.93	0.513	0.929
Efficiency (EB/ME_P)	0.55	78.63	140.44	0.536	0.928
	0.65	70.61	179.43	0.489	0.935
	0.75	65.58	218.41	0.437	0.938
LBM/protein	4.6838	74.09	177.33	0.468	0.933
	allometric	67.13	181.52	0.501	0.935
Gain of empty body	linear	69.74	179.95	0.490	0.934
	allometric	71.47	178.90	0.480	0.934

- the protein deposition as estimated by N balances is overestimated by 15.5%
- the 'real' EB is $9.46 \times \Delta F + 7.5 \times (1-0.155)\ \Delta P$.

The value of 100 kcal ME per $kg^{3/4}$ has been chosen, because this figure is in good agreement with the data computed by VERSTEGEN et al. (1973). Furthermore, this figure has been estimated by KOTARBINSKA (1969) in pigs under quite normal housing conditions. The figure of 15.5% for the overestimation of protein deposition using N balances is based on the data from JUST NIELSEN (1970).

Within combinations of factors the value of 4.6838 for the factor $LBM/$protein was not useful, because this value adapted to another average bodyweight of pigs between 25 and 100 kg. To estimate the gain of the empty body, a linear increase of the amount of gut fill was assumed.

If a maintenance requirement of 100 kcal $ME/kg^{3/4}$, a $LBM/$protein changing with bodyweight and the gain of empty body linear increasing with bodyweight was taken into account, then an EB of $9.46 \times \Delta F$ (found) $+\ 5.7 \times 0.845 \times \Delta P$ (found) will be obtained with an efficiency between 0.55 and 0.65. The results of these two combinations of factors for the various sets of data have been given in Table 3.16, together with the data of fat and protein deposition, found by the various authors.

On the basis of the average found protein deposition multiplied by 0.845 and the average found fat deposition, for the 10 sets of data EB was calculated to be 1998.72 kcal. The average calculated EB in the EBK model were 1776.79 and 2077.84, when the efficiencies were 0.55 and 0.65, respectively. An EB of 1998.72 kcal corresponds to an efficiency of 0.62. This value is used in the following computations, therefore.

In the equation to compute protein deposition,

$$\Delta P = (EB - 9.46\ \Delta L_E)/(5.7 - 9.46K) \qquad \text{Eqn. 2.18}$$

EB, ΔL_E and K will be estimated using the following equations:

$$EB = (ME - 100\ W^{3/4}) \times 0.62$$

$$\Delta L_E = (W - 0.916 + 0.049\ W)$$

$$K = (W - 0.060\ W^{0.984} - 0.021\ W^{1.565})/(0.176\ W^{0.954})$$

The fat deposition will be estimated from Equation 2.12

$$\Delta F = (EB - 5.7\ \Delta P)/9.46$$

The bodyweight on each day will be computed from the cubic curve, for each pig separately.

Table 3.16. Values of the four traits, when calculated per set of data with two combinations of the factors in the EBK model.

				Maintenance = 100; Efficiency = 0.55				Maintenance = 100; Efficiency = 0.65			
	Protein (g)		Fat (g)	Level		Correlation coefficients		Level		Correlation coefficients	
	N bal.	*N* bal. ×0.845	Energy balance	Protein (g)	Fat (g)	Protein	Fat	Protein (g)	Fat (g)	Protein	Fat
Daily gain, as given by the authors											
Breirem (1935)	89.54	75.83	183.43	64.06	147.85	0.854	0.959	56.39	186.37	0.852	0.960
Lund (1938)	91.96	77.87	180.55	59.14	147.55	0.317	0.910	51.74	185.31	0.273	0.923
Ludvigsen and Thorbek (1955)	109.66	92.86	219.24	79.25	171.25	0.288	0.985	70.15	216.55	0.194	0.986
Just Nielsen (1970)	113.34	95.98	124.96	71.06	153.43	0.515	0.962	63.00	193.96	0.427	0.966
Verstegen (1971)	94.19	79.76	110.66	81.04	106.27	0.314	0.884	74.76	138.25	0.245	0.901
Verstegen et al. (1973)	96.55	81.76	110.62	70.57	97.46	0.404	0.684	65.16	126.17	0.382	0.744
Daily gain, calculated from the cubic curve											
Breirem (1935)	88.30	74.78	187.60	59.89	152.57	0.616	0.929	52.13	191.55	0.591	0.937
Ludvigsen and Thorbek (1955)	109.66	92.86	219.24	81.96	169.62	0.257	0.986	72.85	214.92	0.167	0.986
Just Nielsen (1970)	113.34	95.98	124.96	87.90	143.17	0.806	0.971	79.85	183.68	0.789	0.971
Chemical analysis of empty body											
Just Nielsen (1970)	95.98	95.98	131.13	85.03	143.23	0.710	0.258	77.07	183.38	0.712	0.272
Average (10 sets of data)	100.25	86.37	159.24	73.99	143.24	0.551	0.930	66.31	182.01	0.512	0.936

4. DAILY PROTEIN AND FAT DEPOSITION IN PIGS ON RESTRICTED AND AD LIBITUM FEED

4.1. MATERIAL AND METHODS

4.1.1. *Material*

4.1.1.1. Data on bodyweight gain, feed intake and slaughter quality of restrictedly fed pigs

Observations were made on 1644 pigs. These pigs were fattened at the testing station 'Zuid-Nederland' between May 1969 and July 1970. The pigs underwent performance testing (PT), combined testing (CT) or the so-called castrated males/females test (NK). Piglets were sampled in order to obtain a representative sample of a litter. The number of piglets per litter tested were 2 males in PT, 2 males and 2 females in CT, and 2 castrated males and 2 females in NK. The testing period was between 25 and 100 kg. The adaptation period at the testing station lasted about 14 days. The composition of the feed, and the feeding scheme applied were the same for all pigs and are presented in Table 4.1. The testing methods are described in detail by KROES (1969). Only data were used from litters in which observations were made on 2 castrated males, 2 males or 2 females. Thus 78 animals were excluded. The remaining data are summarized in Table 4.2.

The following observations per pig were made:

- weight at the beginning and at the end of the testing period and at intervals of a fortnight;
- the feed intake in the age intervals preceding the weight observations;
- the age at the weight observations.

In addition bodyweight gain, feed intake and carcase traits, corresponding to the testing method were observed (Table 4.3).

4.1.1.2. Data on bodyweight gain, feed intake and slaughter quality of ad libitum fed pigs

Observations were made on 233 DL females, divided in 29 progeny groups and 3 series. These pigs were fattened at the Department of Animal Husbandry of the Agricultural University, Wageningen, between January 1972 and September 1973. Progeny groups per sire ranged from 4 to 9 pigs. The piglets in Series 2 came from planned insemination in one herd. The piglets in Series 1 and 3 came from 13 and 29 herds, respectively. In Series 1 an attempt was made to find 4 females from 2 different litters, descending from one sire. As this was very difficult 3 females from 3 different litters of the same sire were bought for Series 2 and 3. Data were also collected to investigate the effect of the development of the sire at a given age on the optimum slaughter weight. Therefore sires were chosen that were heavy or small at a certain age. The different

TABLE 4.1. Composition and energy content of the feed, used at the testing stations, and the feeding schedule applied.

I Composition and energy content of the feed.

Ingredients	g/kg	net energy[1]
barley	100	217.6
maize	395	983.9
milo	100	245.1
pollards	100	176.7
wheat semolina	70	135.0
soja oilmeal	85	170.3
dried whey (delactosed)	25	46.3
fishmeal (67%)	40	82.8
lucerne	50	57.6
min. fattening pigs	20	–
bicalcium phosfate	5	–
Vitamin ABD	10	–
	Total	2115.3

ME-content 2115.3/0.7 = 3022 kcal

II Feeding schedule applied.

Weight (kg)	Quantity of feed (kg)
25	1.0
30	1.3
35	1.6
40	1.8
50	2.1
60	2.4
70	2.7
80	3.0
90–100	3.3

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[1] Calculated from the feed values, given by the C.V.B.

groups are summarized in Table 4.4.

The piglets arrived at an age of 6–7 weeks. Within 14 days the feeding level was increased to ad libitum. This ad libitum feeding regime was used during the testing period. The feed composition was equal to the feed used at the testing stations (Table 4.1). Fifty percent of the pigs were fattened for about 4 months. The others – sampled at random by pen and by litter – were fattened for 6 months.

Ten pigs had to be eliminated (2 in Series 1, 7 in Series 2 and 1 in Series 3): five died during the test and five were culled for retarded growth or disease. Pneumonia and diarrhoea did not occur. Sometimes leg weakness was observed, which was cured with 1 or 2 vitamin injections.

All pigs were weighed weekly in a fixed sequence; feed intake was estimated by weighing the self-feeders. At the end of the fattening period all pigs were dissected according to the IVO dissection method (Bergström and Kroeske, 1968). The analysed traits are presented in Table 4.5.

TABLE 4.2. Numbers of restrictedly fed pigs per breed, testing method and sex.

Breed Sex Testing method	DL			DY		
	m	*f*	*cm*	*m*	*f*	*cm*
Performance test	188			30		
Combined test	132	126		6	6	
Castrated males/females test		506	508		32	32

TABLE 4.3. Bodyweight gain, feed conversion and carcase traits determined per testing method.

Traits	PT	CT[1]		NK
	m	*m*	*f*	*cm* and *f*
daily gain (g)	+	+	+	+
feed conversion (kg feed/kg gain)	+	+	+	+
backfat thickness: ultrasonic (mm)	+	+		
mid-back (mm)			+	+
eye muscle (%)			+	+
ham (%)			+	+
eye muscle + ham (%)			+	+
meat quality (subj. judgement)			+	+
index (points)	+	+		

[1] The data of the females in the combined test consisted of the mean value of the two litter mates.

TABLE 4.4. Numbers of pigs of the 29 progeny groups.

Sire	Development of the sire	Series 1		Series 2		Series 3	
		pigs	litters	pigs	litters	pigs	litters
1	small	8	2	8	3	–	–
2	heavy	8	2	7	2	–	–
3	heavy	4	1	8	2	–	–
4	small	6	2	9	3	–	–
5	small	7	2	5	2	–	–
6	small	8	2	9	3	–	–
7	heavy	8	2	–	–	9	3
8	heavy	8	2	–	–	–	–
9	small	8	2	–	–	–	–
10	heavy	–	–	6	2	–	–
11	small	–	–	9	3	9	3
12	heavy	–	–	8	2	9	3
13	small	–	–	9	3	9	3
14	small	–	–	–	–	9	4
15	heavy	–	–	–	–	9	3
16	heavy	–	–	–	–	9	3
17	small	–	–	–	–	9	3
18	heavy	–	–	–	–	9	3
19	small	–	–	–	–	9	3

TABLE 4.5. Bodyweight gain, feed conversion and carcase traits used in the calculations of the ad libitum fed pigs.

daily gain (g)
feed conversion (kg feed/kg gain)
lean cuts: ham and shoulder (both defatted), eye muscle, lean offal
fat cuts: fat from ham and shoulder, belly, flare fat, fat offal, kidneys, lower jaw fat, 'krabbetjes' (= lower half of 1rst to 4th rib)
offal: head, feet, tail
backfat thickness (mid-back measurements)
meat quality (transmission value)

4.1.2. *Methods*

4.1.2.1. Computation of the growth curve

Often the average growth curve is estimated by assuming a linear bodyweight gain between the moments of observations. From a review of literature on growth in pigs (CÖP, 1971), it was clear that daily bodyweight gain between conception and mature weight changes continuously. Therefore the coefficient of determination (R^2) was used, to find which equation in Table 4.6 gave the best description of the relation between weight for age and age. It followed from the research of CÖP et al. (1970), that the average fit of this relation to the shape of a growth curve is quite possible. Therefore besides R^2, the standard deviation is also used to judge the fit. Thus $ln\ R^2/(1-R^2)$ was substituted for R^2. By this substitution the highest values indicate the best fit (KEULS, 1971). The rate of fit is presented in Table 4.6 for the equations used. This table shows that a cubic equation gives the best fit for the growth of all groups of pigs. Therefore this equation was used to describe the growth curve per pig and to compute the weights at various ages.

For all pigs, fed restrictedly a growth curve was computed, which was used

TABLE 4.6. Values of $ln\ R^2/(1-R^2)$ for the fit of computed and found weights in restrictedly fed pigs, and in various equations.

Equations	DL					DY				
	PT	CT		NK		PT	CT		NK	
	m	*m*	*f*	*cm*	*f*	*m*	*m*	*f*	*cm*	*f*
$W = A\,e^{kt}$	4.79	4.71	4.20	4.02	4.16	4.83	4.47	3.98	4.28	4.46
$W = A\,e^{k(t-t')} - A$	6.44	6.18	6.26	6.67	6.69	6.54	6.56	6.62	6.67	6.61
$W = a' + b't + c't^2$	7.50	7.08	7.00	7.38	7.43	7.73	7.90	7.30	7.48	7.57
$W = a' + b't + c't^2 + d't^3$	8.00	7.56	7.69	8.10	8.10	8.40	8.80	7.88	8.18	8.30
$1 - {}^{1}/W = a' + kt$	2.70	3.72	2.53	2.47	2.50	2.67	2.55	2.44	2.55	2.62
$ln\ W = a' + kt$	5.10	5.12	4.62	4.47	4.58	5.06	4.76	4.36	4.69	4.91
$W = a' + kt$	4.45	4.34	4.79	5.00	4.89	4.49	4.70	5.18	4.76	4.58
$ln\ W = a' + k\ ln\ t$	6.52	6.41	6.57	6.97	6.94	6.89	6.94	6.55	6.97	6.86
$ln\ W = a' + k\ ln(t + 40)$	6.91	6.66	6.50	6.54	6.65	7.21	6.86	6.15	6.84	7.14

for further computations. The same was done for all pigs fed ad libitum. Subsequently the average growth curve per group was computed by taking the average of the computed weights of all pigs in one group for each day in the fattening period.

4.1.2.2. Estimation of the daily feed intake

From the pigs in the testing station, only feed intake per pen was known between two subsequent weight observations. As follows from Table 4.1 the amount of feed supplied was related to the bodyweight. The feeding regime can be described by a square function:

$$y = -0.41625 + 0.064175\,x - 0.000285\,x^2 \quad (R^2 = 0.991) \qquad 4.1$$

in which y = amount of feed (kg/day)
x = bodyweight (kg)

In the management system of the testing station, the amount of feed is weighed at two-day intervals and adjusted to the bodyweight. In the calculations it is assumed that the increase in amount of feed between two weighings is in accordance with the square function given above.

For the calculations of the feed intake of the pigs fed ad libitum, the cumulative feed intake per pig was estimated separately for the first 4 months and then for subsequent 2 monthly period. Afterwards the feed intake per day was computed by the method of parabolic splines, as described by DUCHATEAU et al. (1972).

4.1.2.3. Correction for maintenance requirements at low temperatures

The minimum temperature in the piggery for the pigs fed ad libitum was set at 22 °C at the arrival. This temperature was gradually decreased to 15 °C when the pigs weighed 100 kg. From the calculations of VERSTEGEN (1971) and VERSTEGEN et al. (1974) it can be assumed that the pigs were kept above the lower critical temperature and that the maintenance requirement was not influenced.

The climatic control in the testing station 'Zuid-Nederland' was such that a temperature of at least 16 °C could be maintained. It is assumed that only during October to May the temperature was 16 °C and that in the rest of the year the average temperature was 18–19 °C.

At a thermoneutral heat production of 160 kcal/$W^{3/4}$ the lower critical temperature is $T_{cr} = 21 - 0.1\,W$ (VERSTEGEN, 1971). The feeding regime at the testing station is 40 g per kg bodyweight at 25 kg, increasing to 45 g at 35 kg and subsequently decreasing to 37–38 g at a weight of 80–90 kg (Table 4.1). The correction for maintenance requirement at lower critical temperature for a pig of 25 kg can be calculated as follows:

Above the lower critical temperature the heat production of pigs under 50 kg is about $0.3\,ME + 86.5 \times W^{3/4}$ kcal (VERSTEGEN, 1971). The ME intake at 25 kg is $25 \times 0.040 \times 3022 = 3022$ kcal.

So heat production at this feeding level is $0.3 \times 3022 + 86.5 \times 11.18$ kcal.

At 16°C, the heat production required to maintain homoiothermy is:

a. 160 kcal/$W^{3/4}$ (basis for zone of thermoneutrality): 1788.85 kcal;

b. additional heat production to cover the difference between the lower critical temperature – 18.5°C at 25 kg and thermoneutral heat production of 160 kcal/$W^{3/4}$ – and actual ambient temperature of 16°C. According to VERSTEGEN (1971), 5.8 kcal/$W^{3/4}$ are required per °C difference. So the extra requirements are $5.8 \times 2.5 \times 11.18 = 162.11$ kcal.

So totally the thermoneutral heat requirements are 1951 kcal. VERSTEGEN et al. (1973) showed that the efficiency of *ME* for maintenance below the lower critical temperature is 100 percent.

Thus $1000/3022 \times 77.9 = 25.8$ g extra feed are required for maintenance. In this way maintenance requirement was corrected for any difference that may occur between heat requirements and heat production for all pigs fed restrictedly.

4.1.2.4. Computations

With Eqns, 2.18 and 2.12 the daily protein and fat deposition at each day on test were calculated per pig (restrictedly fed pigs) or per pen (ad libitum fed pigs). The course of the daily protein and fat deposition was calculated in relation to bodyweight within breed, testing method and sex for the pigs fed restrictedly. For pigs fed ad libitum the same calculations were made for groups descending from heavy sires and for groups from small sires.

The differences in level in daily protein and fat deposition at the subsequent weights were tested by calculating the least significant difference (LSD) with $p \leqslant 0.05$.

For the pigs fed restrictedly the average daily protein and fat deposition during the whole test period, the standard deviation and the coefficients of variation were computed within breed, testing method and sex. In the pigs fed ad libitum the averages, standard deviations and coefficients of variation of the daily protein and fat deposition were calculated for the first 4 months of the fattening period, the total fattening period and between 25 and 100 kg bodyweight.

To estimate the contrasts between the breeds, between the males, castrated males and females and to estimate the components of variance of the traits, daily protein and fat deposition, the statistical Model 4.1. was analysed by the method of least squares (HARVEY, 1960):

$$y_{ijklm} = \mu + r_i + s_{ji} + d_{kji} + g_l + e_{ijklm} \qquad \text{(Model 4.1).}$$

In which:

y_{ijklm} = value of the *m*th animal
μ = least squares mean
r_i = effect of the *i*th breed ($i = 1, 2$)
s_{ji} = effect of the *j*th sire ($j = 1, 85$)
d_{kji} = effect of the *k*th dam ($k = 1, 405$)
g_l = effect of the *l*th sex ($1 = 1, 3$)
e_{ijklm} = error.

TABLE 4. 7. Components of variance and E (MQ).

Components of variance	df.	E (MQ)
Breed	1	$\sigma_e^2 + 3.44\,\sigma_d^2 + 19.53\,\sigma_s^2 + K_r^2$
Sire	83	$\sigma_e^2 + 3.11\,\sigma_d^2 + 15.37\,\sigma_s^2$
Dam	320	$\sigma_e^2 + 3.30\,\sigma_d^2$
Sex	2	$\sigma_e^2 + K_g^2$
Error	913	σ_e^2

The data for these computations were sampled so that from each sire data were known of 2 litters and 2 males and/or 2 females and/or 2 castrated males per litter. The *k* values to estimate the components of variance were calculated according to HENDERSON (1) – method (HENDERSON, 1953). The *E*(*MQ*) for the effects presented in Model 4.1. are given in Table 4.7. The heritabilities for both traits, daily protein and fat deposition, were estimated from the sire component in Model 4.1. If all effects were considered to be random their relative contributions to the total variance in Model 4.1. were calculated. The *k* values used for breed and sex were 157.31 and 421.14.

For the pigs fed restrictedly, the phenotypic correlation coefficients between daily protein and fat deposition, and some growth and carcase traits were calculated within litters, breeds, testing methods and sexes. As for the females in the combined test only the average results of bodyweight gain, feed conversion and backfat thickness were known, the between litter correlation coefficients were calculated in two groups. In the ad libitum fed pigs, the phenotypic correlation coefficients between daily protein and fat deposition, and growth rate, feed conversion and carcase traits were calculated from the averages per pen for the various traits for the first 4 months of the fattening period and then for the total period.

4.2. RESULTS

4.2.1. *Daily protein and fat deposition*

4.2.1.1. Pigs fed restrictedly

The course of the daily protein and fat deposition in relation to bodyweight is presented in Figure 4.1. In all groups the daily protein deposition increased with increasing bodyweight from 25 to 95 kg. Males showed this increase most strikingly. They had a maximum deposition of about 180 g at a bodyweight of 95 kg. The differences in fat deposition between the groups were smaller than for protein. The order of the groups in level of fat deposition was reversed to that for protein deposition. From 65–70 kg onwards the daily fat deposition in all groups increased more slowly. Between 85 and 95 kg no further increase in daily fat deposition was observed in males.

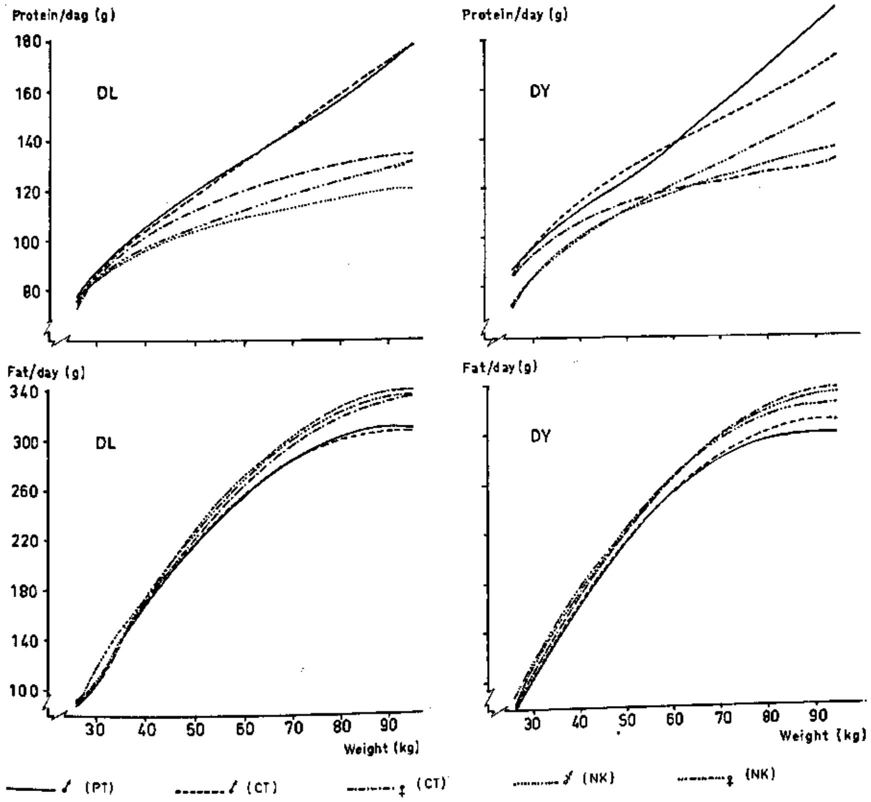

FIG. 4.1. Mean change in daily protein and fat deposition in restrictedly fed pigs.

Breed differences

The course of the daily protein and fat deposition in DY and DL pigs was compared within testing methods and within sexes. As in the combined test of DY the numbers of pigs were small and the pigs were related, only males in performance testing and females and castrated males in castrated males/females test were used for this comparison. In Figure 4.2, the difference in daily protein and in fat deposition between DY and DL pigs in relation to bodyweight is presented.

In castrated males and females the calculated protein deposition in DL pigs was higher than in DY initially. From 40–50 kg onwards significant ($p < 0.05$) differences in protein deposition were observed in favour of the DY pigs. In DY males the daily protein deposition was significantly higher than in DL males during the whole testing period. Differences between the breeds at the end of the testing period were about 14 g in castrated males and males, and 20 g in females.

Also the differences between breeds in daily fat deposition increased during the whole period. From 40–50 kg onwards the castrated males and females of

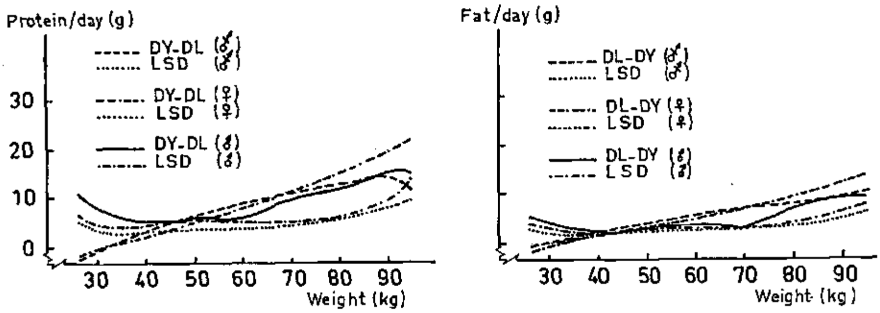

FIG. 4.2. Mean difference in daily protein and fat deposition between the breeds, DY and DL.

the DY breed showed a significantly lower daily fat deposition than those of the DL breed. In males the difference in this trait was smallest between 40 and 50 kg. Except for this range the fat deposition in DY was significantly lower than in DL males.

Differences between sexes

Sex differences in daily protein and fat deposition in relation to bodyweight were calculated within testing methods and within breeds. Therefore a comparison of males and females followed from data of the combined test and a comparison of castrated males and females from the castrated males/females test. In Figure 4.3. the differences are presented.

The differences in daily protein deposition between DL males and females

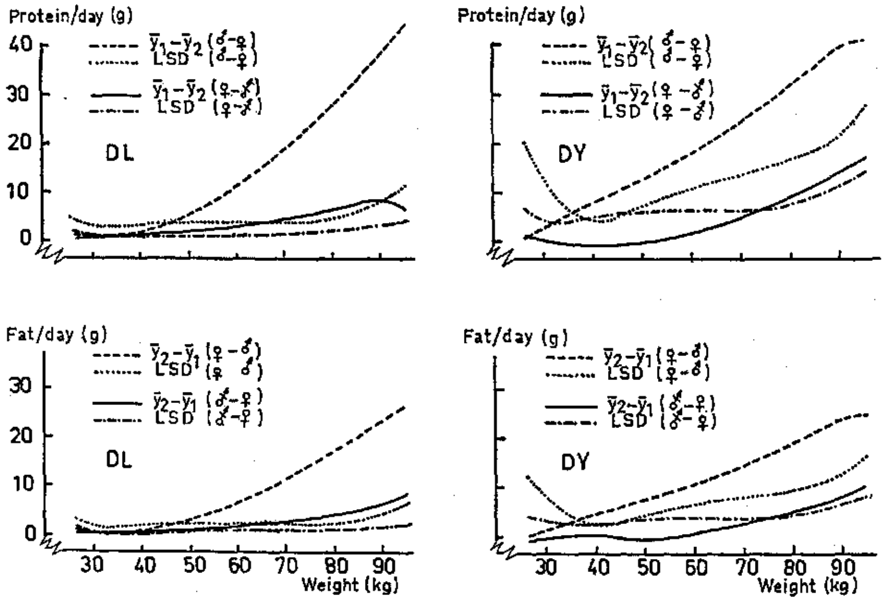

FIG. 4.3. Mean differences in daily protein and fat deposition between sexes.

were very small until 40 kg. In DY breed this difference increased almost linearly. At the end of the testing period the difference between males and females in both breeds was about 40 g per day. The difference in daily protein deposition between females and castrated males was smaller than between males and females. The difference was significant in DL from about 40 kg onwards and in DY from 75 kg. At the end of the testing period the difference between females and castrated males was about 7 g in DL and about 16 g in DY.

The daily fat deposition in males was significantly lower in males than in females from 40 kg onwards. By the end of the fattening period the difference between males and females had increased to about 24 g in both breeds. The difference in daily fat deposition between females and castrated males was less than 2 grams in both breeds until 60 kg. Afterwards the difference increased rapidly until 7 g in DL and 10 g in DY at 90–95 kg. From about 50 kg onwards the fat deposition in DL breed was significantly lower in females than in castrated males. In DY breed this difference was only significant from 80 kg onwards.

4.2.1.2. Pigs fed ad libitum

The course of the daily protein and fat deposition for these pigs is presented in Figure 4.4. Separate computations were done for progeny groups of heavy

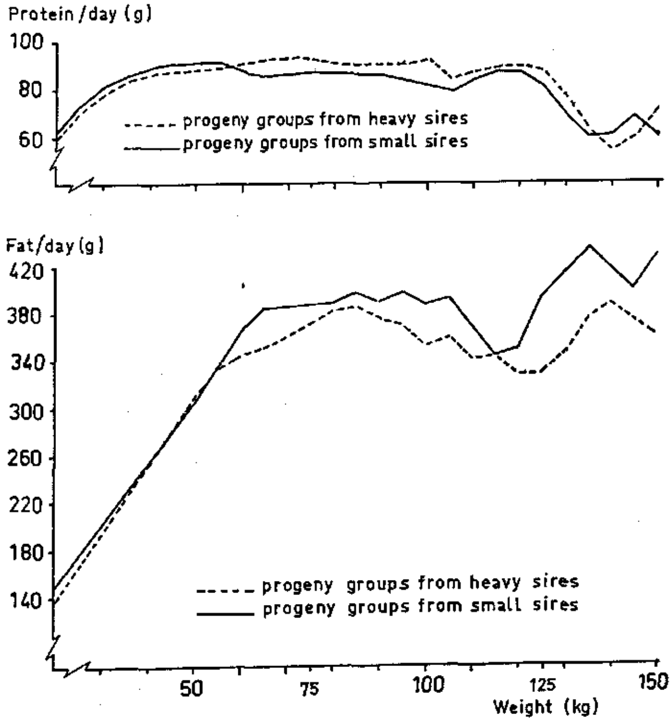

FIG. 4.4. Mean change in daily protein and fat deposition in ad libitum fed pigs.

and small sires. The shape of the curves are quite similar for the two groups. The decrease in daily protein and fat deposition at 105 kg occurs at the same time 50% of the pigs were slaughtered. At 120 kg the protein deposition decreased rather rapidly. The increase in daily fat deposition was approximately linear until 65 kg to 370 g per day. Afterwards the daily fat deposition remained rather constant.

4.2.2. *Variation and some sources of variance in daily protein and fat deposition*

4.2.2.1. Pigs fed restrictedly

The averages, standard deviations and coefficients of variation of daily protein and fat deposition in the whole testing period are presented in Table 4.8. Differences in means between breeds were tested within testing methods and within sexes. The average daily protein deposition of males in performance testing and of females and castrated males in castrated males/females testing of the DY breed were significantly higher than in the DL breed ($p < 0.05$). However fat deposition showed opposite results for these three groups ($p < 0.005$). Breed comparison by means of the combined test showed that only DY males had a higher daily protein deposition ($p < 0.005$). Sex differences were tested within breeds and testing methods. In DL breed, the differences in both traits between males and females and between castrated males and females were significant ($p < 0.05$). In DY breed only the difference from 3.89 g in daily protein deposition between females and castrated males was not significant.

Differences between breeds and between sexes were also estimated by means of least squares and Model 4.1. The contrasts between DL and DY and between sexes are presented in Table 4.9. All contrasts in this table were significant ($p < 0.005$). Components of variance were estimated for the effects in Model 4.1 (Table 4.10). The difference in contribution to the total variance between

TABLE 4.8. Averages, standard deviations and coefficients of variation of the computed daily protein and fat deposition in restrictedly fed pigs.

				Protein deposition			Fat deposition		
Breed	Testing method	Number of pigs	Sex	$\bar{x}$ (g)	s (g)	cv (%)	$\bar{x}$ (g)	s (g)	cv (%)
DY	PT	30	*m*	136.37	7.87	5.77	220.76	5.91	2.68
	CT	6	*m*	134.17	4.04	3.01	225.01	6.06	2.69
		6	*f*	115.27	5.85	5.08	238.02	7.74	3.25
	NK	32	*cm*	112.73	9.59	8.51	237.40	8.77	3.69
		32	*f*	116.53	8.10	6.95	233.33	6.51	2.79
DL	PT	188	*m*	127.56	9.64	7.56	224.15	7.01	3.12
	CT	132	*m*	126.18	10.58	8.38	225.15	7.63	3.39
		126	*f*	113.26	10.90	9.62	236.85	8.59	3.63
	NK	508	*cm*	105.31	10.48	9.95	243.64	8.89	3.65
		506	*f*	109.03	10.10	9.26	240.63	8.39	3.49

TABLE 4.9. Mean differences in daily protein and fat deposition between breeds and sexes.

Differences	Protein (g)	Fat (g)
DY–DL	7.5	– 4.9
m – *f*	13.5	–11.9
m – *cm*	17.7	–14.9
f – *cm*	3.8	– 2.9

TABLE 4.10. Relative contribution (%) to the total variance for daily protein and fat deposition by the components: breed, sex, sire, dam and error.

Components	Protein	Fat
Breed	18.6	12.3
Sex	8.9	9.8
Sire	3.2	1.6
Dam	22.3	17.9
Error	47.0	58.4

TABLE 4.11. Average daily protein and fat deposition of ad libitum fed pigs.

	Protein			Fat		
	$\bar{x}$ (g)	s (g)	cv (%)	$\bar{x}$ (g)	s (g)	cv (%)
First part of the fattening period	81.82	13.93	17.03	294.70	66.56	22.59
Total fattening period	78.28	12.65	16.16	319.02	70.89	22.22
Period between 25 and 100 kg	86.84	6.79	7.82	317.23	30.80	9.71

dam and sire component is striking. The estimated heritabilities for daily protein and fat deposition were 0.176 and 0.080.

4.2.2.2. Pigs fed ad libitum

Averages of the traits were calculated for the first 4 months of the fattening period, the total period and from 25–100 kg (Table 4.11). It follows from this table that the daily protein deposition in these pigs is about 33% lower and the daily fat deposition 23% higher than in the restrictedly fed pigs. The large standard deviations and the coefficients of variation for both traits proved to be caused by a testing period based on days on test. If the traits were calculated between 25 and 100 kg than the variation in protein deposition in the ad libitum fed pigs and the restrictedly fed pigs was rather similar. However the variation in fat deposition remained twice as much.

4.2.3. *Phenotypic correlation coefficients between daily protein and fat deposition, and some growth and carcase traits*

4.2.3.1. Pigs fed restrictedly

The values of the correlation coefficients between daily protein and fat deposition, and some growth and carcase traits are presented in Tables 4.12 and 4.13. It followed from these tables that the values of the correlation coefficients between daily protein and fat deposition and gain and feed traits were all significant ($p < 0.005$) and mostly higher than 0.7. The values of the correlation coefficients between daily protein and fat deposition and carcase traits and the index values were partly significant and mostly lower than 0.4. Another general tendency from these tables was that the absolute values of the correlation coefficients between daily protein deposition and gain and feed traits were higher, and between daily protein deposition and carcase traits were lower than for daily fat deposition.

Comparison of the values of the correlation coefficients within breeds and testing methods showed that the values in males were mostly lower than in females; those in females were mostly lower than in castrated males. However these sex differences were significant in 3 cases only. These were between DL females and castrated males. The correlation coefficients were between daily protein deposition and feed conversion ($p < 0.01$), daily protein deposition and net daily gain ($p < 0.05$) and between daily fat deposition and feed conversion ($p < 0.01$).

No significant differences in correlation coefficients between the various traits in the two breeds were observed.

4.2.3.2. Pigs fed ad libitum

The values of the correlation coefficients between daily protein and fat deposition and daily gain, feed conversion and carcase traits are given in Table 4.14. The values of the correlation coefficients calculated during the first 4 months of the fattening period proved to be slightly higher in general than those estimated during the whole period. Only the value of the correlation coefficient between daily fat deposition and feed conversion proved to be significant.

There were some differences between the values of the correlation coefficients in restrictedly fed pigs and those in ad libitum fed pigs. Therefore Table 4.15 gives the differences in values of the correlation coefficients, estimated in ad libitum fed DL females during the first part of the fattening period and in the restrictedly fed DL females. Testing the differences showed that almost all differences were significant. Especially striking are the higher values of the correlation coefficients between daily protein deposition and quantity of meat and between fat deposition and backfat thickness. The value of the correlation coefficient between daily protein deposition and bodyweight gain decreased significantly. The value of the correlation coefficient between daily protein deposition and daily fat deposition was –0.808 in restrictedly fed females and +0.157 in ad libitum fed pigs.

TABLE 4.12. Values of the correlation coefficients between the calculated daily protein deposition and some growth and carcase traits in restrictedly fed pigs.

Traits	DL					DY				
	PT	CT		NK		PT	CT		NK	
	m	*m*	*f*	*cm*	*f*	*m*	*m*	*f*	*cm*	*f*
Daily gain (from cubic curve)	0.986	0.989	0.990	0.991	0.990	0.980	0.966	0.999	0.996	0.993
Daily gain	0.924	0.947	0.952	0.970	0.975	0.979	0.988	0.983	0.992	0.978
Feed conversion	–0.724	–0.762	–0.811	–0.930	–0.880	–0.754	0.397	–0.986	–0.948	–0.861
Productive feed conversion	–0.964	–0.969	–0.985	–0.981	–0.980	–0.947	–0.507	–0.995	–0.992	–0.973
Net daily gain				0.893	0.832				0.924	0.882
Ham percentage				0.317	0.276				0.584	0.096
Eye muscle percentage				0.263	0.263				0.173	0.168
Ham + eye muscle perc.				0.373	0.363				0.534	0.169
Meat qualitty				–0.037	–0.095				0.230	0.049
Backfat thickness	–0.136	0.023	–0.159	–0.283	–0.238	–0.029	0.961	0.126	–0.232	–0.419
Fat/day	–0.729	–0.716	–0.816	–0.818	–0.806	–0.696	0.503	–0.052	–0.927	–0.796
Index	0.272	0.153				0.193	–0.751			
df.	92	64	61	252	251	13	1	1	14	14
$p \leqslant 0.05$ $\lvert r \rvert \geqslant$	0.170	0.205	0.209	0.105	0.105	0.441	0.988	0.988	0.426	0.426
$p \leqslant 0.01$ $\lvert r \rvert \geqslant$	0.239	0.286	0.293	0.149	0.149	0.592	0.999	0.999	0.574	0.574

TABLE 4.13. Values of the correlation coefficients between the calculated daily fat deposition and some growth and carcase traits in restrictedly fed pigs.

Traits	DL					DY				
	PT	CT		NK		PT	CT		NK	
	m	*m*	*f*	*cm*	*f*	*m*	*m*	*f*	*cm*	*f*
Daily gain (from cubic curve)	–0.609	–0.615	–0.731	–0.734	–0.718	–0.553	0.709	–0.999	–0.895	–0.726
Daily gain	–0.534	–0.613	–0.713	–0.777	–0.717	–0.560	0.629	–0.994	–0.893	–0.708
Feed conversion	0.717	0.831	0.785	0.907	0.841	0.823	0.870	0.996	0.950	0.808
Productive feed conversion	0.873	0.849	0.892	0.899	0.890	0.882	0.484	1.000	0.960	0.906
Net daily gain				–0.633	–0.523				–0.754	–0.589
Ham percentage				–0.404	–0.249				–0.628	–0.233
Eye muscle percentage				–0.323	–0.288				–0.165	–0.189
Ham + eye muscle perc.				–0.469	–0.361				–0.566	–0.252
Meat quality				0.058	0.081				–0.228	0.018
Backfat thickness	0.196	0.218	0.296	0.385	0.304	0.019	0.718	–0.052	0.323	0.293
Protein/day	–0.729	–0.716	–0.816	–0.818	–0.806	–0.696	0.503	–0.997	–0.927	–0.796
Index	–0.497	–0.525				–0.456	–0.894			
df.	92	64	61	252	251	13	1	1	14	14
$p \leqslant 0.05$ $\|r\| \geqslant$	0.170	0.205	0.209	0.105	0.105	0.441	0.988	0.988	0.426	0.426
$p \leqslant 0.01$ $\|r\| \geqslant$	0.239	0.286	0.293	0.149	0.149	0.592	0.999	0.999	0.574	0.574

TABLE 4.14. Values of the phenotypic correlation coefficients between protein and fat deposition, and daily gain, feed conversion and carcase traits in ad libitum fed pigs.

Traits	First part of fattening period		Total fattening period	
	Protein	Fat	Protein	Fat
Daily gain	0.761	0.757	0.617	0.789
Feed conversion	–0.381	0.775	–0.402	0.450
Productive feed conversion	–0.383	0.826	–0.356	0.652
Lean cuts	0.743	0.398	0.651	0.084
Fat cuts	0.231	0.782	0.280	0.741
Offal	0.413	0.286	0.542	0.131
Backfat thickness	0.034	0.796	–0.015	0.631
Meat quality	–0.135	0.022	0.326	0.067
Protein/day		0.157		0.007
Fat/day	0.157		0.007	

df = 27 $|r \geqslant 0.31|$ $p \leqslant 0.05$
$|r \geqslant 0.43|$ $p \leqslant 0.01$

TABLE 4.15. *Difference in the values of correlation coefficients between daily protein and fat deposition, and daily gain, feed conversion and carcase traits for pigs fed restrictedly and ad libitum.*

Traits	Protein			Fat		
	Restrictedly	Ad libitum	Difference	Restrictedly	Ad libitum	Difference
Daily gain (from cubic curve)	0.990	0.761	**	–0.721	0.757	**
Feed conversion	–0.869	–0.384	**	0.831	0.775	n.s.
Prod. feed conversion	–0.981	–0.383	**	0.890	0.826	n.s.
Lean cuts	0.363	0.743	**	–0.361	0.398	**
Backfat thickness	–0.223	0.034	n.s.	0.302	0.796	**
Protein/day				–0.808	0.157	**
Fat/day	–0.808	0.157	**			

* $p \leqslant 0.05$
** $p \leqslant 0.01$

4.3. DISCUSSION

KIELANOWSKI (1968 and 1972) and FOWLER et al. (1973) have stated that daily protein and fat deposition are important parameters for the selection for meat production traits in pigs. According to these authors, these parameters are more closely related to the aim of breeding than any others. FOWLER et al. (1973) defined this aim as increasing the quantity of protein from a given amount of feed. According to them the selection on bodyweight gain, feed conversion and carcase traits should be replaced by selection for lean tissue growth rate or lean tissue feed conversion.

However it is not sufficient to select only for the highest amount of protein from a given amount of feed, as the following important aspects of meat production are not included:

- the aim of breeding is not only producing more protein but to increase the amount of edible parts or in other words to maximize the production of expensive edible parts; (Hence the amount of protein in skin, bristles, fatty tissue, bones, viscera and offal should be as small as possible. OSLAGE (1965) estimated the amount of protein in these parts at nearly 50% of all protein.)
- apart from the amount of protein there are qualitative traits that are important in meat production, e.g. a minimum amount of intramuscular fat should be available;
- the constitution of the producing animal should be taken into account; no abnormalities in the metabolism in the muscle should occur.

Therefore selection for daily protein and fat deposition cannot be considered as a complete alternative for index selection based on bodyweight gain, feed conversion and carcase traits. Daily protein and fat deposition may be very important as components in the selection index, because they take into account the differences in feed intake of the pig and the chemical composition of the carcase or parts of it.

The relation of feed intake to bodyweight gain, feed conversion and carcase traits has been reviewed (cf. VANSCHOUBROEK et al., 1967; BRAUDE, 1972; DAVIES and LUCAS, 1972a, b). Daily bodyweight gain and backfat thickness will increase with increase of feed intake. The relation between feed conversion and feeding level is more complicated. Increasing a low feeding level will decrease the feed conversion, but a rise above a certain level (about 70–80% of the ad libitum level) will cause an increase of the feed conversion. This curvilinear relation of these two parameters in caused mainly by two factors:

- the maintenance part of feed intake necessary per kg bodyweight gain;
- the energy content per unit of bodyweight gain.

If one plots the feed intake above maintenance against bodyweight gain (feed minus maintenance/bodyweight gain), there will be a continuous rise in productive feed conversion.

ZAGOŽEN and SCHRÖDER (1970) found that using productive feed conversion instead of total feed conversion increased the values of the correlation coefficients between feed conversion and carcase traits by 20% to 25%. When feeding was ad libitum this increase was higher than with restricted feeding. The same tendency was found by FOWLER (1966).

When the productive feed conversions of pigs have to be compared, it is necessary to know the relation between the mean daily bodyweight gain and mean production feed. Then pigs which excel in that respect can be chosen for reproduction. Minimum limits for feed intake should be set because there exist large differences in feed intake between and within breeds (BAUMGARDT, 1969). The differences in bodyweight gain with the same amount of productive feed are mainly caused by differences in the proportions of fat and protein deposited. From the results of KOTARBINSKA (1968) and VAN ES (1970) who found that per g protein about 3 g water were also deposited and that fat gain partly replaces the water gain, it is clear that muscle gain is about three times as efficient as fat gain.

In the present investigations it was studied whether the traits, protein and fat deposition, are usable parameters for the selection towards a better suitability for meat production. In Chapter 3, a number of equations with which the protein and fat deposition can be calculated were tested. Data obtained from ad libitum fed pigs and from restrictedly fed pigs (data from a testing station) were used to calculate:

- the course of daily protein and fat deposition in relation to bodyweight;
- the variation in daily protein and fat deposition between pigs;
- the relation between daily protein and fat deposition and daily bodyweight gain, feed conversion and carcase traits.

Daily protein and fat deposition

From the literature data it is clear that daily protein deposition increases in the first part of the fattening period and decreases in the latter part. The literature is not consistent about the weight at which the decrease starts. GÄDEKEN (1971) stated that selection for bodyweight gain and meat production has increased the bodyweight at which the decrease in protein deposition starts. Moreover the protein increases more in the first part and towards a higher weight in males and females than in castrated males. The results from restrictedly fed pigs found in this study and given in Figure 4.1, are in good agreement with data given in the literature.

The differences between females and castrated males, however, are smaller and occurred at a higher weight than in the results published by LUDVIGSEN and THORBEK (1955), PIATKOWSKI and JUNG (1966), and JUST NIELSEN (1970). KIELANOWSKI (1972b) suggested that the maintenance requirement for fast growing animals is higher than other animals. Then in females the computed protein deposition was relatively lower than in males because of this underestimation of maintenance. Computed fat deposition was higher on the other hand. This may explain why the difference in protein deposition between females and castrated males found in this study was smaller and occurred at a higher bodyweight than in the literature.

From 50 kg bodyweight onwards the differences between the breeds Dutch Landrace and Dutch Yorkshire were significant. This finding agreed well with the fact that the Large White and Yorkshire breeds usually have a somewhat higher daily bodyweight gain than the Landrace types. As far as is known the N balances of these breeds have not been compared.

The course of protein and fat deposition in ad libitum fed pigs was different from that in restrictedly fed pigs. Between 40 and 100 kg bodyweight the daily protein deposition was constant and the maximum deposition was about 90 g per day. From the literature it was expected that the protein deposition in ad libitum fed pigs would be at least as high as in restrictedly fed pigs. Two factors, however, may have contributed to the level of protein deposition. Firstly the wastage of feed has not been taken into account. Secondly the maintenance requirement of the restrictedly fed pigs housed singly and the ad libitum fed pigs housed in groups is assumed to be the same. The activity of the pigs housed in groups especially during the weighing, may have caused an underestimation of maintenance and thus also an underestimation of protein deposition. On the other hand the fat deposition is then overestimated. At about 100 kg the activity would have had an influence because some pigs reached sexual maturity around 100 kg and showed oestrus. In the next part the effect of wastage will be discussed.

Fat deposition increased linearly up to 70 kg bodyweight in ad libitum fed pigs. From 70 kg bodyweight onwards, the fat deposition remained fairly constant, whereas in the reviewed literature the fat gain continued to increase up to 90–100 kg bodyweight. This difference in results is caused by the feed intake which in this study remained nearly constant from 70 kg onwards. In the literature, however, feeding level increased above 70 kg bodyweight.

Variation in daily protein and fat deposition

It has already been discussed that protein and fat deposition may be used in a selection index for suitability for meat production. These traits should be replacements for daily bodyweight gain and feed conversion. One very essential point is that any trait used for selection should have variation because the effect of selection is proportional to this variation. The coefficient of variation may be used as index for this variation.

In Table 4.16 the various coefficients of variation for the traits of the restrictedly fed pigs per breed, per testing method and per sex have been given. The traits involved are daily protein deposition, daily fat deposition, daily gain and feed conversion. This table shows that the coefficient of variation for protein deposition is 1.6 times as high as that for daily gain and feed conversion. The coefficient of variation for fat deposition, however, is about 30% less than for

TABLE 4.16. Coefficient of variation (%) of the traits: daily protein deposition, daily fat deposition, daily gain and feed conversion.

Breed	Testing method	Sex	Protein	Fat	Daily gain	Feed conversion
DY	PT	*m*	5.77	2.68	3.62	3.66
	CT	*m*	3.01	2.69	2.07	3.68
		f	5.08	3.25	2.54	3.18
	NK	*cm*	8.51	3.69	4.85	5.54
		f	6.95	2.79	4.07	4.22
DL	PT	*m*	7.56	3.12	4.65	4.64
	CT	*m*	8.38	3.39	5.30	5.49
		f	9.62	3.63	5.57	4.51
	NK	*cm*	9.95	3.65	5.31	6.15
		f	9.26	3.49	5.08	5.70

feed conversion and daily gain. In pigs fed ad libitum the coefficient of variation for daily protein deposition was about 17% and for fat deposition 22%. They were the same in the first part of the fattening period and over the whole fattening period. Calculated over the weight range 25 to 100 kg, these coefficients of variation were 7.82% and 9.71% for daily protein and fat deposition, respectively. These differences in coefficients of variation may be because the fattening period was based on age instead of weight and the weight range varied between the groups of pigs. The initial weight of the groups was 16.3 kg (± 2.34) and the final weight was 106.0 kg (± 7.62).

In the literature no coefficients of variation of daily protein and fat deposition have been given. From the investigations of PIATKOWSKI and JUNG (1966), it was calculated that the coefficient of variation of protein deposition in males, castrated males and females was 7.41%, 6.85%, and 5.27%, respectively (15 animals per sex). Calculations from JUST NIELSEN's (1970) data on chemical composition of the empty body of 80 pigs showed that the coefficients of variation in daily protein and fat deposition were 7.44% and 17.18%, respectively. The variation in fat deposition was higher than in protein deposition. This difference may have been caused by the variation in slaughter weight, mean 90.9 kg, *s.d.* 4.02 kg. This may be seen in Figure 2.2, which shows that fat deposition was highest between 80 and 95 kg bodyweight.

The differences in protein deposition between Dutch Landrace (DL) and Dutch Yorkshire (DY) were nearly all significant. GÄDEKEN (1971), however, concluded that between white-skinned breeds hardly any differences in daily protein deposition exist. But there is evidence that DY may have more meat than DL. However ham and eye muscle percentage are about 1% higher in DL (KROES, 1969). Therefore the meat quantity in the other parts should be higher in DY than in DL. It can be concluded that the proportions of muscle in different parts of the body are not the same in DL as in DY. This statement is supported by MINKEMA et al. (1974) who found more shoulder meat in DY than in DL ($p \approx 0.055$).

KIELANOWSKI (1972) estimated that males deposit 35% more protein than castrated males, FARRIES and KALLWEIT (1969) estimated this difference at 30% and PIATKOWSKI and JUNG (1966) at 28%; in this investigation 17% was found. Also females deposit more protein than castrated males: 14% (KIELANOWSKI, 1972), 11% (PIATKOWSKI and JUNG, 1966) and 3% (in this investigation). It has been pointed out before that the maintenance requirement may be higher in more meat-type pigs. Therefore the small difference in calculated protein deposition between sexes in this investigation may be less than in the literature data. It has been examined whether the productive feed intake with restricted feeding has differed between the sexes. The maximum difference found was 30 g between the groups. Moreover the feed intake in males was lower than in females and castrated males. These differences would have caused a difference of about 1 to 2 g in protein deposition between sexes.

Ad libitum fed animals (DL-females) deposited 12% less protein and 32% more fat than restrictedly fed females in the weight range 25–100 kg. On the basis of the literature the ad libitum fed pigs should retain at least as much protein as the restrictedly fed pigs. The feed intake in the period 25–100 kg was 2.58 kg in ad libitum fed pigs and 2.21 kg in restrictedly fed (DL) females. However wastage of feed from the self-feeders was not taken into account. Wastage will cause a reduction in productive feed and thus in energy gain. Equations 2.18 and 2.12 show that protein deposition would be estimated higher and fat deposition less if wastage was subtracted. Per % of reduced feed the calculated protein deposition will increase linearly by 1.26 g and fat deposition will decrease linearly by 5.85 g. It is generally accepted that some % of feed is wasted in a system of ad libitum feeding from a self-feeder. Thus there may be an underestimation of protein deposition and overestimation of fat deposition caused by wastage. VAN ES (1971) and also FOWLER and LIVINGSTONE (1972) have shown that a higher feeding level will increase the amount of intramuscular fat so that the value of LBM/protein will decrease. This may also cause a systematic underestimation of protein deposition.

Heritability is an important parameter in selection. In the pigs fed restrictedly, the heritabilities computed for daily protein and fat deposition were 0.176 and 0.080, respectively. For daily gain, feed conversion and backfat thickness the heritability was 0.249, 0.231 and 0.545, respectively. These three latter values are in good agreement with data from the literature (cf. FLOCK, 1968). Although the data used was limited, the perspectives for the values of the heritability of calculated protein and fat deposition are not very good. When better equations are available to compute protein and fat deposition, new calculations should be done. As far as is known, only MORE O'FERRALL and TIMON (1968) have estimated heritabilities of protein and fat deposition. From a selection experiment over 12 generations of mice they found a realized heritability of 0.09 (± 0.09) for protein and of 0.35 (± 0.10) for fat.

Relation between protein and fat deposition, daily gain, feed conversion and carcase traits

The values of the phenotypic correlation coefficients of protein and fat deposition with daily gain, feed conversion and carcase traits are given in Tables 4.12 and 4.13 (restrictedly fed pigs) and in Table 4.14 (ad libitum fed pigs). When the results from ad libitum fed pigs are interpreted it should be kept in mind that there is only a small number of groups (29). Moreover it cannot be quantified how much the results are influenced by a difference in specific environment per pen (wastage, activity, size of groups etc.).

The value of the correlation coefficient between daily gain and protein deposition would be very high (nearly 1) if the amount of feed above maintenance is the same for all animals at the same weight. This is true because a more rapid growth with the same amount of feed at the same liveweight can nearly only be caused by a higher protein deposition.

According to VAN ES (1972), the variation in maintenance requirement seems to be limited and the costs of synthesizing protein and fat is considered to be independent of feeding level and stage in the fattening period. The restrictedly fed pigs used in this study were fed according to weight (see Table 4.1) and the calculations done showed that there was hardly any difference in the amount of productive metabolizable energy (ME_P). Therefore the high values of the correlation coefficients between protein and fat deposition and gain and feed traits in the restrictedly fed pigs can be explained mainly from the feeding system.

If it is assumed that in pigs fed according to bodyweight, daily gain and protein deposition are nearly the same kind of trait and the same is true for daily fat deposition and feed conversion, then the values of the correlation coefficients between carcase traits and protein and fat deposition are also nearly the same as those found for daily gain and feed conversion. In fact these values were nearly the same and also in good agreement with values found in the literature (FLOCK, 1968; METZ and POLITIEK, 1969).

If the feeding level varies continuously, the ratio of protein to fat will change continuously (DAVIES and LUCAS, 1972 a, b). Therefore the values of correlation coefficients will differ according to the feeding level applied. By analysing data from the energy and N balances, the dependency of the values of correlation coefficients on feeding level could be shown. The results of this analysis are given in Table 4.17 and they agree well with the results obtained for the ad libitum fed pigs (given in Table 4.14). From the literature it is clear that the protein deposition changes very little with feeding level above a certain amount of feed whereas fat deposition increases continuously with feeding level. The small values of correlation coefficients between protein deposition and fat deposition agrees very well with this finding (KIELANOWSKI, 1972). A negative value of the correlation coefficient between fat and protein deposition may be found if pigs with the highest protein deposition have a lower feeding level. The values of the correlation coefficients between protein deposition and meat and also between fat deposition and 'fat-cuts' were higher in ad libitum fed pigs than in restrictedly fed pigs. This may be caused partly by the much greater variation in weight at slaughter in ad libitum fed pigs than in restrictedly fed pigs. However also ZAGOŽEN and SCHRÖDER (1970) found higher values of the correlation coefficients between productive feed conversion and carcase traits in ad libitum fed pigs than in restricted fed pigs.

TABLE 4.17. Values of correlation coefficients between daily gain, and daily protein and fat deposition.

Data	Protein	Fat
BREIREM (1935)	0.835	0.664
LUND (1938)	0.444	0.545
LUDVIGSEN and THORBEK (1955)	0.404	0.921
JUST NIELSEN (1970)	0.730	0.632
VERSTEGEN (1971)	0.697	0.625
VERSTEGEN et al. (1973)	0.466	0.502

5. SUMMARY

In pig breeding it is quite common to select for bodyweight gain, feed conversion and slaughter quality. Various values have been found by different research-workers for the relationships between these traits. These differences in values have mainly been caused by differences between feeding levels and by those between chemical composition of carcases. Protein and fat deposition can be calculated from bodyweight gain and feed intake; these traits would take into account differences in feeding level and chemical composition of carcases better than bodyweight gain and feed conversion do.

Therefore an investigation was done

- to find out how precisely protein and fat deposition could be predicted from bodyweight gain, bodyweight and feed intake, and
- to study the variation in protein and fat deposition at restricted and ad libitum feeding and the relation between these factors, growth and carcase traits.

For the calculation of protein and fat deposition three models were obtained from data in the literature (EBC, EBK and MEK models – Section 2.3). These models were based on physiological data connected with bodyweight and feed utilization (maintenance, protein and fat deposition).

In the MEK model it was assumed that all ME was used for maintenance, protein and fat deposition according to the following equation:

$$ME = ME_M + c\,\Delta P + d\,\Delta F.$$

The EBC and EBK models started from the energy balance:

$$EB = 5.7\,\Delta P + 9.46\,\Delta F.$$

In order to estimate the amount of ME_P or EB that was used for protein and fat deposition, respectively, the research-workers calculated from literature or their own data the relationships between the components of growth. EB was calculated from ME using the equation

$$EB = (ME - ME_M) \times \text{efficiency}.$$

The equations that were used to calculate protein (ΔP) and fat (ΔF) deposition in the EBC, EBK and MEK models, were:

	EBC model	EBK model	MEK model
ΔP	$P/PW\,\dfrac{EB-9.46\Delta PWF}{5.7\,P/PW-9.46}$	$\dfrac{EB-9.46\Delta L_E}{5.7-9.46K}$	$\dfrac{d\Delta L_E-(ME-ME_M)}{dK-c}$
ΔF	$\dfrac{EB-5.7\Delta P}{9.46}$	$\dfrac{EB-5.7\Delta P}{9.46}$	$\dfrac{ME-ME_M-c\Delta P}{d}$

In these models 4 factors were varied:

- maintenance requirement: 80, 100 or 120 kcal $ME/kg^{3/4}$;
- efficiency for synthesizing protein and fat from ME_p. For the EBC and EBK models the same figure was assumed for protein as for fat: 0.55, 0.65 or 0.75. In the MEK model the ME costs (kcal/g) for synthesizing protein and fat were assumed to be: 16 and 13, 13 and 13, or 11.4 and 12.6;
- the ratio protein to protein + water in the EBC model: a constant value was assumed or a value was calculated from the amount of protein and water at each bodyweight. These amounts have been estimated using allometric equations;
- the amounts of protein, water and fat gain (in the EBC model) or the amount of bodyweight gain minus gut fill (in the EBK and MEK models). The alternative values of this factor have been obtained using linear or allometric equations between bodyweight and the amounts of ash and gut fill or gut fill.

The equations or values used for calculating the values of the 4 factors are shown in Table 3.4.

To judge the precision of the prediction of protein and fat deposition the following 4 traits were calculated:

- the level of protein and fat deposition;
- the values of correlation coefficients between calculated and found protein and fat deposition.

The data used consisted of energy and N balances from 6 different investigations, and results of chemical analysis of the empty body of pigs. In addition, bodyweight gain was estimated using a cubic curve in 3 sets of data mentioned above. Thus, totally 10 sets of data were available for the computations. For the computations the values of correlation coefficients between calculated and found protein and fat deposition were transformed by the Z transformation of FISHER.

With the statistical Model 3.1, the following effects were tested for each trait and each model:

- differences between sets of data,
- differences between factors, and
- differences between models.

The level of the four traits differed considerably between the various sets of data (Tables 3.5 and 3.7). In addition the interaction between data and factors was always significant. These interactions are also shown in Table 3.6 by the great differences between sets of data for the values of regression coefficients of the traits on the factors. The differences between sets of data might be caused by:

- differences between feeding level, feed composition, sex or breed;
- systematic differences between experimental procedures used by the research-workers for energy and N balances, weighings etc.

Computation of bodyweight gain from a cubic curve doubled the value of the correlation coefficient between calculated and found protein deposition in

JUST NIELSEN's data, compared with those, found by using the weight gain obtained from linear interpolation between 2 weighings. Using a cubic curve, in LUDVIGSEN and THORBEK's data the same value of correlation coefficient was found, and in BREIREM's data a lower value, compared with those obtained by calculating bodyweight gain from linear interpolation. The value of the correlation coefficient between calculated and found fat deposition in JUST NIELSEN's data was 0.970, using data from energy balances, compared with 0.257 using chemical analysis of the empty body. With reference to JUST NIELSEN (1970), it has been stated that more data are necessary to be sure about the value and precision of results from energy and N balances or from comparative slaughter techniques.

It has been indicated that the interactions between factors and sets of data have been partly caused by systematic differences in the various sets of data between bodyweights of the pigs (Table 3.14).

The relative contribution of the variance in calculated protein and fat deposition to differences between sets of data was 60 to 70% in the three models; the relative contribution to this effect by the variance in the value of correlation coefficients between calculated and found protein and fat deposition was 95 to 99% (Table 3.8). The relative contribution of the variance in protein and fat deposition to the factors, maintenance and efficiency was – excluding protein deposition in the MEK Model – considerably higher than their contribution to the other two factors.

If a higher maintenance requirement, a lower efficiency or a greater amount of water in the bodyweight gain were considered, the protein deposition and the value of the correlation coefficient between calculated and found protein deposition increased; however, then the fat deposition and the value of correlation coefficient between calculated and found fat deposition decreased (Tables 3.6 and 3.15). These changes in protein and fat deposition follow from the equations in Section 2.3, but they can also be explained by the difference between energy content of protein and fat. The changes in the values of correlation coefficients between calculated and found protein and fat deposition has been explained by a non-linear relationship between calculated and found protein and fat deposition.

It is doubtful, whether the highest values of the correlation coefficients between calculated and found protein deposition also gave the best prediction of these traits.

There were only small differences between the 3 models (Table 3.10). The value of 4.6838 for *LBM*/protein in the EBK and MEK models was lower than it should be, if based on the average bodyweight of the pigs in the various sets of data. Therefore with this value, protein deposition was overestimated and fat deposition was underestimated. The values of correlation coefficients between calculated and found protein deposition were significantly lower in the MEK model than in the EBC and EBK models.

The equations used for the calculation of protein and fat deposition in Chapter 4 were based on the EBK model. To make a choice between the different combinations of the 4 factors it was assumed that:

- maintenance requirement is 100 kcal $ME/kg^{3/4}$,
- protein deposition using N balances was overestimated by 15.5%, and
- 'real' EB was: 9.46 ΔF (found) + 5.7 (1−0.845) ΔP (found).

If this 'real' EB was taken into account, a value of 0.62 for the factor efficiency was obtained. For the factor LBM/protein the value was used, that was obtained at each bodyweight from the bodyweight and the amount of fat, gut fill and protein, using allometric equations (Table 3.3). ΔL_E was calculated from the bodyweight and amount of gut fill changing linearly in relation to weight.

The variation in protein and fat deposition and the relation between these traits, growth and carcase traits were investigated in pigs fed restrictedly and ad libitum. The data of the restrictedly fed pigs were obtained from 356 males, 540 castrated males and 770 females of the DL and DY breeds (Table 4.2). The data of the ad libitum fed pigs were obtained from 29 progeny groups (4 to 9 DL females per group) of sires (Table 4.4). The restrictedly fed pigs were tested from 25 to 100 kg bodyweight, and the feed was adjusted according to liveweight (Table 4.1). The ad libitum fed pigs got the same ration. They were fattened – starting at an age of about 9 weeks – for 4 or 6 months. The pigs were divided at random between treatments within litters and within pens. The bodyweight at each day was computed using a cubic curve. For the restrictedly fed pigs it was assumed that the feeding level was proportional to the feeding schedule advised (Table 4.1). For the ad libitum fed pigs the daily feed intake was computed from the weekly intakes by the method of 'parabolic splines'.

The course of protein and fat deposition of restrictedly fed males, females and castrated males in relation to bodyweight was in rather good agreement with the data in literature (Figure 4.1). The protein deposition in castrated males and females of the DL breed was significantly lower than those in the DY breed from about 45 kg onwards; in males of DL breed the protein deposition was lower during the whole testing period. At the end of the testing period the difference between males and females was about +40 g protein per day. At that moment the difference between females and castrated males was +7 g protein in the DL breed and +16 g in the DY breed. The average difference between breeds and between sexes for the whole testing period are given in Table 4.9. The average daily protein deposition was 7.53 g higher in the DY breed than it was in the DL breed, and the fat deposition was 4.90 g lower in the DY breed. The differences between sexes were smaller than those mentioned in the literature. Probably, these smaller differences were partly caused by an underestimation of maintenance in pigs with a higher protein deposition. In ad libitum fed pigs the average daily protein deposition was about 25% lower than in restrictedly fed pigs, and the daily fat deposition was about 25% higher (Tables 4.8 and 4.11). These differences could be partly attributed to wastage of feed with self-feeders, by differences in activity between restrictedly fed pigs (housed individually) and the ad libitum fed pigs (housed in groups) and the possible influence of the feeding level on the ratio LBM to protein.

The coefficients of variation of daily protein deposition was 1.6 times higher than those of bodyweight gain and feeding level; the coefficients of variation of daily fat deposition were 30% lower. The values of the heritabilities of protein and fat deposition were 0.176 and 0.080. These values computed for the traits bodyweight gain, feed conversion and backfat thickness were 0.249, 0.231 and 0.545, respectively.

The values of correlation coefficients between protein deposition and bodyweight gain in restrictedly fed pigs were nearly +1. It was argued that these values were to be expected when the feeding schedule was according to bodyweight. The values of correlation coefficients between bodyweight gain and feed conversion, and carcase traits were nearly the same compared with those between protein and fat deposition, and carcase traits (Tables 4.12 and 4.13). The values of correlation coefficients between protein deposition, fat deposition, bodyweight gain and feed conversion in ad libitum fed pigs were significantly lower than those in restrictedly fed pigs (Table 4.15). The value of the correlation coefficient between bodyweight gain and protein deposition in ad libitum fed pigs was in rather good agreement with the value found in literature (Table 4.17). The value of correlation coefficient between protein deposition and lean cuts (0.743) and this between fat deposition and backfat thickness (0.796) in ad libitum fed pigs were significantly higher than those in restrictedly fed pigs. However one should keep in mind that only 29 groups of pigs were fattened ad libitum. To make clear the variation in protein and fat deposition and the relationships between these traits and bodyweight gain, feed conversion and carcase traits, it is necessary to collect more energy and *N* balances of pigs fed individually and at various feeding levels.

6. SAMENVATTING

In de varkensfokkerij is het gebruikelijk te selecteren op groei, voederverbruik en slachtkwaliteit. Voor de relaties tussen deze kenmerken worden door de diverse onderzoekers variërende waarden gevonden. Als oorzaken voor deze verschillen moeten zowel verschillen in voerniveau tussen varkens of groepen varkens als ook verschillen in chemische samenstelling tussen de karkassen verantwoordelijk worden gesteld. Eiwit- en vetaanzet zouden berekend kunnen worden uit de groei en voeropname, en deze kenmerken zouden méér dan groei en voederverbruik rekening houden met verschillen in voeropname en chemische samenstelling.

Daarom werd een onderzoek verricht om na te gaan:
- hoe nauwkeurig eiwit- en vetaanzet uit groei en voeropname kunnen worden berekend;
- welke variatie de kenmerken eiwit- en vetaanzet vertonen zowel bij ad libitum als beperkt gevoerde varkens, alsook hoe de relatie is tussen deze kenmerken en groei, voederverbruik en slachtkwaliteit.

Voor het berekenen van de eiwit- en vetaanzet uit groei en voeropname werden een drietal modellen verkregen aan de hand van literatuurgegevens (EBC-, EBK-, en MEK-model – hoofdstuk 2.3). Deze modellen waren gebaseerd op het inpassen van min of meer bekende en aanvaarde fysiologische kengetallen, verband houdende met de groei en de voerbesteding. Er werd afgezien van het gebruik van multiple regressivergelijkingen of allometrische vergelijkingen voor het berekenen van de eiwit- en vetaanzet, omdat – in navolging van wat geschiedde ten aanzien van de voederwaardebepaling, het vaststellen van voedernormen en het vinden van een optimaal stalklimaat – het testen van de bruikbaarheid van o.a. energie- en N-balansen voor de varkensfokkerij hoofddoel was. Daarnaast biedt het gebruik van fysiologische kengetallen het voordeel dat voor verschillen in milieu-omstandigheden tussen groepen dieren kan worden gecorrigeerd, indien de relaties tussen voederbenutting enerzijds en voerniveau en stalklimaat en huisvestingsomstandigheden anderzijds, bekend zijn.

Het opgestelde MEK-model ging uit van de opgenomen hoeveelheid beschikbare energie, en een toedeling ervan naar onderhoud, eiwit en vet volgens de volgende vergelijking:

$$ME = ME_M + c\Delta P + d\Delta F$$

Het EBC- en EBK-model gingen uit van de energiebalans:

$$EB = 5{,}7\ \Delta P + 9{,}46\ \Delta F$$

Om de toedeling van ME_P resp. EB naar eiwit en vet te kunnen schatten werd door de onderzoekers gebruik gemaakt van uit de literatuur of uit eigen onderzoek berekende relaties tussen de componenten van de groei onderling. De *EB* werd uit de *ME* berekend volgens de vergelijking:

$$EB = (ME - ME_M) \times \text{efficientie.}$$

De vergelijkingen welke werden gebruikt voor het berekenen van de eiwit- (ΔP) en vetaanzet (ΔF) in het EBC-, EBK- en MEK-model, waren:

	EBC-model	EBK-model	MEK-model
ΔP	$P/PW \dfrac{EB-9{,}46\Delta PWF}{5{,}7\,P/PW-9{,}46}$	$\dfrac{EB-9{,}46\Delta L_E}{5{,}7-9{,}46K}$	$\dfrac{d\Delta L_E-(ME-ME_M)}{dK-c}$
ΔF	$\dfrac{EB-5{,}7\,\Delta P}{9{,}46}$	$\dfrac{EB-5{,}7\,\Delta P}{9{,}46}$	$\dfrac{ME-ME_M-c\Delta P}{d}$

In de modellen werden 4 faktoren gevariëerd, en wel:
- de onderhoudsbehoefte: 80, 100 of 120 kcal $ME/kg^{3/4}$;
- de efficiëntie, waarmee eiwit en vet worden gevormd uit ME_P. In het EBC- en EBK-model werd eenzelfde efficiëntie voor eiwit en vet verondersteld: 0,55, 0,65 of 0,75. In het MEK-model werden de volgende *ME*-behoeften (kcal/gram) voor de vorming van eiwit resp. vet getoetst: 16, en 13, 13 en 13, en 11,4 en 12,6.
- de verhouding eiwit – eiwit + water in het EBC-model: constant òf door op elk gewicht via een allometrische vergelijking in relatie tot het gewicht, de componenten eiwit en water te schatten en vervolgens de verhouding te berekenen. In het EBK- en MEK-model werden als waarden voor *LBM*/eiwit (*K*) getoetst: een constante waarde, òf door op elk gewicht de hoeveelheid *LBM* en eiwit via allometrische vergelijkingen in relatie tot het gewicht te schatten, en vervolgens de verhouding te berekenen;
- de hoeveelheid van de gewichtstoename, die terecht komt in eiwit, water en vet (EBC-model) of de toename van het gewicht min darminhoud (EBK- en MEK-model). De alternatieve waarden voor deze factor werden verkregen door de hoeveelheden as en darminhoud of de hoeveelheid darminhoud via lineaire relaties met het gewicht of via allometrische vergelijkingen te schatten.

Per model werden dus 36 combinaties van factoren onderzocht. De vergelijkingen en de waarden, die werden gebruikt voor het berekenen van de waarden van de 4 factoren zijn weergegeven in tabel 3.4.

De nauwkeurigheid waarmee eiwit- en vetaanzet berekend kunnen worden uit de groei en de voeropname, werd beoordeeld aan:
- het niveau van de berekende eiwit- en vetaanzet;
- de waarden van de correlatiecoëfficiënten tussen berekende en bepaalde eiwitaanzet en die tussen berekende en bepaalde vetaanzet.

Het materiaal dat werd gebruikt bestond uit energie- en *N*-balansen, afkomstig uit 6 verschillende onderzoekingen, en uit chemische analyses van gehomogeniseerde varkens. Verder was het mogelijk in 3 van de 6 groepen gegevens de groei van de varkens via een derdemachtscurve te berekenen. Het was gebleken, dat het gewicht op een bepaalde dag hierdoor nauwkeuriger kon worden geschat (tabel 4.6). Deze nauwkeurigheid was met name van belang omdat energie- en *N*-balansen meestal op korte gewichtstrajecten betrekking hebben. In totaal werd dus aan de hand van 10 materialen de nauwkeurigheid voor de berekeningen van de eiwit- en vetaanzet getoetst.

Ten behoeve van de analyse werden de waarden van de correlatiecoëfficiënten tussen berekende en bepaalde eiwit- en vetaanzet getransformeerd via de *Z*-transformatie van FISHER.

Achtereenvolgens werden per model voor de 4 kenmerken: de berekende eiwit- en vetaanzet en de waarden van de correlatiecoëfficiënten tussen berekende en bepaalde eiwit- en vetaanzet, onderzocht (model 3.1):

- de verschillen tussen materialen, zowel t.a.v. het niveau van de kenmerken als t.a.v. de interactie tussen materialen en factoren,
- de verschillen tussen factoren, en
- de verschillen tussen modellen.

Het niveau van de 4 kenmerken bleek per materiaal aanzienlijk te verschillen (tabel 3.5 en 3.7). Ook de interactieterm tussen materialen en factoren was steeds significant. Het bestaan van deze interactieterm werd ook geïllustreerd door de grote verschillen per materiaal tussen de waarden van de regressiecoëfficiënten van de 4 kenmerken op de 4 factoren (tabel 3.6). Als oorzaken voor de verschillen tussen materialen werden genoemd:

- verschillen in voerniveau, voersamenstelling, ras en geslacht;
- systematische verschillen in methodiek tussen de onderzoekers bij het verzamelen van de energie- en *N*-balansen, gewichten, etc.

Het bepalen van de groei per dag door interpolatie van de gewichten via een derdemachtscurve bleek in het materiaal van JUST NIELSEN (1970) de waarde van de correlatiecoëfficiënt tussen berekende en bepaalde eiwitaanzet te verdubbelen; in het materiaal van LUDVIGSEN en THORBEK (1955) bleek het werken met de oorspronkelijke groeicijfers en de groei bepaald via een derdemacht, geen verschillen te geven voor de waarde van de correlatiecoëfficiënt, terwijl in de cijfers van BREIREM (1935) een lagere waarde werd gevonden via deze laatste methode. De waarde van de correlatiecoëfficiënt tussen berekende en de via energiebalans bepaalde vetaanzet bedroeg 0,970 in het materiaal van JUST NIELSEN (1970), en die tussen de berekende en via chemische analyse van gehomogeniseerde varkens gevonden vetaanzet 0,257. Refererend aan een overzicht, gegeven door JUST NIELSEN (1970) over het verschil tussen energie- en *N*-balansen en vergelijkende slachtproeven werd gesteld dat meer gegevens verzameld moeten worden om inzicht te krijgen in de waarde en nauwkeurigheid van beide technieken.

Aangetoond werd dat de gevonden interactie tussen factoren en materialen voor een deel is veroorzaakt door systematische verschillen in gewicht van de varkens in de verschillende materialen (tabel 3.14). Omdat alle varkens naar gewicht werden gevoerd, kon ook de interactie tussen materialen en efficiëntie ten dele aan gewichtsverschillen worden toegeschreven.

De relatieve bijdrage van het materiaaleffect aan de totale variantie in berekende eiwit- en vetaanzet was 60 tot 70 % in de 3 modellen; de relatieve bijdrage van dit effect aan de totale variantie in de waarden van de correlatiecoëfficiënten tussen de berekende en bepaalde eiwit- en vetaanzet was zelfs 95 tot 99 % (tabel 3.8). De bijdrage van de factoren, onderhoud en efficiëntie, aan de totale variantie in berekende eiwit- en vetaanzet was – uitgezonderd berekende eiwitaanzet in het MEK-model – aanzienlijk groter dan die voor de beide andere factoren.

Het in rekening brengen van een hogere onderhoudsbehoefte, het dalen van de efficiëntie, en het verminderen van de hoeveelheid water in de gewichtstoename, verhoogden het niveau van de eiwitaanzet en de waarde van de correlatiecoëfficiënt tussen berekende en bepaalde eiwitaanzet (tabel 3.6 en 3.15). Met betrekking tot de berekende vetaanzet en de waarde van de correlatiecoëfficiënt tussen berekende en bepaalde vetaanzet werd het omgekeerde gevonden. Deze verandering van de berekende eiwit- en vetaanzet volgt uit de vergelijkingen in hoofdstuk 2.3, en is ook verklaarbaar uit het verschil in energie-inhoud voor eiwit en vet. De verandering van de waarden van de correlatiecoëfficiënten tussen berekende en bepaalde eiwit- en vetaanzet werd verklaard uit de niet-lineaire relatie tussen berekende en bepaalde eiwit- en vetaanzet. Gesteld is, dat het discutabel is, of de hoogste waarde van de correlatiecoëfficiënt tussen berekende en bepaalde eiwit- en vetaanzet samengaat met de beste aanpassing.

De verschillen tussen de 3 modellen waren vrij gering (tabel 3.10). De waarde 4,6838 voor de *LBM*/eiwit in het EBK- en MEK-model bleek lager te zijn dan op grond van het gemiddelde gewicht van de varkens in het onderzoek mocht worden verwacht. Dit had een overschatting van de eiwitaanzet en een onderschatting van de vetaanzet tot gevolg. De waarde voor de correlatiecoëfficiënt tussen berekende en bepaalde eiwitaanzet in het MEK-model bleek significant lager te zijn dan die in het EBC- en EBK-model.

Voor de in hoofdstuk 4 gebruikte vergelijkingen voor het berekenen van de eiwit- en vetaanzet werd een combinatie van de 4 factoren gekozen binnen het EBK-model. Voor deze keuze werd gesteld:

- de onderhoudsbehoefte bedraagt 100 kcal $ME/kg^{3/4}$;
- de eiwitaanzet wordt via de N-balans met 15,5 % overschat;
- de 'werkelijke' EB heeft bedragen 9,46 ΔF (bepaald) + 5,7 (1–0,845) ΔP (bepaald).

Het in rekening brengen van deze 'werkelijke' EB resulteerde in een efficiëntie van 0,62. Voor de *LBM*/eiwit werd gekozen voor de waarde, die op elk gewicht werd verkregen uit het gewicht en de via allometrische vergelijkingen geschatte hoeveelheden vet, darminhoud en eiwit (tabel 3.3). Voor het berekenen van ΔL_E werd gekozen voor een lineaire verandering van de darminhoud in relatie tot het gewicht.

De variatie in de berekende eiwit- en vetaanzet als ook de relatie tussen deze beide kenmerken en de groei, het voederverbruik en de slachtkwaliteit werd onderzocht bij beperkt en ad libitum gevoerde varkens. Het materiaal van de beperkt gevoerde varkens bestond uit 356 beren, 540 borgen en 770 gelten van het NL- en GY-ras (tabel 4.2). Het materiaal van de ad libitum gevoerde varkens bestond uit 29 nakomelingen groepen (4 tot 9 NL-gelten per groep) van beren (tabel 4.4). De beperkt gevoerde varkens werden gerantsoeneerd naar gewicht (tabel 4.1) en ze werden individueel gevoerd over het traject van 25 tot 100 kg. De onbeperkt gevoerde varkens kregen voer van dezelfde samenstelling als de beperkt gevoerde, en ze werden – beginnende op ongeveer 9 weken – gedurende 4 maanden of 6 maanden gemest. De verdeling van de varkens over de 2 behandelingen geschiedde volgens toeval, binnen tomen en binnen hokken. Het gewicht op elke proefdag werd per varken bepaald door een derdemachtscurve te berekenen uit de wekelijks of elke 14 dagen vastgestelde gewichten. De voeropname per dag werd berekend uit de totale opnamen per week of per 14 dagen. Voor de beperkt gevoerde varkens werd verondersteld dat het geadviseerde voerschema was gevolgd, òf dat er procentueel van was afgeweken. Voor de ad libitum gevoerde varkens werd via het berekenen van 'deel parabolen' over het proeftraject de voeropname per dag berekend.

Het verloop van de eiwit- en vetaanzet in relatie tot het gewicht kwam voor de beperkt gevoerde beren, borgen en gelten in grote lijnen overeen met datgene wat hierover in de literatuur bekend is (figuur 4.1). De eiwitaanzet was bij de borgen en gelten van het NL-ras vanaf 40–50 kg en bij NL-beren gedurende het gehele gewichtstraject significant lager dan bij het GY-ras. Het verschil tussen beren en gelten bedroeg aan het einde van de testperiode ongeveer +40 g eiwitaanzet per dag. Tussen de gelten en borgen was het verschil op dat moment +7 g bij het NL-ras en +16 g bij het GY-ras. De gemiddelde verschillen over de hele toetsperiode tussen rassen en tussen geslachten zijn weergegeven in tabel 4.9. De eiwitaanzet per dag was bij de GY-varkens 7,53 g hoger dan bij de NL-dieren, en de vetaanzet was 4,90 g lager. Uit de literatuur waren geen verschillen in eiwit- en vetaanzet bekend tussen de witte rassen. De verschillen tussen de geslachten waren geringer, dan de literatuurgegevens hierover aangegeven. Als mogelijke oorzaak voor een onderschatting van de geslachtsverschillen werd genoemd, dat varkens die meer eiwit aanzetten een hogere onderhoudsbehoefte hebben. Bij de ad libitum gevoerde varkens was de gemiddelde eiwitaanzet ongeveer 25% lager dan die bij de beperkt gevoerde, en de vetaanzet ongeveer 25% hoger (tabel 4.8 en 4.11). Als mogelijke oorzaken voor het verschil in eiwitaanzet zijn genoemd het morsen van voer uit de droogvoerbakken, het verschil in activiteit tussen beperkt (en individueel) en ad libitum (en in groepen) gevoerde varkens en de mogelijke invloed van het voerniveau op de *LBM*/eiwit.

De variatiecoëfficiënt voor de berekende eiwitaanzet was 1,6 keer hoger dan die voor groei en voederverbruik en de variatiecoëfficiënt voor de vetaanzet was ongeveer 30% lager (tabel 4.16). De waarden, die voor de erfelijkheidsgraad voor de eiwit- en vetaanzet werden gevonden, waren 0,176 en 0,080. Voor groei, voederverbruik en spekdikte werden daarentegen waarden gevonden van: 0,249, 0,231 en 0,545.

De waarden van de correlatiecoëfficiënten tussen eiwitaanzet en groei per dag waren bij de beperkt gevoerde varkens vrijwel gelijk aan +1. Het is beargumenteerd dat deze waarden bij voeren naar gewicht ook mochten worden verwacht. Bij de peperkt gevoerde varkens stemden de waarden van de correlatiecoëfficiënten tussen groei en voederverbruik, en slachtkwaliteit vrijwel overeen met die tussen eiwit- en vetaanzet, en slachtkwaliteit (tabel 4.12 en 4.13). De waarden van de correlatiecoëfficiënten tussen eiwitaanzet, vetaanzet, groei en voederverbruik waren bij de ad libitum gevoerde varkens significant lager dan bij de beperkt naar gewicht gevoerde varkens (tabel 4.15). De waarde van de correlatiecoëfficiënt tussen groei en eiwitaanzet bij de ad libitum gevoerde varkens was in overeenstemming, met die welke uit literatuurgegevens werd berekend (tabel 4.17). De waarde van de correlatiecoëfficiënt tussen vleeshoeveelheid en eiwitaanzet bij de ad libitum gevoerde varkens (0,743) en die tussen vetaanzet en rugspekdikte (0,796) waren significant hoger dan die bij de beperkt gevoerde varkens. Bij de interpretatie van de resultaten moet echter terdege rekening worden gehouden met het feit, dat het hier slechts 29 groepen varkens betrof. Om een goed inzicht te krijgen in de variatie van de eiwit- en vetaanzet en de relaties van deze kenmerken met groei, voederverbruik en slachtkwaliteit zijn meer gegevens nodig over energie- en *N*-balansen van individueel en bij een variabel voerniveau gemeste varkens.

Curriculum vitae

W. A. G. Cöp werd geboren op 2 juni 1943 in Ottersum (L). Na het behalen van het einddiploma Gymnasium α aan het R.K. Gymnasium 'Rolduc' te Kerkrade in 1961, begon hij zijn studie aan de Landbouwhogeschool te Wageningen. In 1967 slaagde hij met lof voor het ingenieursexamen in de studierichting Veeteelt. Na zijn afstuderen trad hij in dienst bij de afdeling Veeteelt van de Landbouwhogeschool. Na een tweetal jaren onderzoek te hebben verricht op het gebied van het bloedgroepen onderzoek bij varkens, was hij van 1969 tot 1974 werkzaam in het onderwijs en onderzoek in de Veefokkerij. Sinds april 1974 is hij verbonden aan het Instituut voor Veeteeltkundig Onderzoek 'Schoonoord' te Zeist.

REFERENCES

Baumgardt, B. R.: Voluntary feed intake. In: Animal growth and nutrition. Lea and Febiger. Philadelphia. 1969: 164–174.

Bergström, P. L. and D. Kroeske: Methods of carcass assessment in research on carcass quality in the Netherlands. I. Description of the methods. Proc. E.A.A.P.-Conf. Dublin. (1968): 11 pp.

Blaxter, K. L.: The effect of dietary energy supply in growth. In: Growth and development of mammals. Butterworths. London. 1968: 329–344.

Braude, R.: Feeding methods. In: Pig Production. Butterworths. London. 1972: 279–291.

Breirem, K.: Undersøgelser over væksten hos svin II. Energieomsætningen hos svin. 162. Beretning forsøgslaboratoriet. København. 1935: 1–277.

Breirem, K. and T. Homb: Energy requirements for growth. In: Handbuch der Tierernährung. Band II. Parey. Berlin. 1972: 546–584.

Brinke, H. W. ten: De invloed van de ligplaats op de mestresultaten en de slachtkwaliteit van mestvarkens gehuisvest bij lage temperaturen. Scriptie Gezondheids- en Ziekteleer. Wageningen. 1970: 28 pp.

Centraal Veevoeder Bureau in Nederland: Voedernormen voor de landbouwhuisdieren en voederwaarde der veevoeders. 24th ed. 1965.

Close, W. H.: Nutrition-environmental interactions of growing pigs. PhD Thesis, The Queen's University of Belfast. (1970): 1–235.

Cöp, W. A. G., De groei bij varkens. (literatuuroverzicht). Meded. Landbouwhogeschool. Wageningen. 71–4 (1971): 1–40.

Cöp, W. A. G., J. Stelwagen en W. J. Koops: Een analyse van de groei bij beren tijdens het eigenprestatieonderzoek. Meded. Landbouwhogeschool. Wageningen. 70–2 (1970): 1–22.

Cunningham, E. P.: Animal breeding theory. Landbruksbokhandelen. Vollebekk. 1969: 1–272.

Davies, J. L. and I. A. M. Lucas: Responses to variations in dietery energy intakes by growing pigs. 2. The effects on feed conversion efficiency of changes in level of intake above maintenance. Anim. Prod. 15 (1972a): 117–125.

3. Effect of level of intake of diets of differing protein and fat content on the performance of growing pigs. Anim. Prod. 15 (1972b): 127–137.

DuChateau, P., D. L. Nofziger, L. R. Ahuja and D. Swartzendruber: Experimental curves and rates of change from piecewise parabolic fits. Purdue University. Lafayette. Ind. (1972): 1–18.

Duniec, H., J. Kielanowski and Zofia Osinka: Heritability of chemical fat content in the loin muscle of baconers. Anim. Prod. 3 (1961): 195–198.

Elsley, F. W. H., I. McDonald and V. R. Fowler: *The effect of plane of nutrition on the* carcasses of pigs and lambs when variations in fat content are excluded. Anim. Prod. 6 (1964): 141–154.

Es, A. J. H. van: Simulation of the growth of veal calves fed liquid milk replacers. 5th Symp. on energy metabolism. Zürich. E. A. A. P. publ. 12 (1970): 97–100.

Es, A. J. H. van: Groei (chemisch gedeelte). Fysiologie der Dieren. Wageningen. 1971.

Es, A. J. H. van: Maintenance. In: Handbuch der Tierernährung. Parey. Berlin. 1972: 1–54.

Es, A. J. H. van: The energy value of rations for monogastic animals. Int. Symp. on: Energy management in mixed feeds. Luxemburg. (1974): 16 pp.

Farries, E. und L. Angelowa: Vergleichende Untersuchungen zur Nährstoffverdaulichkeit und Stickstoffretention bei veredelten Landschweinen, Wildschweinen und F_1-Kreuzungen. Z. Tierphys., Tierernähr. und Futtermittelk. 23 (1968): 263–266.

Farries, E., L. Angelowa und J. Schröder: Über Verdaulichkeit der Rohnährstoffe und Stickstoffretention beim Piétrainschwein im Verlaufe der Mastperiode. 2. N-Retention und N-Verwertung in Anhängigkeit vom Wachstum. Z. Tierphys., Tierernähr. und Futtermittelk. 23 (1968): 340–349.

FARRIES, E. und E. KALLWEIT: Vergleichende Untersuchungen zum Stickstoff-Ansatz bei Ebern und Kastraten. Landwirtsch. Forschung. Sonderheft 23/II (1969): 13–22.

FLOCK, D. K.: Zuchtplanung beim Schwein auf der Grundlage von Ergebnisse der Stationsprüfung. Habil. Schrift. Göttingen. 1968: 1–162.

FOWLER, V. R.: The prediction of pig carcass composition from feed conversion efficiency data corrected for differences in the maintenance component. Proc. 9th E.A.A.P.-conf. Edinburgh. (1966).

FOWLER, V. R., M. BICHARD and A. H. R. PEASE: Objectives in pig breeding. Pig breeders round table. Wye. (1973): 49 pp.

FOWLER, V. R., and R. M. LIVINGSTONE: Modern concepts of growth in pigs. In: Pig Production. Butterworths. London. 1972: 143–161.

FULLER, M. F., and A. W. BOYNE: The effects of environmental temperature on the growth and metabolism of pigs given different amounts of food. 1. Nitrogen metabolism, growth and body composition. Br. J. Nutr. **25** (1971): 259–272.

GÄDEKEN, D.: Über die Variabilität des Eiweissansatz beim Fleischschwein. Der Tierzüchter. **23** (1971): 651–653.

GRAY, R. and K. J. MCCRACKEN: Utilization of energy and protein by pigs adapted to different temperature levels. 6th Symp. on energy metabolism. Stuttgart. E.A.A.P. publ. **14** (1974): 161–164.

HARVEY, W. R.: Least squares analysis of data with unequal subclass numbers. U.S.D.A., A.R.S., 20-8, July 1960.

HAZEL, L. N.: The genetic basis for constructing selection indexes. Genetics. **28** (1943): 476–490.

HAZEL, L. N. and J. L. LUSH: The efficiency of three methods of selection. J. Hered. **33** (1942): 393–399.

HEL, W. VAN DER en M. W. A. VERSTEGEN: Vergelijkende mestproef met varkens op roostervloer en op gestrooide vloer bij lage temperatuur. Lab. Veeteelt. Wageningen. 1969.

HENDERSON, C. R.: Estimation of variance and covariance components. Biometrics **9** (1953): 226–252.

HOLMES, C. W.: The energy and protein metabolism of pigs at a high ambient temperature. Anim. Prod. **16** (1973): 117–133.

HOMB, T.: Proteinverwertung bei wachsenden Schweinen 30–105 kg Lebendgewicht. Z. Tierphys., Tierernähr. und Futtermittelk. **29** (1972): 123–132.

HÖRNICKE, H.: Methoden zur Bestimmung der Körperzusammensetzung lebender Schweine. Vet. Habil. Schrift. Hannover. 1960.

HOUSEMAN, R. A. and I. MCDONALD: The prediction of body composition in bacon pigs from measurements of feed intake and live-weight gain. Anim. Prod. **17** (1973): 295–304.

HUXLEY, J. S.: Problems of relative growth. Methuen. London. 1932.

JESPERSEN, J.: Bilag til forsøgslaboratoriets eferårsmøde. København. 1952.

JONGE, H. DE: Inleiding tot de medische statistiek. Deel 2. Leiden. 1964.

JUST NIELSEN, A.: The energy value of balanced feed rations for growing pigs determined by different methods. 381. Beretning fra forsøgslaboratoriet. København. 1970: 1–212.

JUST NIELSEN, A.: Anatomical and chemical composition of Danish Landrace pigs slaughtered at 90 kilograms live weight in relation to litter, sex and feed composition. J. Anim. Sci. **36** (1973): 476–483.

KEULS, M.: Personal communication (1971).

KIELANOWSKI, J.: Conversion of energy and the chemical composition of gain in bacon pigs. Anim. Prod. **8** (1966): 121–128.

KIELANOWSKI, J.: The method of pig progeny testing applied in Poland. I. General principles and physiological background. Proc. E.A.A.P.-Conf. Dublin. (1968): 15 pp.

KIELANOWSKI, J.: Protein requirements of growing animals. In: Handbuch der Tierernährung. Band II. Parey. Berlin. 1972: 528–546.

KIELANOWSKI, J.: Energy requirements of the growing pig. In: Pig Production. Butterworths. London. 1972b: 183–201.

KLEIBER, M.: The fire of live: An introduction to animal energetics. Wiley. New York. 1961.

KOTARBINSKA, MARIA: The chemical composition of the body in growing pigs. Proc. E.A.A.P.-Conf. Dublin. (1968): 7 pp.

KOTARBINSKA, MARIA: Investigations into the energy metabolism of growing pigs. Wydawnictwa Wlasne N 238. (1969): 1–48.

KOTARBINSKA, MARIA and J. KIELANOWSKI: Energy balance studies with growing pigs by the comparative slaughter technique. 4th Symp. on energy metabolism. Warsaw. E.A.A.P. publ. **12** (1969): 299–310.

KROES, Y.: 37e verslag van de cie. van overleg voor de varkenshouderij, tevens belast met het toezicht op de selektiemesterijen. (1969).

KUIPERS, A., M. W. A. VERSTEGEN, W. VAN DER HEL en W. J. KOOPS: De invloed van een aantal milieu-faktoren op karkasmaten van slachtvarkens. Bedrijfsontwikkeling. **4** (1973): 457–461.

LOGTESTIJN, J. G. VAN: Vlees. Stichting pressa trajectina. Utrecht. 1969: 1–81.

LUDVIGSEN, J. and GRETE THORBEK: The effect of aureomycin on the metabolism of pigs and metabolic processes in barrows and gilts. Heat production of pigs at various periods of age with a special view to sty ventilation. 283. Beretning fra forsøgslaboratoriet. København. 1955: 1–110.

LUND, A.: Experimentelle undersøgelser vedrørende svinets avitaminose A. 180. Beretning fra forsøgslaboratoriet. København. 1938: 1–304.

METZ, S. H. M. en R. D. POLITIEK: Een analyse van selectiemesterijgegevens. Veeteelt- en Zuivelber. **12** (1969): 25–30.

MINKEMA, D., W. A. G. CÖP, G. A. J. BUITING and J. G. C. VAN DE PAS: Pure breeding, compared with reciprocal crossbreeding of Dutch Landrace (NL) and Dutch Yorkshire (GY) pigs. Symp. on breed evaluation and crossing experiments with farm animals. Zeist (1974): 16 pp.

MORE O'FERRALL, G. J. and V. M. TIMON: Selection for bodyweight and tissue growth in mice. Proc. E.A.A.P.-Conf. Dublin. (1968).

NEHRING, K.: Investigations on the scientific basis for the use of net energy for fattening as a measure of feed value. 4th Symp. on energy metabolism. Warsaw. E.A.A.P. publ. **12** (1969): 5–20.

OSLAGE, H. J.: Untersuchungen über die Körperzusammensetzung und den Stoffansatz wachsender Mastschweine und ihre Beeinflussung durch die Ernährung.

II. Körperzusammensetzung und Stoffansatz wachsender Mastschweine unter den Bedingungen normaler Ernährung. Z. Tierphys., Tierernähr. und Futtermittelk. **17** (1962): 357–382.

III. Einfluss einer eingeschränkten Energiezufuhr im zweiten Teil der Mastperiode auf Körperzusammensetzung und Stoffansatz wachsender Mastschweine. Z. Tierphys., Tierernähr. und Futtermittelk. **18** (1963a): 14–34.

IV. Einfluss einer eingeschränkten Energiezufuhr im ersten Teil der Mastperiode auf Körperzusammensetzung und Stoffansatz wachsender Mastschweine. Z. Tierphys., Tierernähr. und Futtermittelk. **18** (1963b): 35–57.

V. Über den Mineralstoffgehalt und den Mineralstoffansatz wachsender Mastschweine. Z. Tierphys., Tierernähr. und Futtermittelk. **19** (1964): 330–357.

OSLAGE, H. J.: Untersuchungen zum Stoff-, und Energieumsatz wachsender Mastschweine. 3. Mitt. Stickstoff-, Fett- und Energieansatz. Landbauforschung Völkenrode. **15** (1969): 107–138.

OSLAGE, H. J. and H. FLIEGEL: Nitrogen and energy metabolism of growing – fattening pigs with an approximately maximal feed intake. 3th Symp. on energy metabolism. Troon. E.A.A.P. publ. **11** (1965): 297–306.

OSLAGE, H. J., H. FLIEGEL, F. E. FARRIES und K. RICHTER: Stickstoff-. Fett-, und Energieansatz bei wachsende Mastschweine. Z. Tierphys., Tierernähr. und Futtermittelk. **21** (1966): 50–65.

OWEN, J. B. and J. R. MORTON: The association of food conversion ratio, age at slaughter and carcass quality in pigs fed ad libitum. Anim. Prod. **11** (1969): 317–324.

PEDERSEN, O. K.: The influence of carcaseweight and nutrition on the anatomical and chemical composition of pigs of Danish Landrace. 404. Beretning fra forsøgslaboratoriet. København. 1973: 1–119.

Piatkowski, B.: Untersuchungen über den Einfluss niedriger Umgebungstemperaturen auf den Stoffwechsel wachsender Schweine. Arch. Tierernähr. **8** (1958): 161–181.

Piatkowski, B. und H. Jung: Der Eiweissansatz wachsender Schweine verschiedenen Geschlechts und verschiedener Typrichtung. 1. Stickstoffansatz und -verwertung sowie Gewichtszuwachs in den einzelnen Wachstumsabschnitten. Arch. Tierz. **9** (1966): 307–319.

Schiemann, R., W. Jentsch, W. Klippel, F. Schmidt, St. Trela und B. Tscheschmedschiew: Vergleichende Untersuchungen zwischen der Methodik der Gesamtstoffwechselmessungen und der Tierkörperanalytik an wachsenden Ratten und Schweinen. Arch. Tierernähr. **12** (1962): 321–342.

Schierbaum, E.: Untersuchungen über die Beziehungen zwischen Rückenspeckdicke und Gesammtkörperfettgehalt. Vet. Diss. Hannover. 1961: 1–57.

Schmidt, J., M. von Schleinitz, E. Lagneau und C. Zimmermann: Über die Zusammensetzung des Schweinekörpers. Wiss. Arch. Landwirtsch. B. **5** (1931): 237–375.

Schmidt, J., M. von Schleinitz, E. Lagneau und C. Zimmermann: Über die Zusammensetzung des Schweinekörpers bei Mastschweinen verschiedener Gewichtsklassen. Arbeiten der D.L.G. **59** (1933): 1–118.

Sørensen, P. H.: Influence of climatic environment on pig performance. In: Nutrition of pigs and poultry. Butterworths. London. 1962: 88–103.

Standal, N.: On the farm testing in Norway. Conf. Pigs, progress and potential. Brighton. (1970): 12 pp.

Thorbek, Grete: Studies on the energy metabolism of growing pigs. 4th Symp. on energy metabolism. Warsaw. E.A.A.P. publ. **12** (1969): 281–290.

Vanschoubroek, F., R. de Wilde and Ph. Lampo: The quantitative effects of feed restriction in fattening pigs on weight gain, efficiency of feed utilization and backfat thickness. Anim. Prod. **9** (1967): 67–74.

Verstegen, M. W. A.: Heat production and energy balances of growing pigs at normal and low temperatures. 5th Symp. on energy metabolism. Zürich. E.A.A.P. publ. **13** (1970): 173–176.

Verstegen, M. W. A.: Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups. Meded. Landbouwhogeschool. Wageningen. 71–2 (1971): 1–115.

Verstegen, M. W. A.: Huisvesting en klimaat. Collegediktaat Wageningen. 1972: 1–143.

Verstegen, M. W. A., W. H. Close, I. B. Start and L. E. Mount: The effects of environmental temperature and plane of nutrition on heat loss, energy retention and deposition of protein and fat in groups of growing pigs. Br. J. Nutr. **30** (1973): 21–35.

Verstegen, M. W. A. and W. van der Hel: The effects of temperature and type of floor on metabolic rate and effective critical temperature in groups of growing pigs. Anim. Prod. **18** (1974): 1–11.

Verstegen, M. W. A., W. van der Hel and W. A. G. Cöp: Energy balances in groups of pigs in relation to some environmental factors. 6th Symp. on energy metabolism. Stuttgart. E.A.A.P. publ. **14** (1974): 147–160.

Walstra, P.: Internationale vergelijking van varkensrassen. (1974). (In preparation).

Wenk, G. and A. Schürch: Influence of the level of energy and protein in the feed on the energy metabolism of growing pigs. 6th Symp. on energy metabolism. Stuttgart. E.A.A.P. publ. **14** (1974): 173–176.

White, J.: Accreditation progress. Conf. Pigs, progress and potential. Brighton. (1970): 12 pp.

Zagožen, F. and J. Schröder: Leistungsfutteranteil je kg Gewichtszunahme als Hilfsmerkmal zur Schätzung der Schlachtkörperzusammensetzung bei der Eigenleistungsprüfung beim Schwein. Züchtungsk. **42** (1970): 53–65.