Nitrogen and energy metabolism of sows during several reproductive cycles in relation to nitrogen intake

Promotor:	dr. ir. M.W.A. Verstegen buitengewoon hoogleraar op het vakgebied van de veevoeding, in het bijzonder de voeding van de eenmagigen
Co-promotor:	dr. ir. A.W. Jongbloed hoofd van de afdeling varkens van het voormalig IVVO-DLO / wetenschappelijk onderzoeker ID-DLO te Lelystad

Nitrogen and energy metabolism of sows during several reproductive cycles in relation to nitrogen intake.

H. Everts

Proefschrift
ter verkrijging van de graad van
doctor in de landbouw- en milieuwetenschappen,
op gezag van de rector magnificus,
dr. C.M. Karssen,
in het openbaar te verdedigen
op vrijdag 21 oktober 1994
des namiddags te half twee in de aula
van de landbouwuniversiteit te Wageningen.

Aan Martje,
Simon en Rozemarijn

STELLINGEN

1. In de zeugenhouderij kan de excretie aan mineralen beter worden uitgedrukt per gespeende big dan per zeug per jaar.

   dit proefschrift

2. Bij het streven naar een constante spekdikte bij zeugen met toenemende leeftijd, neemt de totale hoeveelheid aan vet in het dier toe.

   dit proefschrift

3. Een multifasen-voeder-systeem kan aanzienlijk bijdragen tot een verdere vermindering van de excretie aan stikstof per gespeende big.

   dit proefschrift

4. De fokkerij kan bijdragen aan de vermindering van het voergebruik en de stikstofuitscheiding door zich richten op het fokken lichtere zeugen met goede reproduktieprestaties en een lange levensduur.

   dit proefschrift

5. Er is een relatie tussen lichaamssamenstelling en reproduktie bij zeugen. Het wordt tijd een goed onderzoek uit te voeren om deze relatie in kaart te brengen.

   dit proefschrift

6. Het formuleren van de gewenste ontwikkeling van de lichaamssamenstelling, in het bijzonder de maximale eiwitmassa, is van essentieel belang bij het ontwerpen van voerstrategieën voor zeugen.

7. Het worpnummer is veel belangrijker voor de voedernormen voor zeugen, dan tot nu toe aangenomen.

8. Een proefopzet voor response surface analysis, zoals aangegeven door Toyomizu *et al.* (1993), verdient een nader onderzoek ten aanzien van de bruikbaarheid bij landbouwhuisdieren.
Toyomizu, M. et al., Anim. Prod. 56: 251-259

9. Het gebruik van de resultaten van langdurige incubatietijden bij de berekening van de afbraaksnelheid van voedermiddelen in de pens met behulp van *in situ* nylonbags levert een onjuiste afbraaksnelheid op.

10. Door het geven van te veel vrijheid in de opvoeding, kunnen kinderen later niet om gaan met maatschappelijke grenzen.

11. Het zich behelpen dient een wezenlijk element van het kamperen te zijn.

12. Ondanks het grote aantal mountainbikes blijft Nederland een relatief vlak land.

H.Everts
Nitrogen and energy metabolism of sows during several reproductive cycles in relation to nitrogen intake

Wageningen, 21 oktober 1994

Voorwoord

De basis voor dit proefschrift wordt gevormd door een serie proeven, die in het kader van project 359 in de periode van juli 1986 tot en met februari 1990 op het toenmalige Instituut voor Veevoedingsonderzoek (IVVO-DLO) te Lelystad zijn uitgevoerd. Alle mensen die daarbij direct of indirect betrokken zijn geweest, wil ik hartelijk danken voor hun bijdrage in welke vorm dan ook.

Bij het voorbereiden van het project heb ik een beroep kunnen doen op de ervaring en kennis van een aantal mensen. Met name wil ik graag de toenmalige directie, F. de Boer en A.J.H. van Es, het hoofd van de afdeling varkens, A.W. Jongbloed, en S.M.H. Metz bedanken voor hun bijdrage en inzet bij het opzetten van dit project.

De uitvoering van dit project werd mede mogelijk gemaakt door een substantiële subsidie van het Financieringsoverleg Mest- en Ammoniakonderzoek (FOMA).

De dieren voor deze proef werden in de varkensstal op een voortreffelijke wijze verzorgd door Teun Koorn en André Huyskens. Zij hebben daar heel wat porties voer afgewogen en bovendien de dieren vaak gewogen en gemeten.

Af en toe mochten sommige zeugen een uitstapje van enkele weken naar de stofwisselingseenheid maken. Daar verbleven ze in de respiratiekamers en werden dan met veel zorg omgeven door de medewerkers van de stofwisselingseenheid onder leiding van Roel Terluin. Bij technische problemen met de respiratiekamers stond Ad van Beers altijd paraat met een oplossing.

Bij de eerste proeven deed Bert Wieman de gasanalyse en de uitwerking van de proeven. Dit werk werd echter al vrij snel overgenomen door Ruud Dekker en hij heeft de rest van de proef heel wat uren bij het Sondenapparaat staan "hengelen" en alle proeven nauwgezet uitgerekend.

Soms mochten er zeugen op reis naar buiten de polder. Helaas was dat voor hen slechts een enkele reis. In de eerste jaren ging Harm Kuiper heel wat keren mee naar het slachthuis in Harderwijk om bloed op te vangen en het maagdarmkanaal van de inhoud te ontdoen. Later gingen er ook vaak anderen mee. Het meest gevaarlijke en zware werk was wel in kleine blokjes zagen van de diepgevroren karkassen. Na het fijnmalen konden dan de monsterzakjes en de extractiehulzen gevuld worden. Dit geheel van werkzaamheden was altijd een voortreffelijk stuk teamwerk onder leiding van Ruud Dekker. Gelukkig kon uit de analyses niet worden geconcludeerd dat de monsters ernstig verontreinigd waren door menselijk weefsel.

De monsters stroomden in grote getale naar het laboratorium om daar geanalyseerd te worden op van alles en nog wat. De mensen van de monstervoorbereiding, het Weende lab, het elementen lab en het chromatografie lab werden, al dan niet gewenst, voorzien van een behoorlijke "werkvoorraad". Ik dank alle medewerkers van het laboratorium voor het vaak snel opleveren van de analyseresultaten.

Na de praktische uitvoering van de proeven kwam het meeste werk voor mij. In de periode 1990-1991 werd een uitgebreid verslag van dit project voor het FOMA geschreven. In die periode bleek er een goede mogelijkheid te zijn voor het schrijven van dit proefschrift. Ondanks het feit dat de tijdsplanning meerdere malen moest worden bijgesteld, is het dan nu toch zo ver gekomen dat het proefschrift klaar is.

Met Paul Goedhart en Jan Kogut heb ik vaak gediscussieerd over de statistische verwerking van de gegevens, waarvoor hartelijk dank. Bij het schrijven van de artikelen heb ik veel gehad aan de discussies met Martin Verstegen en Age Jongbloed. Zo verschenen er steeds weer nieuwe concept-artikelen. De opmerkingen in de kantlijn van Martin waren vaak zeer waardevol, maar helaas vrijwel onleesbaar. Voor hun opbouwende kritiek en hun inzet, vooral in de laatste fase van het schrijfwerk, ben ik Martin en Age zeer dankbaar.

Silco Langelaar wil ik bedanken voor zijn nuttige adviezen en hulp bij het opmaken van het manuscript.

In de afgelopen twee jaar was de tijd die ik kon besteden aan het onderzoek met schapen sterk gelimiteerd. Dat de geplande proeven toch goed konden worden uitgevoerd, is in belangrijke mate te danken aan de gewaardeerde inzet van Leon Šebek en de medewerkers van het schapenbedrijf.

Ons gezin werd, vooral het laatste jaar, in toenemende mate geconfronteerd met mijn schrijfwoede in de late avonduren. Wanneer ik aanwezig was, had ik mijn gedachten niet bij de zaken die voor jullie belangrijk waren. Simon en Rozemarijn, jullie kregen soms duidelijk te weinig aandacht. Martje, bedankt voor je begrip, hulp en incasseringsvermogen.

CIP-GEGEVENS KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Everts, H.

Nitrogen and energy metabolism of sows during several reproductive cycles in relation to nitrogen intake / H. Everts. - Lelystad : ID-DLO. - Ill.
Proefschrift Wageningen. - Met lit. opg.
ISBN 90-800665-2-4
Trefw.: energiestofwisseling ; varkens / stikstof

Everts, H. Nitrogen and energy metabolism of sows during several reproductive cycles in relation to nitrogen intake (Stikstof- en energiestofwisseling bij zeugen gedurende meerdere reproduktiecycli in relatie tot de stikstofopname).
By feeding the same diet during pregnancy and lactation sows are fed above the nitrogen requirement during pregnancy due to the relatively high nitrogen requirement during lactation. For feeding closer to the requirements at least two diets are needed: one diet with a low nitrogen content during pregnancy and an other diet with a higher nitrogen level during lactation. The consequences of such a feeding strategy were investigated. A lower nitrogen supply during pregnancy had no effect on the development of the products of conception, but the development of the maternal protein mass was reduced during the first reproductive cycle. In the second and third parity a compensatory effect was observed. The nitrogen excretion decreased with about 35 % during pregnancy. Sow with a higher lysine supply during lactation mobilized a less nitrogen and more fat during lactation. The nitrogen excretion per sow per year can be reduced with about 25 %. However, the efficiency of the utilization of dietary nitrogen into retained nitrogen remained at a relatively low level.
For an further improvement of the efficiency of the utilization of dietary nitrogen into retained nitrogen a multiphase feeding strategy in combination with a restricted development of the live weight of sows is proposed.
Ph.D. thesis, Institute for Animal Science and Health (ID-DLO) Branch Runderweg, P.O. Box 160, 8200 AD Lelystad, The Netherlands

Content

Chapter 1

Introduction

Introduction

Under optimal conditions a sow can produce at least 25 weaned piglets per year. Furthermore, a sow is able to farrow at least 10 times in her life. In such an ideal situation a sow produces about 120 weaned piglets in a reproductive life time of 4.5 years. However, in practice in the Netherlands the mean number of weaned piglets per sow per year is 21 (TEA-2000, CBK-plus, 1993), and the mean productive life time of sows is 2.38 year (TEA-2000, CBK-plus, 1993). This means a production of 50 piglets during the life of a sow. Apart from specific diseases, the discrepancy between an ideal situation and the situation in practice is caused by smaller litter sizes, higher mortality of piglets, a lower breeding frequency and a higher replacement rate of sows than in an ideal situation. All these points can be related to failures in housing, breeding, management and nutrition of sows.

For three reasons special attention has to be paid to the nutrition of breeding sows. Firstly, an optimal nutrition is an essential condition to enable the sow to express her potential productivity. Secondly, nutrition can be changed rather easily without high costs for investments. And thirdly, the feed is the most important input for the process of piglet production in terms of energy, nitrogen and minerals. This last point is very meaningful, because this is one of the elements that determines sustainability in pig production. Uniform criteria for sustainable livestock production are very difficult to formulate (de Wit et al., 1994). The definition of sustainability, in terms of an equilibrium between input and output of the total production process (from natural resource into consumable products), depends mainly on the selected scale (farm, region, country, continent). In a sustainable animal production system the production level of the animals is not maximized, but optimized. Above the optimal production level, a further increase of the input results in a smaller increase of production than the previous increase. Thus the gross efficiency of utilization of nutrients must be at the highest level. In this way the losses are minimized. At such an optimal production level the health and the well-being of the animals must also be guaranteed.

Nutrition research can contribute by optimizing the feed supply to the sow in such a way, that the sow can produce sufficient weaned piglets per year during a long period and that the feed is used in the most efficient way with minimal losses to the environment.

About 7 months after birth a sow can reach puberty. At this moment the productive reproduction cycle can start. The most important processes in this cycle are oestrus, successful mating, pregnancy, farrowing, lactation and weaning. After weaning the next cycle can start when the sow returns to oestrus. By domestication and selection the length of the anoestrus period is significantly shortened compared with the wild living sows in northern Europe.

Apart from the rearing period, an ideal sow is about 3/4 of her productive live time pregnant, about 1/5 of the time lactating and the remaining time waiting to start her next reproductive cycle. Therefore, pregnancy is the most important physiological status for a sow, also when the amount of consumed feed is considered.

During pregnancy the products of conception and the maternal body mass of the sow (suppletion of lactation losses and/or development to a more mature status) are increasing. The development of the products of conception in relation to the metabolizable energy supply is described by Noblet et al. (1985). The nutrient supply during pregnancy can be used to manipulate the maternal body composition during pregnancy within the potential for deposition of nutrients in the sow. The relation between nutrient supply and deposition of nutrients in the maternal body are important for building sow models (AFRC, 1990; Whittemore and Morgan, 1990). This relationship is needed for predicting the response of a certain level of nutrient supply on performance and for determining the nutrient requirements.

Protein is an influential nutrient, because it supplies the animal with essential and non-essential amino acids needed for maintenance, development of the products of conception and the maternal protein gain. When it is supplied above the optimal required amounts, this results in unnecessary excretion and possible pollution to the environment.

Requirements of pregnant sows are reviewed for energy by Verstegen et al. (1987), Noblet and Etienne (1987) and AFCR (1990) and for nitrogen by Vanschoubroek and van Spaendonck (1973), Speer (1990), Whittemore and Morgan (1990) and Pettigrew (1993).

In practice the lactation period is much shorter than the natural lactation period. The lactation period is very important for the survival of piglets. During the first weeks of life piglets must rely mainly on the milk production of the mother, due to the small amounts of ingested creep feed (about 0.5 kg.piglet^{-1}; Everts, 1991). In practice a lactating sow with a high milk production is unable to consume the required amount of feed, at least in the first week of lactation. Therefore, she mobilizes from her available body stores of fat and protein (Etienne et al. ,1985). The amounts of mobilized tissues depend on the nutrient supply during lactation and on the nutrient supply during the preceding pregnancy period. Mullan and Williams (1989) observed that an increased gain during pregnancy also increased the amount of live weight that was mobilized during lactation. In addition an increased gain during pregnancy reduced feed intake during subsequent lactation in first litter sows.

The protein requirements for lactating sows are reviewed by Whittemore and Morgan (1990), Speer (1990) and Pettigrew et al. (1992ab). The energy requirements during lactation are reviewed in the form of models by Whittemore and Morgan (1990) and Pettigrew et al. (1992ab).

There is no clear evidence for a direct relationship between reproductive performance of sows and body composition. Whittemore et al. (1988) observed a relation between body condition and reproductive performance. However, Young et al. (1991) did not confirm such a relationship. In women a relation between body composition and reproductive cycling is shown by Frisch (1988). In literature data about body composition of gilts are more often presented than of older sows. Besides, a considerable part of the data about the body composition is based on anatomical dissection. In many of these investigations the development of the maternal body of the gilt was studied by comparing pregnant and non-pregnant gilts. Knowledge about the chemical body composition of sows and the development of the body stores during successive reproductive cycles is very scarce. A reliable prediction of the body composition based on non-invasive measured parameters can be very helpful to achieve knowledge about the optimal body composition needed for an optimal reproductive performance of sows. Whittemore and Yang (1989) presented a set of prediction equations based on data from sows and gilts. Their equations indicated that the amount of body protein can be predicted more accurately than the amount of body fat.

The nutrition during pregnancy and during lactation will affect the body composition of sows. Due to possible carry-over effects nutrition during pregnancy and lactation are closely related. Therefore, it is better to focus on the nutrition during the whole reproductive cycle, instead of looking at pregnancy or lactation separately.

In the last decades the feeding of sows in practice was based on a feeding system with one feed for pregnant and lactating sows. In such a system the protein supply during pregnancy exceeds the requirements for normal development of the products of conception and 5 kg of maternal protein gain as proposed by Vanschoubroek and van Spaendonck (1973). During lactation the protein supply remains in most cases below the requirements due to an insufficient feed intake and/or a relatively low protein level in the lactation diet. The long term consequences of such a feeding system for the development of protein and fat stores in the body and for the reproductive performance of sows are unknown. One of the consequence is a high nitrogen excretion, which may be harmful for the environment. To improve the situation in practice it seems interesting to feed more closely to the protein requirements during pregnancy and during lactation. It is of interest to study the effect dietary nitrogen supply on the efficiency of the utilization of ingested protein to retained protein and on the development of the body stores during successive parities. The observed effects of such a feeding strategy on protein metabolism of sows can be used to design a concept for optimizing the nutrition of sows with respect to nitrogen excretion, reproductive performance and longevity. However, the basic knowledge to derive such a concept is to a large extent unknown.

The following questions can be raised:

a. Is the body composition of the piglets at birth and at weaning affected by the level protein supply during pregnancy?

b. Is the development of the body stores of sows affected by the protein supply during pregnancy and lactation during successive parities?

c. Is it necessary for a good lactation performance to compensate the lower protein supply during pregnancy with a higher protein supply during lactation?

d. Is the energy metabolism of the sows affected by the level of protein supply during the reproductive cycle?

e. Is the performance and longevity of sows affected by the level of protein supply during pregnancy and lactation?

f. Is the efficiency of utilization of ingested protein, the level of retention and the level of excretion affected by the protein supply during a reproductive cycle?

To answer these questions correctly a very large and expensive series of investigations during several years is desired. Such experiments should include at least three levels of protein supply during pregnancy and during lactation and at least two levels of energy supply in pregnancy and lactation. When sows are slaughtered at the beginning of pregnancy, at the end of pregnancy and after weaning during three successive parities 1620 sows from a much larger population should be slaughtered. For the measurement of retention and excretion on the short term also numerous balance trials are required. Moreover, such a study might also include more than one breed. It may be clear that such a large scale investigation is beyond the capacity of our institute (facilities and money). Therefore, a more limited design for our studies was chosen. We chose to have a 2 x 2 factorial approach with two levels of nitrogen during pregnancy and within each level two levels of nitrogen levels during lactation.

Experimental design

In the present study different levels of protein supply during pregnancy and during lactation were investigated. In this study a difference in protein supply means also a difference in essential amino acid supply. During pregnancy sows were supplied with protein according to a level as observed in practice (Diet C) or according to a level of protein just sufficient for normal development of the products of conception and 5 kg of maternal protein gain (Diet L). During lactation sows were supplied with protein according to a level as observed in practice (Diet C) or according to a level equal to the calculated protein requirement (Diet H). Sows fed diet C during pregnancy and during lactation are representing the practical situation. Sows fed diet L during pregnancy and diet H during lactation are representing a situation where the supply matches more closely the protein requirements. To study the interaction between pregnancy and lactation also the other possible combinations of protein supply were included in the design (Table 1.1)

Table 1.1
Tested combinations of protein supply during pregnancy and lactation

Pregnancy	Lactation	Treatment combination
Diet C	Diet C	CC
	Diet H	CH
Diet L	Diet C	LC
	Diet H	LH

The measurement of short term effects of protein supply on retention and excretion requires a balance technique. To prevent any loss of ammonia and to measure the energy balance the experiments were done in respiration chambers. The balance technique is well known for growing pigs and pregnant sows, but for lactating sows with suckling piglets additional measurements are needed. When the main interest is focused on mobilization of body stores of the sows and total excretion, then it is possible to combine a balance trial with comparative slaughtering of the suckling piglets for determination of the retention in the piglets. The balance trials were done during three successive parities. The balance in mid pregnancy was measured in an experiment with three replicates. In the design it was foreseen to measure the balance in late pregnancy and during lactation with six replicates.

The long term effects on the development of body reserves and the composition of the sows are studied by the comparative slaughter technique. Because balance trials can only give information concerning the change in body composition in a short term, comparative slaughtering is inevitable to measure the actual body composition of sows at different stages of the reproductive cycle.

It is well known that there is a discrepancy between the balance trial and the comparative slaughter technique in growing pig (Just et al., 1982). When both techniques are used in experiments with breeding sows, then also attention has to be paid to the accuracy of these techniques.

The question concerning the effect on reproductive performance of the sows can not be answered as the total number of sows involved in our experiments was too small.

References

AFCR ,1990. AFRC Technical Committee on the Responses to nutrients, Report Number 4, Nutrient Requirements of Sows and Boars. *Nutrition Abstracts and Reviews (Series B)* 60: 383-406

de Wit, J., Oldenbroek, J.K., van Keulen, H. and Zwart, D., 1994. Criteria for sustainable livestock production: a proposal for operationalization. *Agricultural Systems*: submitted

Etienne, M., Noblet, J., Desmoulin, B., 1985. Mobilisation des réserves corporelles chez la truie primipare en lactation. *Reproduction Nutrition Developpement* 25: 341-344

Everts, H., 1991. The effect of feeding different sources of crude fibre during pregnancy on the reproductive performance. *Animal Production* 52: 175-184

Frisch, A., 1988. Fatness and Fertility. *Scientific American* 258: 70-77

Just, A., Fernández, J.A. and Jørgensen, H., 1982. Nitrogen balance studies and nitrogen retention. In: Laplace, J.P., Corring, T., Rerat, A. (Editors), Digestive physiology in the pig 27-29 October 1982, Jouy-en-Josas. *Colloques l'INRA* no. 12: 111-122

Mullan, B.P. and Williams, I.H., 1989. The effect of body reserves at farrowing on the reproductive performance of first-litter sows. *Animal Production* 48: 449-457

Noblet, J., Close, W.H., Heavens, R.P. and Brown, D., 1985. Studies on the energy metabolism of the pregnant sow. 1. Uterus and mammary tissue development. *British Journal of Nutrition* 53: 251-265

Noblet, J. and Etienne, M., 1987. Metabolic utilization of energy and maintenance requirements in pregnant sows. *Livestock Production Science* 16: 243-257

Pettigrew, J.E., Gill, M., France, J. and Close, W.H., 1992a. A mathematical integration of energy and amino acid metabolism of lactating sows. *Journal of Animal Science* 70: 3742-3761

Pettigrew, J.E., Gill, M., France, J. and Close, W.H., 1992b. Evaluation of a mathematical model of lactating sow metabolism. *Journal of Animal Science* 70: 3762-3773

Pettigrew, J.E., 1993. Amino acid nutrition of gestating and lactating sows. *Biokyowa Technical Review* 5: 1-18

Speer, V.C., 1990. Partitioning nitrogen and amino acids for pregnancy and lactation in swine: A review. *Journal of Animal Science* 68: 553-561

Vanschoubroek, F. and van Spaendonck, R., 1973. Faktorieller Aufbau des Protein- und Aminosäurenbedarfes tragender Sauen. *Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde* 31: 71-91.

Verstegen, M.W.A., Verhagen, J.M.F. and Hartog, L.A. den, 1987. Energy requirements of pigs during pregnancy: A review. *Livestock Production Science* 16: 75-89

Young, L.C., King, G.J., Shaw, J., Quinton, M., Walton, J.S. and McMillan, I., 1991. Interrelationships among age, body weight, back fat and lactation feed intake with reproductive performance and longevity of sows. *Canadian Journal of Animal Science* 71: 567-575.

Whittemore, C.T., Smith, W.C. and Philips, P., 1988. Fatness, live weight and performance responses of sows to food level in pregnancy. *Animal Production* 47: 123-130

Whittemore, C.T. and Yang, H., 1989. Physical and chemical composition of the body of breeding sows with differing body subcutaneous fat depth at parturition, differing nutrition during lactation and differing litter size. *Animal Production* 48: 203-212

Whittemore, C.T. and Morgan, C.A., 1990. Model components for determination of energy and protein requirements for breeding sows: a review. *Livestock Production Science* 26: 1-37

Chapter 2

Balance trials and comparative slaughtering in breeding sows: description of techniques and observed accuracy

H. Everts and R.A. Dekker

Institute for Animal Science and Health
(ID-DLO) Branch Runderweg
P.O.Box 160 8200 AD Lelystad
The Netherlands

Published in Livestock Production Science 37 (1994) 339-352
Reproduced with the permission of Elsevier Science B.V., Amsterdam

Balance trials and comparative slaughtering in breeding sows: description of techniques and observed accuracy

H. Everts and R.A. Dekker

Abstract

Balance trials and comparative slaughtering with breeding sows were used to calculate the standard deviation (sd) of the retention and to calculate the contribution of the different error sources to the total variance of retention within a method. During pregnancy and lactation balance trials (nitrogen, carbon, energy, calcium, magnesium and phosphorus) were performed with in total 60 sows. In lactating sows the retention in the litter was calculated from the chemical analysis of weaned piglets.

For the technique of comparative slaughter 12 sows were slaughtered at first mating (live weight 125 kg) as a reference, 14 sows at the end of first pregnancy and 23 sows after the third lactation. In the course of the experiment 11 sows were culled.

The sd of retention in the lactation balance trials was much higher than in pregnancy trials. The main source of variance for nitrogen and Ca retention was the intake and for Mg and P retention the faecal excretion and for carbon and energy retention the gaseous exchange. With comparative slaughter the sd of fat and energy retention was affected by the estimate of body composition at the start of the experiment. The sd of nitrogen and mineral retention was mainly associated with the sampling procedure and analysis of the carcass. From the results it can be concluded that the balance technique resulted in a smaller sd of retention than the comparative slaughter technique when retention is measured over a limited period (< 3 months).

Keywords: balance technique, comparative slaughtering, sows, accuracy

Introduction

Many balance and comparative slaughter experiments with growing pigs have been reported in literature. Depending on the objective of an experiment the most suitable technique can be chosen. When differences in retention of energy, nitrogen or other elements between treatments during a limited period (days) are studied, then a balance trial may be preferred. When differences in retention during an expanded period (months) are studied, then comparative slaughtering may be preferred. Both techniques have their own errors and considerable differences in results between the two techniques are often noticed. Just et al. (1982) concluded from literature and own research, that nitrogen (N) retention in growing pigs is overestimated from 0 to 26 % (mean value of 11 %) compared to the comparative slaughter technique. Also retention of carbon (C), energy (E), calcium (Ca) and phosphorus (P) in balance trials was higher than in comparative slaughtering trials (Just et al., 1982).

The balance technique can be used for pregnant sows and with some adaptations also for lactating sows. Comparative slaughtering is mainly used in sows to estimate the retention during pregnancy (Walach-Janiak et al., 1986a,b; de Wilde, 1980a,b) and occasionally during several parities (Whittemore and Yang, 1989).

Concerning sows there is hardly any information available with regard to the accuracy and the main sources of variance with both techniques. The objective of this study was to determine the accuracy of both techniques and to indicate the contribution of the different error sources to the total variance of retention within a method. This knowledge can be used to indicate the possible ways to improve the accuracy of the techniques.

Materials and methods

Animals

In an experiment investigating the effect of different levels of nitrogen and phosphorus supply on the performance and body composition of sows, six batches of 10 half-sisters (Great Yorkshire * Dutch Landrace) were used. Animals were reared individually from 25 kg live weight on a time fixed feeding schedule. At first mating (live weight 125 kg) two animals of each batch were slaughtered and analyzed as zero references for body composition. During mid-pregnancy (day 50-60) and at the end of pregnancy (day 105-112) the N, E, C, Ca, Mg and P balance were measured. At the end of the first pregnancy at least two animals of each batch were slaughtered and analyzed for their body composition (n = 14). During a lactation period of 25 days the balance of sows was measured for 21 days (day 4-25). During the second and third parity also balances were measured during mid-pregnancy, at the end of pregnancy and during lactation. After the third lactation all remaining sows were slaughtered and analyzed for their body composition (n = 23). To realize the time schedule of the experiment, sows had to be pregnant within 14 days after weaning. Most of the 11 sows culled were not pregnant within 14 days after weaning. Leg problems were an other reason for the culling of some sows.

Respiration chambers

In each respiration chamber (open circuit; volume of 12 m^3) a farrowing crate was built and the sows were tethered to the floor. Sows were laying on a rubber mat and behind the sows a slatted floor covered a tray with a slope towards two corners to collect urine in a bottle. Ambient temperature in the chamber was 20° C during pregnancy and 16-17° C during lactation. For piglets during lactation a part of the chamber was electrically heated with a lamp. In and out going air were analyzed for O_2 (paramagnetic,Servomex 1100), CO_2 (*infrared*, Hartmann & Braun Uras G3), CH_4 (*infrared*, Hartmann & Braun, Uras G3). The volumetric analyses of O_2 and CO_2 (van Es, 1958) were used as a reference. The volume of out going air was measured with gas meters (indirectly calibrated with a mercury pump). About 1 % of out going air was led through hydrochloric acid traps to fix ammonia from the air. The water from the heat exchangers was also collected in bottles with hydrochloric acid to fix the ammonia.

Chemical analyses

Samples of feeds, faeces, urine, water collected from the heat exchanger,ammonia traps for outgoing air and slaughter material (carcass, slaughter offal, weaned piglets) were analyzed as indicated in Table 2.1.

Table 2.1. **A survey of analyses in different samples**

Sample:	Feeds[1]	Faeces[2]	Urine[3]			Heat ex. water[4] and acid traps	Slaughter material	
			A	B	C		Carcass	
Offal								
Dry matter	2	2					3	3
Ash	2	2					3	3
Nitrogen	2	2	2			2	3	3
Fat	2	2					3	3
Carbon	2	2	2				3	3
Energy	2	2	2				3	3
CO_2				2				
Calcium	2	2			2		3	3
Magnesium	2	2			2		3	3
Phosphorus	2	2			2		3	3

[1] Feed analyzed per balance period.

[2] Faeces per animal.

[3] Urine per animal; A = with H_2SO_4; B = with formalin; C = with HCl.

[4] Heat ex. water = water collected from the heat exchanger per balance period.

Samples were analyzed for dry matter (NEN 3332), ash (NEN 3329), N-Kjeldahl (NEN 3145), fat (EG L15/29), energy (adiabatic bomb IKA, C400, Germany), carbon (Dumas, Hereaus CHN), CO_2 in urine(weight increase of soda lime due to acidification with sulphuric acid), calcium and magnesium (atomic absorption spectrometry after dry ashing and inclusion in HNO_3) and phosphorus (molecular absorption spectrometry (molybdate-vanadate) after dry ashing and inclusion in HNO_3). For analyses of minerals in slaughter material samples were extracted with petroleum ether 40/60 after freeze drying and subsequently ground over a 1 mm screen.

Balance trials during pregnancy

The feed allowance for the pregnant animals during a collection period of at least 7 days were weighed and sampled in duplicate in advance. All analyses in the diet were done in the two separate samples. Water consumption was measured with an electronic device and contribution of mineral supply from water was included in the Ca balance using the mineral levels as given by the water supply company. No Mg or P were detectable in the water. The intake of Ca from drinking water was excluded from the calculation of variance due to the lack of variance in the Ca concentration in the water. During the collection period faeces was collected twice daily and stored in a container with formalin at -20° C. After the collection period the total amount of faeces was weighed, thawed overnight, mixed in a cutter and from this mix two samples were taken for analysis. Nitrogen was analyzed in fresh material and the other analyses were done in air dry samples. Urine in the container under the respiration chamber was weighed daily and three samples were taken which were conserved with formalin, hydrochloric acid and sulphuric acid, respectively (see Table 2.1). These samples were stored at 5° C and analyzed in duplicate.
In the used housing system the separation between faeces and urine was incomplete. For balance trials this is of minor importance, provided that precautions are taken to minimize N losses (N in out going air, in water collected from the heat exchanger and in dust from filters of the air conditioning). In each balance trial gaseous exchange was measured during two periods of 48 hours. Heat production was calculated according to the equation of Brouwer (1965). Also from N and C balances energy retention was calculated as indicated by Brouwer (1965).

Balance trials during lactation

The principle of balance measurements during lactation was the same as during pregnancy. The balances of sow and piglets were measured together. There was no supply of creep feed to the piglets. The balance of the total period of 21 days was calculated by taking the mean of the weekly results for feed intake and losses in faeces, urine, water collected from the heat exchanger and ammonia in outgoing air. During lactation heat production, CO_2-production and O_2-consumption were not linear related to time due to changes in milk production and litter weight. A number of curves was tested (Everts, unpublished results). The best fitting model was:

$$Y = A + B/(1 + D^*t) \qquad (1)$$

Where Y is heat production in $MJ.d^{-1}$, CO_2 production in $L.d^{-1}$ or O_2 consumption in $L.d^{-1}$; t is time (days of lactation) ; A, B and D are estimated constants. Mean values were calculated as the area below the curve from day 4 to day 25 divided by 21. To calculate the balance of the sow litter gain must be subtracted from the total balance of sow with litter. To avoid problems related to the measurement of milk production and composition, litter gain was calculated from daily live weight gain of the litter, live weight and composition of piglets at birth and live weight and body composition at weaning. For body composition at birth the assumed values per kg live weight were 18.5 g N, 14 g fat, 3.6 MJ energy, 11.8 g Ca, 0.3 g Mg, 6.3 g P representing the calculated mean value from literature (Weniger and Funk, 1953; Berge and Indrebø, 1954; Lenkeit, 1957; Pommeroy, 1960; Wood and Grooves, 1965; Curtis et al, 1967; Etienne and Henry, 1973; Seerley et al., 1978; Becker et al., 1979; Close and Stanier, 1984). Body composition at weaning was obtained by killing and analyzing two piglets with a live weight as close as possible to the mean of the litter. Carbon retention was calculated from protein and fat gain of the litter. The balance of the sow was calculated by difference, without doing further assumptions.

Comparative slaughter technique

Before slaughtering sows were shorn (except the head) and hairs were weighed air dry. These results were not included in the calculation of the variance, because we assumed a fixed nitrogen content of hair as given by Oslage (1965). Before transport to the slaughter house sows were weighed and their back fat thickness was measured ultrasonically (Kraut Kramer USK6). Sows were slaughtered according to a commercial procedure. Blood, claws, cuttings (eyes and ears) were collected as offal. Gastrointestinal tract was emptied by stripping the small intestine and rinsing the stomach and the large intestine. The empty tract was added to the offal. The carcass was chopped in two halves and both halves were weighed. Brain, spinal cord and small cuttings were collected and together with the heart, lungs, liver, spleen and tail added to the

offal. Left half carcass, offal and blood were stored at -20° C. When all animals of a batch had been slaughtered, then all materials were ground and sampled.
Frozen blood and slaughter offal of each animal were sawed into small blocks and mixed together in a cutter. Samples were taken in triplicate for analyses, while the homogenous mass had a temperature below 0° C. Separately triplicate samples were taken for mineral analysis.
After removal of visible ice, weighing of the left carcass half and removal of teeth and molars, the half carcass was treated in the same way as offal. Teeth and molars were not analyzed. Weaned piglets were completely analyzed including gut content. Two piglets of each litter together were treated in the same way as offal. All results of the chemical analyses were corrected to warm fresh weights using the ratio between warm fresh weight and the weight of the frozen material (-20° C).

Statistical analyses

The results of 30 balance trials with pregnant sows (mid and late pregnancy) and of 30 balance trials with lactating sows were used separately to estimate the standard deviation (sd_B) of balance trials. This estimate did not include the variance due to weighing amounts of feed, faeces and urine with electronic balances due to the extremely small errors. The analyses of feed and faeces are expressed in dry matter (=DM). Thus the analysis of components in feed and faeces included the variance due to DM determination. In this way the sd of a balance was calculated as:

$$sd_B = (I^2 \times \sigma_I^2 + F^2 \times \sigma_F^2 + U^2 \times \sigma_U^2)^{½} \qquad (2)$$

where

sd_B = standard deviation of retention of a component in balance ($g.day^{-1}$)
I = dry matter intake ($kg.day^{-1}$)
F = kg dry matter faeces ($kg.day^{-1}$)
U = produced urine ($kg.\ day^{-1}$)
σ_I^2 = mean σ^2 of all sets of two simple analyses of a component in DM feed ($g^2.kg^{-2}$)
σ_F^2 = mean σ^2 of all sets of two simple analyses of a component in DM faeces ($g^2.kg^{-2}$)
σ_U^2 = mean σ^2 of all sets of duplicate analyses of a component in urine ($g^2.kg^{-2}$)

Calculation of sd for balances of N, C and E included additional terms to cover all possible losses (for N: N losses in water collected from the heat exchanger and in outgoing air; for C: gaseous losses as CO_2 and CH_4; for E: energy losses due to gaseous exchange). During lactation a term for litter gain was included. The variance of two simple analyses included also the variance due to sampling. As these two sources of variance were confounded, the total variance is named in this paper as analytical variance or analytical error.

The data of 49 slaughtered sows were used to calculate the standard deviation of body composition (sd_S). The same assumptions as for balance trials were used. The sd_S was calculated as:

$$sd_S = (W_C^2 \times \sigma_C^2 + W_O^2 \times \sigma_O^2)^{1/2} \qquad (3)$$

where

sd_S = standard deviation of the amount of a component in the body (kg)

W_C = carcass weight at slaughtering (kg)

W_O = weight of the slaughter offal (including blood) at slaughtering (kg)

σ_C^2 = mean σ^2 of all sets of three simple analyses of a component in carcass

σ_O^2 = mean σ^2 of all sets of three simple analyses of a component in offal

The variance of the three simple analyses included also the variance due to sampling. Due to the linkage between variance of sampling and analysis total variance is named as analytical variance in this paper.

From body composition of the reference animals equations were derived to predict the body composition of remaining sows at mating using multiple regression. The standard deviation of retention over a time span (sd_R) was calculated by including the residual variance of the prediction equation of a component at mating to equation 3.

Results

Balance trials during pregnancy

Mean retention, sd_B of retention and the contribution of different error sources to total variance of retention are given in Table 2.2. The sd_B for N, C and E balance was about 5 % of the retention. The sd_B of retention of minerals and of fat gain was much higher. For N and Ca variance due to intake was the main source of variance. However, the analytical error analysis of the feed was relatively low and nearly equal in pregnancy and lactation balances (sd of N, C, E, Ca, Mg and P in the DM of the diets was 0.34 g, 2.14 g, 40 kJ, 0.13 g, 0.04 g and 0.09 g, respectively). For C and E most of the total variance was due to gaseous exchange. Energy balance and fat gain calculated from heat production showed a smaller sd_B than calculated from N and C balance. For Mg and P faecal losses were the most important source of variance.

Balance trials during lactation

Mean retention, sd_B and the contribution of the different error sources to the total variance of retention during lactation are shown in Table 2.3. However, the variance due to the estimate of litter gain had to be added and the procedure to estimate the variance of gaseous exchange was changed. To obtain an estimate of variance due to gaseous exchange during the total balance period the mean residual variance of the calculated regression equations of heat production, CO_2 production and O_2 consumption against the time were used (equation 1).

Table 2.2

Contribution of different sources of σ^2 (g^2; energy MJ^2) to total σ^2 (g^2; energy MJ^2), mean observed retention level ($g.d^{-1}$; energy $MJ.d^{-1}$) and sd_B of balance trials ($g.d^{-1}$; energy $MJ.d^{-1}$) during pregnancy

	σ^2						ret[1]	sd_B
Source:	Feed	Faeces	Urine	N-air[2]	Gas ex[3]	Total		
Amounts(kg)	2.54	0.56	3.9	4.6	-	-		
Component								
N	0.765	0.083	0.444	0.0009	-	1.294	16.0	1.13
C	29.44	7.215	0.99	-	38.6	76.244	187.6	8.73
Ca	0.115	0.048	0.006	-	-	0.169	6.7	0.41
Mg	0.009	0.043	0.00011	-	-	0.052	0.5	0.23
P	0.051	0.161	0.00002	-	-	0.212	4.4	0.46
E (heat)	0.008	0.018	0.00028	-	0.130	0.156	9.3	0.39
E (C & N)							9.3	0.45
Fat gain (heat)							174	10.80
Fat gain (C & N)							173	12.36

[1] ret = retention of a component ($g.d^{1}$; energy $MJ.d^{-1}$).

[2] N-air = ammonia in outgoing air and in water collected from the heat exchanger.

[3] Gas ex = gaseous exchange.

The main sources of variance in the lactation balances were similar to those of the pregnancy balances. However, for Ca the main source of variance shifted from intake to litter gain. Comparing the sd_B's of retention during pregnancy (Table 2.2) with those during lactation (Table 2.3), it can be seen that sd_B for balances of N, C, E and fat are about 2.0 to 2.5 times higher during lactation than during pregnancy. For mineral balances the sd_B was between 4 and 5 times higher during lactation compared to pregnancy.

In this experiment attention was paid to losses in dust on the filters of the air conditioning. During lactation analysis of dust indicated that it was mainly dust from feed enriched with nitrogen from the air. Daily loss of nitrogen in this way was 0.4 $g.d^{-1}$ and of carbon 2.5 $g.d^{-1}$ per animal. During pregnancy the amount of dust was too small to analyze.

Table 2.3

Contribution of sources of σ^2 (g^2; energy MJ^2), total σ^2 (g^2; energy MJ^2), observed retention ($g.d^{-1}$;energy $MJ.d^{-1}$) and sd_B of a balance trial ($g.d^{-1}$; energy $MJ.d^{-1}$) during lactation

	σ^2							ret[1]	sd_B
Source:	Feed	Faeces	Urine	N-air[2]	Gas ex[3]	Litter[4]	Total		
Amounts(kg)	5.17	1.23	6.24	6.9	-	2.75	-		
Component									
N	3.17	0.97	0.035	0.022	-	1.08	5.27	-10.0	2.30
C	122.0	23.90	9.781	-	331.2	28.93	515.8	-370.0	22.71
Ca	0.476	0.97	0.0001	-	-	2.89	4.34	-3.0	2.08
Mg	0.037	0.79	0.0001	-	-	0.01	0.84	1.1	0.91
P	0.210	2.35	0.0001	-	-	0.72	3.28	0.1	1.81
E (heat)	0.033	0.02	0.0628	-	0.668	0.08	0.86	-19.0	0.92
E (C & N)								-19.0	1.18
Fat (heat)								-440	24.8
Fat (C & N)								-438	29.7

[1] ret, [2] N-air, [3] Gas ex : see Table 2.3

[4] Litter = litter gain

Comparative slaughtering

In Table 2.4 the mean level of observed retention, the calculated sd_R and the contribution of the different sources of variance are shown when one pregnancy or three reproductive cycles are investigated. For energy and fat retention the main source of variance was the estimate of the body composition at the start of the experiment. The main source of variance for the estimate of nitrogen and mineral gain was the carcass analysis. Slaughter offal gave the smallest contribution to the total variance due to the relatively small amount of these tissues compared to carcass and the somewhat smaller analytical variance.

It can be calculated that energy gain calculated from fat and protein is less accurate than the analysis (Table 2.4: sd_R analyzed =67 MJ; sd_R calculated = 73 MJ). In Table 2.4 also the standard deviation of retention is calculated on a daily basis (sd_{RD}).

Discussion

In the balance trials the contribution of feed intake to the total variance of retention is considerable, especially at a high feeding level as applied in lactation. To obtain this variance dry matter intake must be squared and multiplied with the variance due to sampling and the analysis (equation 2). Thus, when the intake increased from 2.54 to 5.17 and sd for N due to sampling and analysis is 0.344, then the variance for nitrogen due to intake increased from $0.765(=2.54^2*0.344^2)$ to $3.17\ (=5.17^2*0.0.344^2)$.

In mineral balances the contribution of variance from faeces is important. Especially faeces with a low dry matter content due to insufficient separation between faeces and urine seems to increase variance. In spite of carefully mixing sedimentation of the minerals hampered accurate sampling.

During lactation the analysis of the litter gave an additional source of variance. In Ca balances the litter gain accounted for more than 50 % of the total variance. Mineral analysis in ground animals seems to be less accurate due to less homogenous samples. Balance technique and comparative slaughtering are used in experiments with different objectives. However, comparison of the two techniques is often presented, using comparative slaughtering as reference. For growing pigs this seems to be valid due to minor effect of the estimate of body composition at the start of the experiment on total variance of the total gain, when live weight gain equals at least the half of the initial weight (Susenbeth, 1984; de Greef, 1992). For sows this seems less valid due to a smaller increase in live weight gain (live weight at the start: 125 kg; live weight at slaughter 175 kg; gain 50 kg). The analytical error also seems to increase with live weight of animals due to more problems to get homogeneous samples of ground carcass (harder bones and a tougher skin). The mineral analysis is the most sensitive to the grounding procedure. In spite of precautions as freeze drying, extracting fat and grinding over a 1 mm screen, samples for mineral analysis seem to be still inhomogeneous. Minerals expressed in the ash content were quite stable, but the concentration of ash was variable.

Results from this trial indicate that especially the estimate of body fat and energy at the start of the trial affected the estimate of gain during one or more reproductive cycles considerably. This is in line with results of Hovell et al. (1977) and Walach-Janiak et al. (1986 a,b), who observed also considerable standard deviations by estimating body composition at the start of an experiment.

Comparison of our results for protein and fat gain with those of Hovell et al. (1977), de Wilde (1980 a,b) and Walach-Janiak et al. (1986) is difficult due to differences in statistical approach. All authors indicated that fat deposition had a larger error than protein deposition. Energy deposition was always a calculated value instead of an analyzed value.

Table 2.4

Contribution of sources of σ^2 (kg^2; energy MJ^2), total σ^2 (kg^2; energy MJ^2), estimated gain (kg; energy MJ), sd_R (kg; energy MJ) and sd_{RD} expressed on a daily basis (g.d^{-1};energy MJ.d^{-1}) using comparative slaughtering for a sow with a carcass of 150 kg and 25 kg of offal

	σ^2				Gain		sd_R	sd_{RD}	
Source:	Estimate	Carcass	Offal	Total	preg.[1]	3cycl.[2]		preg.[1]	3cycl.[2]
Amounts (kg)	-	150.0	25.0	-					
Component									
N	0.0013	0.030	0.0002	0.0315	1.1	1.6	0.177	1.64	0.41
Fat	1.9237	0.736	0.0042	2.6639	20.3	6.5	1.63	15.09	3.75
E	3930.0	537.6	5.1	4472.7	975.	555.	66.9	0.62	0.15
Ca	0.0083	0.024	<0.0001	0.0324	0.28	0.63	0.181	1.68	0.42
Mg	<0.0001	<0.0001	<0.0001	<0.0001	0.07	0.015	0.004	0.04	0.01
P	0.0017	0.0052	<0.0001	0.0070	0.15	0.325	0.083	0.77	0.19

[1] preg. = pregnancy period (108 days)

[2] 3cycl. = a period of 3 reproductive cycles (435 days);

Besides the variance due to the method there is also variance due to the between-animal variance. The importance of this sources of variance is shown in Table 2.5. From a regression model analyzing the effect of treatments residual variance was separated into variance due to the estimate at the start of the experiment, due to the analyses of slaughter material and due to remaining causes (mainly between animal variance). Table 2.5 indicates between animal variance as a main source of variance (70-90 %).

It was not possible to compare the retention between both techniques, because balances were not measured continuously. From the comparison of the sd_{RD} of comparative slaughtering (Table 2.4) with the sd_B from balance trials (Table 2.2 and 3) it can be concluded that on a daily basis comparative slaughtering has the lowest standard deviation over a time span of three reproductive cycles. When only one pregnancy is studied, the balance technique is preferred over comparative slaughtering. The balance trials during lactation showed a relative large standard deviation, however theoretically a comparative slaughtering should result in much larger sd, except for magnesium.

Table 2.5

Residual variance from a regression model on comparative slaughtering results to test treatment effects and the estimated contribution of different sources of variance of body gain during the first pregnancy (in kg^2; energy in MJ^2; between brackets percentage)

	Residual[1]		Estimate[2]		Analytical[3]		"Animal"[4]	
Component	σ^2	(%)	σ^2	(%)	σ^2	(%)	σ^2	(%)
N	0.1309	(100)	0.0013	(1)	0.030	(23)	0.099	(76)
Fat	10.626	(100)	1.924	(18)	0.739	(7)	7.963	(75)
E	41955	(100)	3930	(9)	543	(1)	37483	(90)
Ca	0.1068	(100)	0.0083	(8)	0.024	(22)	0.075	(70)
Mg	68.10^{-6}	(100)	4.10^{-6}	(6)	10.10^{-6}	(15)	54.10^{-6}	(79)
P	0.0292	(100)	0.0017	(6)	0.005	(17)	0.023	(77)

[1] Residual = residual variance from the regression

[2] Estimate = variance due to the estimate of body composition at mating

[3] Analytical = variance due to sampling and to analysis

[4] "Animal" = unexplained variance mainly due to between-animal variance

Conclusion

The described techniques for balance trials with pregnant and lactating sows were suitable to measure the balance of the sows. The sd of the energy and nitrogen balance and the fat gain was ranging between 4 and 7 % of the absolute retention level during pregnancy and lactation. The sd's during lactation were about twice as high during lactation than during pregnancy. For the mineral Ca, Mg and P this was even worse. The sd_B can be lowered by paying more attention to analysis of feed and faeces.

The results from slaughter trials indicate the importance of homogenous samples for the chemical analysis. Especially for mineral analysis this is a serious problem. The sd_R of comparative slaughtering is mainly due to the error by predicting body composition at the start of the experiment and to the analytical error of the carcass. It can be concluded that in experiments with sows comparative slaughtering can not be seen as a comparable reference as in experiments with growing pigs, when the two techniques are compared.

Comparing the sd's of both techniques it was concluded that for experiments with a limited time span (<3 months) the balance technique can be preferred for the sows.

There is an need for techniques which can measure body composition in the living animal. Nuclear magnetic resonance seems to be one of these techniques, but at this moment it is very expensive and only suitable for animals smaller than humans.

References

Becker, K., Farries, E. and Pfeffer, E., 1979. Changes in body composition of pig fetuses during pregnancy. *Archiv für Tierernährung* 9: 561-568

Berge, S. and Indrebø, T., 1954. Composition of bodyweight gain of suckling pigs. *Meddelanden fran Norgeslandbrukshogshole* 34: 481-500

Brouwer, E., 1965. Report of the sub-committee on constants and factors. In: Blaxter, K.L. (Editor), Proc. 3rd Symp. on Energy metabolism. *EAAP publication* 11: 441-443

Close, W.H. and Stanier, M.W., 1984. Effects of plane of nutrition and environmental temperature on the growth and development of early-weaned piglet. 1. Growth and body composition. *Animal Production* 38: 211-220

Curtis, S.E., Heidenreich, C.J. and Martin, T.G., 1967. Relationship between bodyweight and chemical composition of pigs at birth. *Journal of Animal Science* 26: 749-751

Es, A.J.H. van, 1958. Gasanalysis in open circuit respiration chambers. In: Thorbek, G. and Aersoe, H. (Editors), 1st symposium on energy metabolism. *EAAP publication* 8: 132-137

Etienne, M. and Henry, Y., 1973. Influence de l'apport energétique sur l'utilisation digestive et metabolique des nutriments et les performances de reproduction chez la truie gestante nullipare. *Annalles de Zootechnie* 22: 311-326

Greef, K.H. de, 1992. Prediction of nutrition: nutrition induced tissue partitioning in growing pigs. PhD Thesis, Agricultural University, Wageningen, The Netherlands

Just, A., Fernández, J.A. and Jørgensen, H., 1982. Nitrogen balance studies and nitrogen retention. In: Laplace, J.P., Corring, T., Rerat, A. (Editors), Digestive physiology in the pig 27-29 October 1982, Jouy-en-Josas. *Les Colloques de l'INRA* 12: 111-122

Lenkeit, W., 1957. Zum Einfluss der Fütterung auf die embryonale Entwicklung. *Züchtungskunde* 29: 397-408

Oslage, H.J., 1965. N(Eiweiß)- und Fettverteilung im Körper wachsende Schweine. *Zuchtungskunde* 37: 339-347

Pommeroy, R.W., 1960. Infertility and neonatal mortality in the sow. III. Neonatal mortality and foetal development. *Journal of Agricultural Science* 54: 31-56

Seerley, R.W., Maxwell, J.S. and McCampbell, H.C., 1978. A comparison of energy sources for sows and subsequent effect on piglets. *Journal of Animal Science* 47: 1114-1120

Susenbeth, A.J.J., 1984. Berechnung der Körperzusammensetzung von Schweinen aus dem mit Hilfe von D_2O bestimmten Körperwasser. Thesis Universität Hohenheim.

Walach-Janiak, M., Raj, St. and Fandrejewski, H., 1986a. Protein and energy balance in pregnant gilts. *Livestock Production Science* 15: 249-260

Walach-Janiak, M., Raj, St. and Fandrejewski, H., 1986b. The effect of pregnancy on protein, water and fat deposition in the body of gilts. *Livestock Production Science* 15: 261-269

Weniger, J.H. and Funk, K., 1953. Untersuchungen über den Calcium- und Phosphor-gehalt ganzer Schweinekörper. *Archiv für Tierernährung* 3: 325-341

Whittemore, C.T. and Yang, H., 1989. Physical and chemical composition of the body of breeding sows with differing body subcutaneous fat depth at parturition, differing nutrition during lactation and differing litter size. *Animal Production* 48: 203-212

Wilde, R.O. de, 1980a. Protein and energy retention in pregnant and non-pregnant gilts. I. Protein retention. *Livestock Production Science* 7: 497- 504

Wilde, R.O. de, 1980b. Protein and energy retention in pregnant and non-pregnant gilts. II. Energy retention. *Livestock Production Science* 7: 505-510

Wood, A.J. and Grooves, T.D.D., 1965. Body composition studies on the suckling pig. 1. moisture, chemical fat, total protein, and total ash in relation to age and bodyweight. *Canadian Journal of Animal Science* 45: 8-13

Chapter 3

Effect of nitrogen supply on the retention and excretion of nitrogen and on energy metabolism of pregnant sows

H. Everts and R.A. Dekker

Institute for Animal Science and Health
(ID-DLO) Branch Runderweg
P.O.box 160, NL 8200 AD Lelystad
The Netherlands

Accepted for publication in Animal Production
Reproduced with the permission of the British Society of Animal Science

Effect of nitrogen supply on the retention and excretion of nitrogen and on energy metabolism of pregnant sows

H. Everts and R.A. Dekker

Abstract

To reduce nitrogen excretion (NEX) the effect of nitrogen supply on nitrogen retention (NR) and NEX was studied in pregnant sows during three parities. A nitrogen supply of 40 g.d^{-1} *(treatment L) was compared with 62 g.d*$^{-1}$ *(treatment C) during day 0 to 85 of pregnancy. In the last month of pregnancy nitrogen supply on treatment L was 50 g.d*$^{-1}$ *and on treatment C 74 g.d*$^{-1}$*. Faecal digestible lysine supply followed the same pattern as nitrogen.*

Nitrogen and energy balances were measured during mid pregnancy (day 50 to 60; n=22) and late pregnancy (day 105 to 112; n=60).

During mid pregnancy treatments had a minor effect on NR and energy metabolism. NEX on treatment L was proportionately about 0.40 lower than on treatment C. During late pregnancy nitrogen retention was lower on treatment L than on treatment C. NEX on treatment L was proportionately reduced by 0.35 compared with treatment C.

In parity 1 the lower NR on treatment L was compensated by a higher fat gain.

Results indicate that nitrogen and faecal digestible lysine supply on treatment L were close to minimal requirement in late pregnancy. Assumed values for maintenance requirement of nitrogen (0.45 g N. kg$^{-0.75}$*) and efficiency of ingested nitrogen to NR (0.6) were in line with the results of the balance trials. The observed nitrogen retention of sows, especially during mid pregnancy, permits a reduced nitrogen supply to reduce NEX.*

Key words: energy metabolism, nitrogen balance, pregnancy, sows

Introduction

Nutrient supply for mature sows during pregnancy needs to meet energy (E) and nitrogen (N) requirements for maintenance and development of products of conception and mammary gland. Younger sows also require additional nutrients to grow to maturity and to compensate for losses during the previous lactation. Energy requirements for pregnant sows are reviewed by Verstegen, Verhagen and den Hartog (1987) and Noblet and Etienne (1987). Nitrogen requirements for pregnant sows are calculated by Vanschoubroek and van Spaendonck (1973) and by Speer (1990). Whittemore and Morgan (1990) designed models to determine optimal protein requirements for breeding sows.

To reduce N pollution due to livestock production it is of interest to assess minimal N requirements instead of optimal requirements for pregnant sows. This requirement must guarantee acceptable litter sizes and piglet weights at birth. A severe N restriction (2-6 g $N.d^{-1}$) has been shown to reduce the nutrient accretion in products of conception (Pond, 1973; Atinmo, Pond and Barnes, 1974; Hammell, Kratzer, Cromwell and Hays, 1976; Leuillet, Etienne and Salmon-Legagneur, 1979; Pond, Maurer and Klindt, 1991). A more moderate N restriction (24-28 g N. d^{-1}) has shown a tendency to lead to lower piglet birth weights in some parities (Mahan, 1977, 1979). Above a level of about 30 g $N.d^{-1}$ foetal growth is guaranteed (Duée, 1976). Higher levels of N supply (> 30 g $N.d^{-1}$) appear to be related to maternal N retention and maternal live-weight gain. It is important also to examine the fate of N intake above the minimum requirement to estimate the contribution of pregnant sows to N pollution and to calculate the possible reduction in N excretion by lowering N and lysine recommendations for breeding sows.

Lysine is usually the first limiting essential amino acid in commercially available diets. A lysine supply of 8.4 to 9.3 $g.d^{-1}.sow^{-1}$ seemed to be sufficient at least for foetal development (Duée and Rerat, 1975; Woerman and Speer, 1976; Corley, Esch, Bahr and Easter, 1983).

In the present experiment the effect of a low dietary N and lysine intake on N and E balance of breeding sows during three subsequent parities was studied to validate minimum requirement for N and lysine and additionally to determine the effect of a low dietary N and lysine intake on N excretion.

Materials and methods

Treatments

During pregnancy two dietary treatments were based on N and faecal digestible lysine (fd-lysine). The control treatment (C) gave a standard N and fd-lysine intake during pregnancy based on current Dutch feeding recommendations (Centraal Veevoeder Bureau, 1986). The experimental treatment (L) gave a lower N and fd-lysine intake based on calculated values for the minimal requirements during late pregnancy for these two nutrients (Table 3.1). The proposed daily intakes were 74 g N and 18 g fd-lysine for days 85-115 for treatment C and 51.5 g N and 10.6 g fd-lysine for the same period for treatment L. Daily intakes of N and fd-lysine during the first part of pregnancy (days 0-85) were 0.83 of the level in the latter part for both treatments. During lactation sows within treatment were allotted to one of two diets: 32.8 g N or 28.5 g N per kg of dry matter.

Daily metabolizable energy intake was 29.5 MJ during the first part of pregnancy and 35.5 MJ during the latter part of pregnancy.

Table 3.1

Calculation of nitrogen (N) and digestible faecal lysine requirements of a sow of 200 kg at day 105 of pregnancy (NR = Nitrogen Retention)

Nitrogen:

N maintenance	: 14.4	g N	(Agricultural Research Council, 1981)
NR intra uterine	: 9.0	g N	(Noblet et al., 1985)
NR udder	: 4.0	g N	(Noblet et al., 1985)
NR maternal	: 3.5	g N	(Vanschoubroek and van Spaendonck, 1973)
		+	
Total	: 30.9	g N	
N-requirement	: 51.5	g N	(=30.9/(0.75*0.80);efficiency 0.75;digestibility 0.8)

Faecal digestible lysine:

Maintenance	: 1.32	g lysine	(Buraczewski, 1973)[1]
Intra uterine	: 3.37	g lysine	(NR*0.375;6 g lysine/16 g N;Becker et al., 1979)
Udder	: 1.73	g lysine	(NR*0.431;6.9 g lysine/16 g N;Buraczewski, 1973)[1]
Maternal	: 1.51	g lysine	(NR*0.431;6.9 g lysine/16 g N;Buraczewski, 1973)[1]
		+	
Total	: 7.93	g lysine	
Requirement	:10.57	g faecal digestible lysine (=7.93/0.75; efficiency 0.75; Poppe and Wiesemüller, 1968)[1]	

[1] = Figures from growing pigs

Animals

During the course of the experiment six groups of 10 half sisters (Large White*Dutch Landrace) were reared individually from a live weight of 25 kg to 125 kg on a time-fixed schedule aiming at a mean growth rate of 600 g.d^{-1}. At a mean live weight of 125 kg animals were artificially inseminated. After mating all animals within a group were randomly allotted to one of the two treatments. Pregnancy was tested ultrasonically and from the pregnant animals four (two of each treatment) were selected with the smallest possible range in mating date. These animals were used in energy and N balance trials during mid pregnancy (day 50 to 60; parity 1 n=6, parity 2 n=8, parity 3 n=8) and late pregnancy (day 105 to 112; parity 1 n=22, parity 2 n=20, parity 3 n=18) during three successive parities. After farrowing, sows within treatment were randomly allotted to one of the dietary lactation treatments. The sows remained on the same combination of treatments for three parities. A sharp time schedule and the number of respiration chambers (n=4) imposed a choice between measuring balances in mid pregnancy and late pregnancy (with the following lactation period). In these situations measurements of the balance in late pregnancy (and lactation) were preferred and therefore the number of balances in mid pregnancy was rather limited.

Diets and feeding level

Diets were manufactured in batches and the levels of ingredients in the diets of each batch were optimized using tabulated values with constraints for net energy value, levels of fd-lysine, methionine and cystine. Diet L had also constraints for a maximum level of nitrogen and total phosphorus. The main ingredients were cassava, maize gluten feed, extracted maize germ meal, wheat middlings, peas, extracted soya bean meal, molasses and alfalfa. The proximate analyses and some essential amino acid levels in the diets are given in Table 3.2. The supply of total essential amino acids in the diets in relation to lysine is shown in Table 3.3 and is compared with that suggested by Whittemore and Morgan (1990). Feeding allowance during pregnancy was 2.5 $kg.d^{-1}$ from day 0 to 85 and 3.0 $kg.d^{-1}$ from day 86 to 115.

Table 3.2
Proximate and amino acid analyses of the diets in dry matter ($g.kg^{-1}$; gross energy $MJ.kg^{-1}$)

Diet	C	L
Dry matter	867	866
Ash	79	74
Crude protein	178	121
Nitrogen	28.5	19.3
Crude fibre	71	71
Crude fat	36	32
Gross energy (MJ)	18.1	17.9
Phosphorus	7.1	4.8
Lysine	8.4	5.7
Cystine	2.9	2.1
Methionine	3.1	2.2

Table 3.3.

The supply of essential amino acids in relation to the lysine supply (lysine = 1.00) in the diets compared with Whittemore and Morgan (1990).

	Diet[1]		Whittemore and Morgan (1990)
	C	L	
Lysine	1.00	1.00	1.00
Threonine	0.76	0.74	0.64
Valine	1.01	1.00	0.71
Isoleucine	0.84	0.73	0.57
Tyrosine + Phenylalanine	1.55	1.46	1.00
Histidine	0.53	0.51	0.36
Cystine + Methionine	0.71	0.76	0.57
Tryptophan	0.22	0.20	0.20

[1] The proportions are based on analyses in the diet, except for tryptophan, which is calculated from tabulated values

Measurements

Sows were weighed before and after the balance trial. New born piglets were weighed individually, when dry (within 12 h *post partum*). Balances were measured in respiration chambers and had a collection period of at least 7 days. In each respiration chamber (open circuit; volume of 12 m^3) a farrowing crate was built and sows were tethered to the floor and laying on a rubber mat. Outgoing air and water from the heat exchangers were analysed for ammonia. Further details concerning the measurement of the balances in respiration chambers are described elsewhere (Everts and Dekker, 1994).

Statistical analysis

Results of balance trials during mid pregnancy were analysed with multiple regression per parity with the model (in first parity sows the term L_k is excluded):

$$Y_{ijk} = \mu + G_i + L_k + P_j + \epsilon_{ijk} \quad (1)$$

where:

μ = mean

$G_i (i = 1,6)$ = effect of group number

$L_k (k = 1,2)$ = effect of previous lactation treatment

$P_j (j = 1,2)$ = effect of pregnancy treatment C or L

ϵ_{ijk} = error component

The effect of group number was included to correct for differences in time and for differences between batches of similar dietary treatments. Previous lactation treatment had no significant effect and therefore model (1) was simplified to:

$$Y_{ij} = \mu + G_i + P_j + \epsilon_{ij} \qquad (2)$$

Values given in Table 3.4 are according to model (2) and corrected for group number. The number of observations per parity in mid pregnancy were too small to test interactions between treatment during pregnancy and during lactation. The effect of parity number was not calculated (not enough within animal comparisons).
Results of balances trials in late pregnancy were also analysed per parity with the model (for first parity sows terms L_k, $\beta_1 {*} x_j.L_k$ and $L_k.P_l$ are excluded):

$$Y_{ijkl} = \mu + G_i + \beta_1 {*} x_j + L_k + P_l + \beta_1 {*} x_j.L_k + \beta_1 {*} x_j.P_l + L_k.P_l + \epsilon_{ijkl} \qquad (3)$$

where:

μ = mean
$G_i (i = 1,6)$ = effect of group number
$\beta_1 {*} x_j$ = effect of total litter size
$L_k (k = 1,2)$ = effect of previous lactation treatment
$P_l (l = 1,2)$ = effect of pregnancy treatment C or L
$\beta_1 {*} x_j.L_l$ = interaction between litter size and previous lactation treatment
$\beta_1 {*} x_j.P_k$ = interaction between litter size and pregnancy treatment
$L_k.P_l$ = interaction between pregnancy treatment and previous lactation treatment
ϵ_{ijkl} = error component

This model also included group number for the same reason as during mid pregnancy. Neither previous lactation treatment nor any interaction term was significant and therefore the model was simplified to:

$$Y_{ijk} = \mu + G_i + \beta_1 {*} x_j + P_k + \epsilon_{ijk} \qquad (4)$$

The values in Table 3.5 are according to model (4) and are corrected for group number and litter size. Parity effect in late pregnancy was estimated within animals and corrected to the mean litter size. In Table 3.5 the differences between parity 1 and 2 and between 1 and 3 are indicated.

Results

Balance trial during mid pregnancy

Differences in N and energy retention between treatments during mid pregnancy were small (Table 3.4). In spite of a mean difference between treatments in nitrogen intake (NI) of 19 $g.d^{-1}$, nitrogen retention (NR) of sows did not differ significantly between treatments. N excretion (NEX) was proportionately reduced on treatment L compared with treatment C by about 0.40 ($P = 0.007$, 0.009 and 0.073 in parities 1, 2 and 3 respectively). The gross efficiency of N utilization (NR/NI) on treatment C was 0.26 (± 0.04), 0.23 (± 0.04) and 0.21 (± 0.04) in parities 1, 2 and 3 respectively. On treatment L these figures were 0.32 (± 0.04), 0.41 (± 0.04) and 0.24 (± 0.03). Only in parity 2 did the gross efficiency differ significantly between the treatments.

Table 3.4

Results of balance trials during mid pregnancy corrected for group number: Live weight (LW, kg), nitrogen balance traits (NI, NR, NEX in $g.d^{-1}$) and energy balance traits (ME, HP, RE, RE_f, RE_p in $kJ.W^{-0.75}$ and $RE_p.RE^{-1}$)

		n	LW	Nitrogen			Energy					
				NI	NR	NEX	ME	HP	RE	RE_f	RE_p	$RE_p.RE^{-1}$
Parity 1	trt C	3	161	63.2	16.2	47.0	655	484	175	122	53	0.31
	trt L	3	160	42.5	13.4	29.1	650	446	199	155	44	0.23
	RSD		6	3.0	2.1	3.3	15	13	32	37	6	0.08
	sign.		ns	**	ns	**	ns	*	ns	ns	ns	ns
Parity 2	trt C	4	180	60.9	13.9	47.0	607	426	178	135	42	0.25
	trt L	4	167	42.1	15.7	26.5	651	439	210	159	50	0.24
	RSD		6	2.9	4.4	4.8	31	22	36	33	14	0.07
	sign.		ns	**	ns	**	ns	ns	ns	ns	ns	ns
Parity 3	trt C	3	205	60.2	12.3	48.0	561	415	148	115	33	0.23
	trt L	5	201	41.6	9.9	31.7	534	411	124	96	28	0.23
	RSD		10	1.9	5.8	7.4	22	24	12	13	16	0.11
	sign.		ns	***	ns	ns	ns	ns	ns	ns	ns	ns

n = number of observations; LW = live weight; NI = nitrogen intake; NR = nitrogen retention; NEX = total nitrogen excretion; ME = metabolizable energy intake; HP = heat production; RE = retained energy (mean of RE calculated from carbon and nitrogen balance and RE calculated from HP); RE_f = retained energy as fat; RE_p = retained energy as protein; $RE_p.RE^{-1}$ = Retained energy as protein divided by total retained energy; trt = treatment; RSD= residual standard deviation; sign= statistical significance.

The effect of treatments on energy metabolism was small. In parity 1 only the heat production was lower on treatment L than on treatment C. The ratio between retained energy as protein (RE_p) and total retained energy (RE) did not differ significantly between treatments. There were no significant carry-over effects from the previous lactation treatments in parities 2 and 3.

Balance trial in late pregnancy

Observed mean litter size (10.9) and mean litter weight at birth (16.6 kg) showed no differences between treatments. In contrast to the balances during mid pregnancy, NR differed significantly between the treatments in late pregnancy (Table 3.5). A mean difference of 25 g.d^{-1} in NI resulted in a

Table 3.5

Results of balance trials in late pregnancy correction for group number and litter size: Live weight (LW, kg), nitrogen balance traits (NI, NR, NEX in g.d^{-1}) and energy balance traits (ME, HP, RE_f, RE_p in kJ.W$^{-0.75}$ and RE_p.RE^{-1})

		n	LW	Nitrogen			Energy					
				NI	NR	NEX	ME	HP	RE	RE_f	RE_p	RE_p.RE^{-1}
Parity 1	trt C	10	205	76.8	27.5	49.3	648	471	174	98	76	0.44
	trt L	12	195	50.0	17.8	32.2	657	466	191	140	51	0.27
	RSD		6	2.4	3.0	2.9	23	17	22	21	9	0.06
	sign.		**	***	***	***	ns	ns	ns	***	***	***
Parity 2	trt C	10	218	73.1	23.3	49.9	632	449	183	122	61	0.33
	trt L	10	220	50.0	17.9	32.1	612	446	164	117	47	0.29
	RSD		8	2.7	3.2	3.3	18	29	26	27	8	0.09
	sign.		ns	***	**	***	ns	ns	ns	ns	**	ns
Parity 3	trt C	8	240	73.4	24.7	48.7	595	440	151	90	61	0.42
	trt L	10	235	48.9	18.0	30.9	585	441	143	99	45	0.31
	RSD		9	3.1	2.5	3.0	22	29	16	16	7	0.06
	sign.		ns	***	***	***	ns	ns	ns	ns	**	**
Parity effect within sows and treatments corrected for litter size:												
Parity 2 - Parity 1			22	-0.9	-1.2	0.3	-30	-20	-10	-3	-7	-0.01
Parity 3 - Parity 1			38	-1.0	-0.9	-0.1	-62	-31	-32	-22	-8	0.01
	RSD		6	2.1	2.9	3.2	22	13	23	20	8	0.04
	sign.		***	ns	ns	ns	***	***	**	**	**	ns

For abbreviations see Table 3.4.

significantly lower NR in all parities on treatment L. Mean NR on treatment L was at a constant level of 17.9 g.d^{-1}. NEX was significantly proportionately reduced by 0.35 on treatment L compared to treatment C.

The gross efficiency of N utilization (NR/NI) on treatment C was 0.35 (± 0.06), 0.33 (± 0.07) and 0.36 (± 0.05) in parities 1, 2 and 3 respectively. On treatment L these figures were 0.35 (± 0.06), 0.35 (± 0.05) and 0.34 (± 0.06) for parities 1, 2 and 3 respectively.

The lower N supply on treatment L resulted in a higher amount of energy retained as fat (RE_f) and a lower ratio RE_p/RE in parity 1. The lower RE_p was compensated by a higher RE_f on treatment L compared with treatment C. In parities 2 and 3 also RE_p was lower on treatment L than on treatment C. But RE and RE_f did not differ significantly between the treatments in parity 2 and 3. The ratio between RE_p and RE was fairly constant in the different parities on treatment L, but on treatment C it seems to show more variation in the different parities. When a maintenance requirement of 400 kJ per kg metabolic live weight was assumed, then the efficiency of energy retention was equal on both dietary treatments (0.75). In parity 1 the efficiency was lower (0.72) than in parities 2 and 3 (0.78). However, these differences were not significant.

As expected parity effects were observed for live weight and for ME intake, RE, RE_f, and RE_p (expressed per unit of metabolic body weight).

Discussion

Validation of the minimum requirement

In this experiment a reduction in N level in the diet for pregnant sows from 25 to 17 g.kg^{-1} neither affected litter size nor litter weight over three parities. The numbers of observations per treatment were small, but the results are in line with those of Duée (1976).

The mean level of NR of sows during mid pregnancy ranged between 10 and 16 g.d^{-1} over three parities. In this period NR is mainly maternal, because retention in products of conception is low (2 g N.d^{-1}; Noblet, Close, Heavens and Brown, 1985). The observed maternal NR during mid pregnancy was at a mean level of about 10 g.d^{-1}. Beyer (1986) observed a similar level of NR during the first half of pregnancy.

In late pregnancy NR was limited to about 17.9 g.d^{-1} on treatment L. This value is in line with the results of Duée, Treil and Camous (1980), Noblet and Etienne (1987) and Kalinowski and Chavez (1990). The difference in NR between mid and late pregnancy on treatment L was comparable to the results of Elsley, Anderson, McDonald, MacPherson and Smart (1966) offering 49 g N.d^{-1} and Noblet and Etienne (1987) offering 46 to 50 g N.d^{-1}. On treatment C NR was about 25 g.d^{-1}. This level of retention is in agreement with the results of

Verstegen, van Es and Nijkamp (1971) feeding more than 70 g N.d^{-1}.
N retained in products of conception and udder during this stage of pregnancy is estimated to be about 14 g.d^{-1} (Noblet et al., 1985). Mean maternal NR on treatment C is therefore about 10 g and equals the level of NR as measured in mid pregnancy. For sows on treatment L maternal NR is limited to about 4 g N.d^{-1} in late pregnancy and this differs considerably from the value observed in mid pregnancy on this treatment.
From these results it was concluded that an intake of 42 g N in mid pregnancy and 50 g N in late pregnancy was sufficient to guarantee development of the products of conception, but this level of N intake affected maternal NR mainly in late pregnancy.
The effects on energy metabolism during mid pregnancy were small. In late pregnancy a lower NR was compensated by a higher fat gain in parity 1. When it is assumed that the values for k_p and k_f are 0.6 and 0.8 (Noblet and Etienne, 1987), then at the same level of ME intake a decrease in RE_p with 1 kJ results in a increase of RE_f with 1.33 kJ (0.8/0.6). For parity 1 it is calculated that the difference in RE_p of 25 kJ between treatment L and C results in a difference of 33 kJ RE_f (25*1.33). Together with a not significant higher ME intake of 9 kJ on treatment L, this results in a total difference in RE_f of 40 kJ RE_f (9*0.8+25*1.33). The observed difference was 42 kJ. In the second and third parity a significant lower RE_p was on treatment L was not compensated with a significant higher RE_f. In these parities the difference between dietary treatments in RE_p were smaller than in parity 1. In contrast to the first parity the ME intake was, in parities 2 and 3, somewhat lower (ns) on treatment L than on treatment C. The combination of these differences in Re_p and ME intake resulted in smaller differences in RE_f than in the first parity.
During mid pregnancy the gross efficiency of nitrogen retention was higher on treatment L than on treatment C. However, this was only significant in parity 2. In late pregnancy the gross efficiency of NR was higher than in mid pregnancy for sows on treatment C. A higher gross efficiency of NR in late pregnancy compared to mid pregnancy was also observed by Close, Noblet and Heavens (1985) and Noblet and Etienne (1987). On treatment L the ratio NR/NI differed less between mid pregnancy and late pregnancy. Compared with the NR/NI of 0.32 as calculated from Table 3.1, it can be concluded that treatment C during mid pregnancy was less efficient than treatment L. The N supply during mid pregnancy on treatment C exceeded the required amount of N to realize the potential of NR in products of conception and in the maternal body. At the end of pregnancy the N supply seems not to exceed the required amount of N to realize the potential NR on both treatments. Due to the fast growing piglets in the uterus, the potential of NR is much higher in this stage of pregnancy than in mid pregnancy. Differences in N supply in late pregnancy resulted therefore in differences in NR and not in differences in gross efficiency. Instead of the ratio NR/NI it is of more interest to study the relationship between NI and NR.

The assumptions of Table 3.1 can be transformed into a linear relationship. The N requirement for maintenance of 0.45 g protein per kg live weight (Agricultural Research Council, 1981) is more or less equivalent to a mean value 0.27 g N per kg metabolic live weight in the range from 120 to 220 kg. This figure and the assumed efficiency from Table 3.1 gives a maintenance requirement of 0.27/0.6 = 0.45 g N per kg metabolic live weight. The efficiency for NR of 0.6 gives a coefficient for NR of 1.0/0.6 = 1.66 in the following equation:

$$NI.W^{-0.75} = 0.45 + 1.66 * NR.W^{-0.75} \quad (5)$$

where

NI = nitrogen intake ($g.d^{-1}$)
NR = nitrogen retention ($g.d^{-1}$)
$W^{0.75}$ = metabolic live weight

When a confidence interval is calculated per $W^{0.75}$ of 2* standard deviation of the N balance as given by Everts and Dekker (1994), then a variation of 0.05 g around the line of equation (5) is allowed.

During mid pregnancy no significant relationship between $NI.W^{-0.75}$ and $NR.W^{-.075}$ could be calculated using the data of both treatments. Figure 3.1 shows that equation (5) fits reasonably for treatment L, but to a lesser extent for treatment C. From Figure 3.1 it can be concluded that N supply on treatment C exceeds the requirement for maintenance, development of conception products and potential maternal NR. The N supply on treatment L was sufficient to achieve a similar level of NR. Beyer (1986) observed a linear relation between digestible N intake and NR. From his data a maintenance requirement of 0.62 g N. $W^{-.075}$ and an efficiency of 0.6 for NR can be calculated, when a N digestibility of 0.8 is assumed.

During late pregnancy a regression analysis between NI and NR showed a significant relationship, but the constant and the efficiency are dependent on the choice of the response variable. The regression with the model as given in equation (5) results in:

$$NI.W^{-0.75} = 0.46\ (\pm 0.08) + 1.66\ (\pm 0.21) * NR.W^{-0.75}\ (adj.R^2 = 0.48;\ RSD = 0.18) \quad (6)$$

However, NR as response variable results in:

$$NR.W^{-0.75} = 0.06\ (\pm 0.04) + 0.29\ (\pm 0.04) * NI.W^{-0.75}\ (adj.R^2 = 0.48;\ RSD = 0.07) \quad (7)$$

Equation (6) is in line with an equation for sows in the second part of pregnancy as given by Beyer (1986), however, the mean level of NR was higher in our experiment. From the data of Beyer (1986) a maintenance requirement of 0.51 g $N.W^{-0.75}$ and an efficiency of 0.6 can be calculated when a N digestibility of 0.8 is assumed.

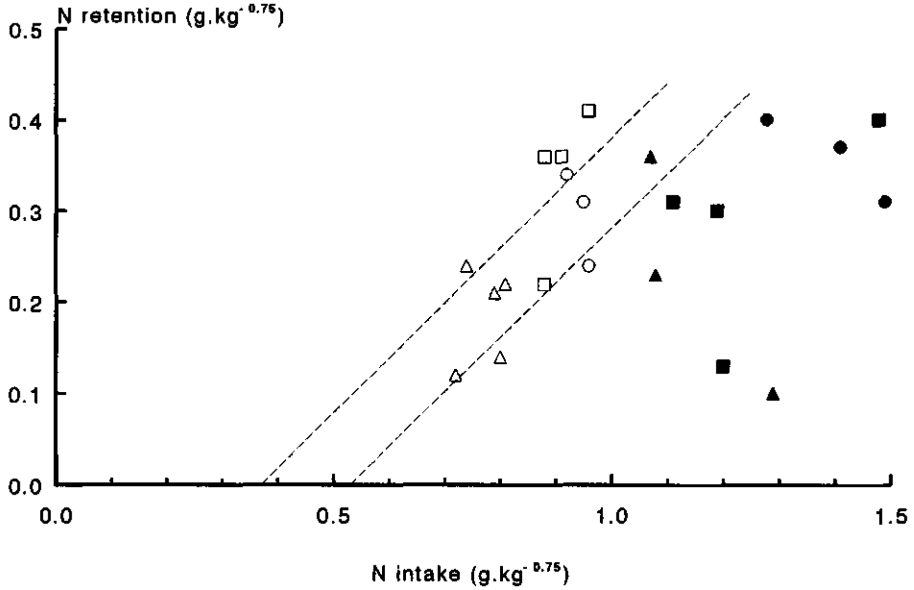

Figure 3.1.

The relationship between nitrogen intake (NI) in g N.W$^{-0.75}$ and nitrogen retention (NR) in g N.W$^{-0.75}$ during mid pregnancy. ○ = diet L, parity 1; □ = diet L, parity 2; △ = diet L, parity 3; ● = diet C, parity 1; ■ = diet C, parity 2; ▲ = diet C, parity=3. The lines indicate the confidence interval of 2 s.d. around the assumed equation (5)

Equation (7) has no significant intercept and therefore the coefficient for NI seems to approach the ratio NR/NI. Figure 3.2 indicates no strong relationship between NR and NI. The explanation for the poor relationship may be that the NR of sows under the confidence interval of Figure 3.2 are fed above their potential capacity to retain N. Most of these observations are from sows on treatment C. The observations above the confidence interval are from sows on treatment L, indicating a higher efficiency at relatively low levels of N intake.

In addition to N, lysine requirement was calculated in Table 3.1. The lysine intake on treatment L was restricted to the same extent as N intake. Theoretically, other amino acids could be limiting in this situation. However, Table 3.3 shows that the other essential amino acids, as a proportion of lysine, were nearly equal for both diets and at a level close to or above the percentages as proposed by Whittemore and Morgan (1990).

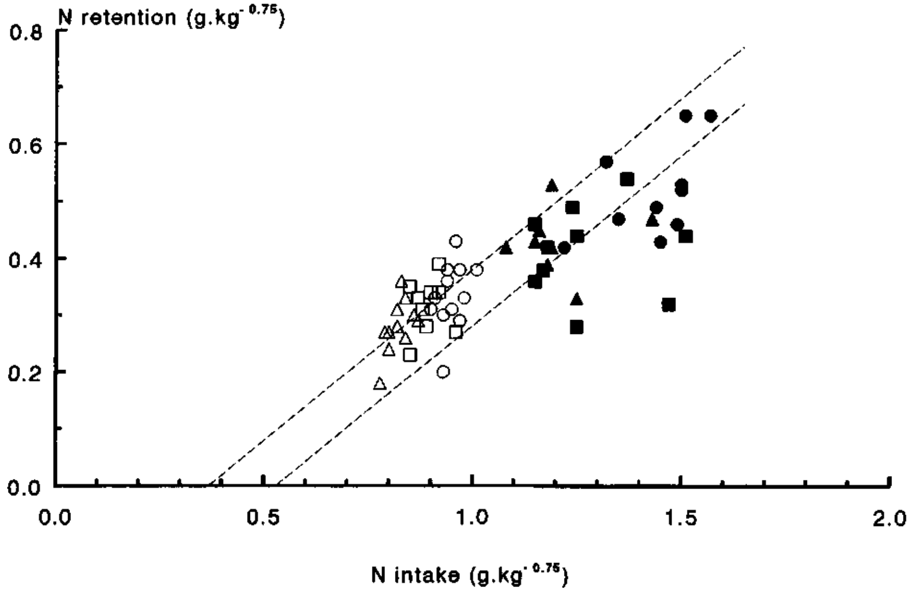

Figure 3.2.
The relationship between nitrogen intake (NI) in g N.W$^{-0.75}$ and nitrogen retention (NR) in g N.W$^{-0.75}$ in late pregnancy. ○ = diet L, parity 1; □ = diet L, parity 2; △ = diet L, parity 3; ● = diet C, parity 1; ■ = diet C, parity 2; ▲ = diet C, parity=3. The lines indicate the confidence interval of 2 s.d. around the assumed equation (5)

N excretion

NEX in mid pregnancy was proportionately reduced by about 0.40 (NEX on treatment C was 48 g N.d^{-1} and on treatment L 28 g N.d^{-1}). Excretion of nitrogen in late pregnancy was proportionately reduced by 0.35 (NEX on treatment C was 49 g N.d^{-1} and on treatment L 32 g N.d^{-1}). The differences in NEX between treatment C an L are mainly related to differences in urinary nitrogen excretion. These figures indicate substantial possibilities to reduce the N pollution by sows during mid and late pregnancy. However, even on treatment L the NEX during pregnancy is considerable. This is mainly due to the large proportion of N needed for the maintenance of the sow. Even with a high efficiency of the utilization of N for retention (0.75) and a digestibility of 0.8 the NEX is 0.68 (1-(9.0+4.0+3.5)/51.5) of ingested N (see Table 3.1).

Effect of parity number

Parity number affected live weight of sows significantly (Table 3.5). The increase in live weight from first to second parity (18-22 kg) is in line with results of Greenhalgh, Elsley, Grubb, Lightfoot, Saul, Smith, Walker, Williams and Peo (1977), Whittemore, Franklin and Pearce (1980) and Everts (1991). The increase in live weight from first to third parity (36-37 kg) was similar as shown by Everts (1991), but higher than observed by Greenhalgh et al. (1977). The effect of parity on live weight was much smaller than reported by Yang, Eastham, Philips and Whittemore (1989). However, in their experiment, feed intake increased with parity number. On treatment C maternal NR tended to decrease in mid pregnancy with increasing parity number, however statistical analysis within animals to test a parity effect was impossible. But it is in line with the observation that NR decreased with increasing live weight (Carr, Boorman and Cole, 1977).

On treatment L in parity 2, NR was higher than in parity 1 (not significant). This suggests that a part of the normal protein growth during the first parity is shifted to the second parity. This can support the idea that a sow tries to reach a certain amount of protein in her body and that this process slowly looses priority when the level of body protein nears the target. When protein supply is limited in the first parity, the animal tries to compensate in the next pregnancy by increasing the N retention.

Most of the values concerning energy metabolism (expressed in kJ.$W^{-0.75}$) in Table 3.5 decreased with parity number. This was a consequence of the constant feeding level over parities. RE decreased less than expected, probably due to a decreasing maintenance requirement for older sows or a higher efficiency of energy retention as suggested by Everts and Dekker (1991). A possible decrease in maintenance requirement is in contrast with the results of Beyer (1986). However, the maintenance requirement can be affected by ambient temperature (Geuyen, Verhagen and Verstegen, 1984), the housing conditions and the behaviour of sows (Cronin, van Tartwijk, van der Hel and Verstegen, 1986). In our experiment the sows were kept at an ambient temperature of 20° C, well adapted to the respiration chambers and always very quiet (recorded standing time).

Conclusions

A reduction in N supply during pregnancy had no effect on litter size nor on litter weight at birth. During mid pregnancy NR didn't differ significantly between the treatments. In general NR did not exceed a level of about 14 g.d^{-1}.

During late pregnancy treatment L seems to be close to the minimum required amount of N and lysine. A lower maternal NR in the last month of pregnancy was calculated. A maintenance requirement of 0.45 g $N.W^{-0.75}$ and an efficiency of 0.6 for NR seems to fit for breeding sows. However, when sows are fed above their capacity to retain nitrogen, then the efficiency decreases. With a restricted supply of N the sow tries to increase the gross efficiency of N (NI/NR).

A level of about 10 g maternal of NR in mid pregnancy can be guaranteed by supplying about 42 g $N.d^{-1}$ and about 9 g of fd-lysine.d^{-1}. This is valid under the condition that other essential amino acids are not limiting.

In late pregnancy a N supply of about 50 g $N.d^{-1}$ guaranteed a normal development of the products of conception and the udder, but decreased the maternal NR. In line with these results Bolduan (1990) concluded that 100 g crude protein.kg^{-1} and 5 g lysine.kg^{-1} in the diet was the minimal requirement for sows.

The restriction of N supply during pregnancy reduced NEX by a similar proportion as the reduction in intake. These results indicate that it is possible to find a balance between reducing the excretion of N, resulting in lowering the possible pollution of the environment and a profitable animal production by feeding sows close to their minimal N requirements.

Acknowledgements

We thank M.W.A. Verstegen and A.W. Jongbloed for their useful comments on the manuscript. This research was partly financed by the Dutch Fund for Manure and Ammonia Research (FOMA).

References

Agricultural Research Council, 1981. The Nutrient Requirements of Pigs. Commonwealth Agricultural Bureaux, Slough.

Atinmo, T., Pond, W.G., Barnes, R.H., 1974. Effect of maternal energy vs. protein restriction on growth and development of progeny in swine. *Journal of Animal Science* 39: 703-711

Becker, K., Farries, E., Pfeffer, E., 1979. Changes in body composition of pig fetuses during pregnancy. *Archiv für Tierernährung* 29: 561-568

Beyer, M., 1986. Untersuchungen zum Energie- und Stoffumsatz von graviden und lactierenden Sauen sowie Saugferkeln- ein Beitrag zur Präzisierung des Energie- und Proteinbedarfes. Promotionsarbeit, Forschungszentrum für Tierproduktion Dummerstorf-Rostock

Bolduan, G., 1990. Erste Ergebnisse zur reduzierte Eiweissfütterung bei tragende Sauen. *Tierzucht* 44: 541

Buraczewski, S., 1973. Views on the pig's requirements for amino acids and new sources of these nutrients suitable for the use in the feeding of pigs. In: New developments on the provision of amino acids in the diets of pigs and poultry. (ECE/AGRI/4) U.N. Economical and Social Council Symposium, vol. 1: 73-97

Carr, J.R., Boorman, K.N. and Cole, D.J.A. 1977., Nitrogen retention in the pig. *British Journal of Nutrition* 37: 143-155

Close, W.H., Noblet, J., Heavens, R.P., 1985. Studies on the energy metabolism of the pregnant sow. 2. The partition and utilization of metabolizable energy intake in pregnant and non pregnant animals. *British Journal of Nutrition* 53: 267-279

Corley, J.R., Esch, M.W., Bahr, J.M., Easter, R.A., 1983. Amino acid supplementation of low-protein diets for swine: effects of gestation treatment on reproductive performance of gilts and sows. *Journal of Animal Science* 56: 108-117

Cronin, G.M., van Tartwijk, J.M.F.M., van der Hel, W. and Verstegen, M.W.A., 1986. The influence of degree of adaptation to tether-housing by sows in relation to behaviour and energy metabolism. *Animal Production* 42: 257-268

Centraal Veevoeder Bureau. 1986. [Nutrient requirements of livestock and feeding value of feedstuffs] Verkorte tabel augustus 1986. Centraal Veevoederbureau, Lelystad

Duée, P.H. and Rerat, A., 1975. Étude du besoin en lysine de la truie gestante nullipare. *Annales de Zootechnie* 24: 447-464

Duée, P.H., Treil, F. and Camous, S., 1980. Influence de l'apport protéique durant la croissance et la première gestation sur les performances de réproduction et la composition corporelle chez la truie. *Annales de Zootechnie* 29: 121-136

Duée, P.H., 1976. Chronologie de l'apport azote pendant le cycle de réproduction chez la truie. *Annales de Zootechnie* 25: 199-212

Elsley, F.W.H., Anderson, D.M., McDonald, I., MacPherson, R.M. and Smart, R., 1966. A comparison of the live-weight changes, nitrogen retention and carcass composition of pregnant and non-pregnant gilts. *Animal Production* 8: 391-400

Everts, H., 1991. The effect of feeding different sources of crude fibre during pregnancy on the reproductive performance of sows. *Animal Production* 52: 175-184

Everts, H. and Dekker, R.A., 1991. Effect of protein/lysine supply and of parity number on energy metabolism during pregnancy and lactation in sows. In: Energy metabolism of farm animals (Ed. Wenk, C. and Boessinger, M.). *European Association for Animal Production publication* no. 58: 317-320

Everts, H. and Dekker, R.A., 1994. Balance trials and comparative slaughtering in breeding sows: description of techniques and observed accuracy. *Livestock Production Science* 37: 339-352

Geuyen, T.P.A., Verhagen, J.M.F. and Verstegen, M.W.A., 1984. Effect of housing and temperature on metabolic rate of pregnant sows. *Animal Production* 38: 477-485

Greenhalgh, J.F.D., Elsley, F.W.H., Grubb, D.A., Lightfoot, A.L., Saul, D.W., Smith, P., Walker, N., Williams, D. and Peo, M.L., 1977. Coordinated trials on the protein requirements of sows. *Animal Production* 24: 307-321

Hammell, D.L., Kratzer, D.D., Cromwell, G.I. and Hays, V.W., 1976. Effect of protein malnutrition of the sow on reproductive performance and on postnatal learning and performance of the offspring. *Journal of Animal Science* 43: 589-597

Kalinowsky, J. and Chavez, E.R., 1990. Nitrogen and trace mineral balance of pregnant gilts under low dietary zinc intake. *Journal of Trace Elements and Electrolytes in Health and Disease* 4: 115-125

Leuillet, M., Etienne, M, Salmon-Legagneur, E., 1979. Consequences d'une tres forte restriction azotée a differentes periodes de la gestation de la truie sur le développement des foetus. *Annales de Biologie Animale Biochemie Biophysique* 19: 217-223

Mahan, D.C., 1977. Effect of feeding various gestation and lactation dietary protein sequences on long term reproductive performance in swine. *Journal of Animal Science* 45: 1061-1072

Mahan, D.C., 1979. Effect of dietary protein sequence on long term sow reproductive performance. *Journal of Animal Science* 49: 514-521

Noblet, J., Close, W.H., Heavens, R.P. and Brown, D., 1985. Studies on the energy metabolism of the pregnant sow. 1. Uterus and mammary tissue development. *British Journal of Nutrition* 53: 251-265

Noblet, J. and Etienne, M., 1987. Metabolic utilization of energy and maintenance requirements in pregnant sows. *Livestock Production Science* 16: 243-257

Pond, W.G. 1973. Influence of maternal protein and energy nutrition during gestation on progeny performance in swine. *Journal of Animal Science* 36: 175-181

Pond, W.G., Maurer, R.R. and Klindt, J., 1991. Fetal organ response to maternal protein deprivation during pregnancy in swine. *Journal of Nutrition* 121: 504-509

Poppe, S. und Wiesemüller, W. 1968. Untersuchungen über den Aminosäurenbedarf wachsender Schweine. 1. Mitteilung - Bestimmung des Lysinbedarfes mit Hilfe der N-Bilanzmethode. *Archiv für Tierernährung* 18: 392-404

Speer, V.C., 1990. Partitioning nitrogen and amino acids for pregnancy and lactation in swine: A review. *Journal of Animal Science* 68: 553-561

Vanschoubroek, F. and van Spaendonck, R. van, 1973. Faktorieller Aufbau des Protein- und Aminosäurenbedarfs tragender Sauen. *Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde* 31: 71-91

Verstegen, M.A.W., Es, A.J. van and Nijkamp, H.J., 1971. Some aspects of energy metabolism of the sow during pregnancy. *Animal Production* 13: 677-683

Verstegen, M.W.A., Verhagen, J.M.F. and Hartog,L.A. den, 1987. Energy requirements of pigs during pregnancy: a review. *Livestock Production Science* 16: 75-89

Whittemore, C.T., Franklin, M.F. and Pearce, B.S., 1980. Fat changes in breeding sows. *Animal Production* 31: 183-190

Whittemore, C.T. and Morgan, C.A., 1990. Model components for the determination of energy and protein requirements for breeding sows: a review. *Livestock Production Science* 26: 1-37

Woerman, R.L. and Speer, V.C., 1976. Lysine requirement for reproduction in swine. *Journal of Animal Science* 42: 114-120

Yang, H., Eastham, P.R., Philips, P. and Whittemore, C.T., 1989. Reproductive performance, body weight and body condition of breeding sows with differing body fatness at parturition, differing nutrition during lactation, and differing litter size. *Animal Production* 48: 181-201

Effect of nitrogen supply on nitrogen and energy metabolism in lactating sows

H. Everts and R.A. Dekker

Abstract

In 56 balance trials with sows the effects of two levels of nitrogen (lysine) supply during lactation (C= 24.7 g $N.kg^{-1}$*; H= 28.5 g* $N.kg^{-1}$*) and of two levels of nitrogen (lysine) supply during pregnancy (C= 24.7 g* $N.kg^{-1}$*; L=16.7 g* $N.kg^{-1}$*) on nitrogen and energy balance during lactation (day 4 -day 25) were investigated during three successive parities (23, 17 and 16 sows in parities 1, 2 and 3, respectively). Retention in piglets was calculated from their body composition at weaning. Mean daily litter gain was 2.72* $kg.d^{-1}$ *and was not affected by the dietary treatments. Mean body weight loss of sows was 0.67* $kg.d^{-1}$ *and was only in parity 2 lower on lactation treatment H compared with lactation treatment C. Nitrogen retention was less negative on lactation treatment H than on lactation treatment C (significant in parity 1) and nitrogen retention was less negative on pregnancy treatment L than on pregnancy treatment C (significant in parity 3). Fat mobilisation on lactation treatment H was higher than on lactation treatment C (significant in parities 2 and 3). The proportion of energy mobilized as protein to the total energy mobilization was significantly lower on lactation treatment H compared with lactation treatment C.*

Estimated daily nitrogen, lysine and ileal digestible lysine requirements for first parity lactating sows were 162 g, 48 g and 37 g respectively. For second parity sows 179 g, 54 g and 42 g and for third parity sows 185 g, 56 g and 43 g.

Nitrogen excretion during lactation was about 0.6 of ingested nitrogen. This resulted in a nitrogen excretion of about 2.3 kg N during a 25 days lactation period.

Body weight of sows, daily litter gain and nitrogen mobilization increased with parity number (after correction for differences in litter size).

Key words: lactating sows, nitrogen, lysine, energy, parity

Introduction

The nitrogen (N) requirement of the lactating sow can be expressed as total N, as digestible N or as (digestible) amino acids. Lysine is often found to be the first limiting amino acid and therefore, the requirement of lactating sows is often expressed as a (digestible) lysine requirement (Chen, D'Mello, Elsley and Taylor, 1978; Etienne, Noblet, Dourmad and Fortune, 1989; Helms, 1978; Sohail, Cole and Lewis, 1978; Wilkinson, Cole and Lewis, 1982). A large variation in estimated N and lysine requirement for lactating sows is observed in literature. For example, Pettigrew (1993) indicated that in literature the estimated total lysine requirement for lactating sows ranged between 20 and 53 $g.d^{-1}$. Also there is variation in number of suckling piglets, the ability of sows to produce milk and growth potential of litters. However, in most experiments the litter gain or the milk production were at a moderate level.

Several methods to determine the protein requirements of lactating sows are used in literature. Apart from criteria as litter gain and body weight change of the lactating sow, measurement of the nitrogen and energy balance of a lactating sow is difficult, because sow and piglets can not be separated for several hours.

In the present study the total balance of the lactating sows plus the sucking piglets is measured and the retention in the piglets is measured by comparative slaughter. With the combination of these two techniques the retention in the sow can be measured without measuring protein milk production or by doing any assumption.

In the present experiment the effect of two different levels of N and lysine supply on nitrogen and energy balance in lactating sows with a high litter gain and fed at similar levels of metabolizable energy was investigated. The main purpose of this experiment was to derive nitrogen and lysine requirements for lactating sows. Also, the impact of differences in nitrogen supply during the preceding pregnancy was studied. The results from this study in combination with the effects of a reduction in nitrogen supply during pregnancy can be used to design a feeding concept that minimizes the nitrogen excretion from sows.

Materials and methods

Animals

In total six groups of 10 half sisters (Large White*Dutch Landrace) were reared from a live weight of 25 kg to 125 kg on a time-fixed schedule aiming at a mean growth rate of 600 $g.d^{-1}$. At a mean live weight of 125 kg, 54 animals were available for the experiment and were inseminated artificially. During pregnancy sows were allotted to treatment C (control diet with 24.7 g $N.kg^{-1}$) or treatment L (experimental diet with 16.7 g $N.kg^{-1}$). Details of the experiments during pregnancy are given elsewhere (Everts and Dekker, 1994b).

Within each of the two pregnancy treatments the sows were allotted to one of the two treatments during lactation: treatment H (high nitrogen/lysine supply) and treatment C (nitrogen/lysine supply according to Centraal Veevoeder Bureau; CVB, 1986). The lysine content in the diets of the lactation treatments C an H were 8.4 and 10.3 g lysine.kg^{-1} DM, respectively. Each sow remained on the same combination of pregnancy and lactation treatments for three successive parities. In total 62 balance trials with lactating sows were carried out during 21 days.

Diets and feeding level

Diets were manufactured in three batches and the level of ingredients in the diets of each batch were optimized using tabulated values (CVB; 1977, 1984) with constraints for the level of faecal digestible lysine, methionine and cystine. The diets had a calculated metabolizable energy content of 13.75 MJ.kg^{-1} in the dry matter.

The control diet (C) was the same as in the trials during pregnancy reported by Everts and Dekker (1994b). Diet H had higher levels of nitrogen, lysine, cystine and methionine than diet C. The main ingredients were cassava, maize gluten feed, extracted maize germ meal, wheat middlings, peas, extracted soya bean meal, molasses and alfalfa. Table 4.1 gives the proximate analysis and levels of some essential amino acids in the diets. The last batch of diet H showed a considerably lower level of nitrogen than planned. Therefore, the results of 6 balances of sows fed this batch of diet H were excluded for further calculations and thus the actual number of balance trials was 56.

On the day of farrowing 1 kg of feed was offered to the sows. The first day after farrowing 3.0 kg was fed. In the next days, feed allowance was increased

Table 4.1

Proximate analysis and analysed levels of some amino acids in the diets in dry matter (g.kg^{-1}; gross energy MJ.kg^{-1})

Diet	C	H
Dry matter	867	871
Ash	79	80
Protein	178	205
Nitrogen	28.5	32.8
Crude fibre	71	91
Crude fat	36	30
Gross energy (MJ)	18.1	18.2
Lysine	8.4	10.3
Cystine	2.9	3.6
Methionine	3.1	4.4

with 0.5 $kg.d^{-1}$ until the planned level of 1 % of the live weight of the sow plus 0.4 kg per suckling piglet was achieved. If consistent feed refusals were observed, then feeding level was not further increased.

Measurements

The sows were placed into the respiration chambers at least two weeks before the expected farrowing date and farrowed inside the chambers. Balance trials started on day 3 or 4 of lactation and ended on day 24 or 25 of lactation. Sows were weighed before and after the balance period. Piglets were weighed at birth (when dry within 12 hours), at the start of the balance trial, during the trial weekly and at the end of the trial. The mean age at weaning was 25 days. In the balance trials faeces and urine were collected from sows and piglets together. The out-going air and the water from the heat exchangers was analysed for ammonia. Comparative slaughtering of piglets was used to measure the retention in the litter. Further details about the balance technique for lactating sows and the procedure of analysing weaned piglets are described elsewhere (Everts and Dekker, 1994a).

Statistical analysis

The balance of a lactating sow was calculated by difference (ingested - faecal losses - urinary losses - gaseous losses - retention in the litter; Everts and Dekker, 1994a). Since no significant interactions were observed between the pregnancy and lactation treatments, an analysis of variance was done to test the main effects of pregnancy treatments and lactation treatments per parity. Litter size was used as a covariable and the group number as a block effect. To test the effect of parity number an analysis of variance was done with litter size as a covariable and the sow as a block effect (within sow comparison). The interactions between parity number and pregnancy treatment and between parity number and lactation treatment were included in the model. The observed significant effects of parity number are presented in Table 4.6.

Results

Live weight of the sows and litter gain during lactation

The number of observation in parity 3 is unbalanced between the treatments due to the fact that 6 observations on lactation treatment H were excluded (Table 4.2). The mean litter size was 9.9, 10.5 and 10.6 for parity 1, 2 and 3, respectively. Lactation treatment had no effect on the mean live weight of sows. On pregnancy treatment L mean live weight was about 6 kg lower than on pregnancy treatment C, but is was only significant in parity 1. Mean live weight of sows increased significantly with parity number from 173 kg for first parity sows to 208 kg for third parity sows (Table 4.6).

Mean live weight loss of the sows during lactation was 0.67 kg per day. On lactation treatment C the live weight loss of sows during lactation was higher than on lactation treatment H in parity 2. Mean live weight loss was not affected by pregnancy treatments nor by parity number.

Mean daily litter gain was 2.72 kg per day and was not affected by dietary treatments. Mean daily litter gain was higher in parities 2 (2.80 kg) and 3 (2.89 kg) than in parity 1 (2.47 kg).

Table 4.2.

Number of observations and main treatment effects on live weight of sows (kg), live weight change of sows (kg.d^{-1}) and litter and piglet gain (kg.d^{-1}) during lactation (day 4 to 25)

	Lactation		Pregnancy		sed	significance
Treatment	C	H	C	L		
Parity 1						
Observations (n)	12	11	12	11		
Mean live weight sow	174	173	176	170	3.0	Pr*
Live weight gain sow	-0.79	-0.63	-0.75	-0.66	0.12	
Live weight gain litter	2.47	2.45	2.46	2.46	0.10	
Daily gain.piglet^{-1}	0.254	0.253	0.251	0.255	0.011	
Parity 2						
Observations (n)	9	8	8	9		
Mean live weight sow	195	194	196	192	4.0	
Live weight gain sow	-0.79	-0.52	-0.61	-0.70	0.09	La**
Live weight gain litter	2.76	2.82	2.71	2.87	0.07	
Daily gain.piglet^{-1}	0.263	0.269	0.258	0.273	0.007	
Parity 3						
Observations (n)	11	5	6	10		
Mean live weight sow	207	210	212	205	7.0	
Live weight gain sow	-0.84	-0.96	-0.98	-0.82	0.17	
Live weight gain litter	2.81	3.04	3.03	2.82	0.16	
Daily gain.piglet^{-1}	0.265	0.289	0.287	0.267	0.014	

Pr*, Pr**, Pr*** = effect of pregnancy treatment with $P<0.05$, $P<0.01$, $P<0.001$
La*, La**, La*** = effect of lactation treatment with $P<0.05$, $P<0.01$, $P<0.001$

Daily piglet gain was 265 $g.d^{-1}.piglet^{-1}$. Dietary treatments had no significant effects on daily piglet gain. The parity number indicated that older sows produce more milk per piglet than first litter sows (Table 4.6).

Chemical composition of weaned piglets

Lactation treatment had no significant effect on the body composition during 3 parities (Table 4.3). On pregnancy treatment L dry matter content of weaned piglets was 7 to 10 g higher than on pregnancy treatment C. Only in parity 2 this differences was significant. Also the fat content of the weaned piglets on pregnancy treatment L was higher than on pregnancy treatment C (only significant in parity 2). The energy content of the weaned piglets on pregnancy treatment L was 0.25 to 0.5 MJ higher than on pregnancy treatment C. This effect was significant in parities 1 and 2. The calculated composition of litter gain showed the same pattern as the chemical composition of the weaned piglets, only the levels were higher.

Table 4.3

Main treatment effects on body composition of weaned piglets

	Lactation		Pregnancy		sed	significance
treatment	C	H	C	L		
Parity 1						
dry matter ($g.kg^{-1}$)	318.8	316.6	313.5	321.9	5.3	
nitrogen ($g.kg^{-1}$)	24.1	23.9	24.1	24.0	0.2	
fat ($g.kg^{-1}$)	137.1	134.5	129.9	141.6	5.9	
energy ($MJ.kg^{-1}$)	8.98	8.83	8.66	9.15	0.21	Pr^*
Parity 2						
dry matter ($g.kg^{-1}$)	323.6	317.2	315.3	325.5	5.3	Pr^*
nitrogen ($g.kg^{-1}$)	24.0	24.4	24.2	24.2	0.2	
fat ($g.kg^{-1}$)	142.1	134.8	134.0	142.9	4.0	Pr^*
energy ($MJ.kg^{-1}$)	9.14	8.86	8.79	9.21	0.18	Pr^*
Parity 3						
dry matter ($g.kg^{-1}$)	315.0	322.8	315.7	322.1	4.1	
nitrogen ($g.kg^{-1}$)	24.2	24.3	24.3	24.2	0.2	
fat ($g.kg^{-1}$)	134.1	141.0	133.8	138.6	4.2	
energy ($MJ.kg^{-1}$)	8.78	9.16	8.84	9.10	0.19	

Pr^*, Pr^{**}, Pr^{***} = effect of pregnancy treatment with $P<0.05$, $P<0.01$, $P<0.001$
La^*, La^{**}, La^{***} = effect of lactation treatment with $P<0.05$, $P<0.01$, $P<0.001$

Nitrogen balance

Nitrogen and lysine intake was significantly higher on lactation treatment H than on lactation treatment C (Table 4.4). Pregnancy treatment had no effect on nitrogen and lysine intake. Nitrogen retention in the litter was significantly higher on lactation treatment H than on lactation treatment C in parity 2. On pregnancy treatment L nitrogen retention in the litter was significantly higher than on pregnancy treatment C in parity 2. Nitrogen retention in the litter was significantly lower in parity 1 than in parities 2 and 3 (Table 4.6). This effect of parity number was more pronounced on lactation treatment H than on lactation treatment C (interaction between parity number and lactation treatment).
Nitrogen retention of sows was less negative on lactation treatment H than on lactation treatment C. Only in parity 1 the difference in nitrogen retention between the lactation treatments was significant. On pregnancy treatment L

Table 4.4
Mean treatment effects on nitrogen balance during lactation (g.d^{-1})

	Lactation		Pregnancy		sed	significance
Treatment	C	H	C	L		
Parity 1						
N-intake	138.1	147.8	143.0	142.8	4.2	La*
Lysine intake	39.7	47.8	43.8	43.7	1.4	La***
N-retention litter	63.3	62.1	62.6	62.8	2.9	
N-retention sow	-13.3	-4.1	-11.0	-6.4	2.3	La***
N-excretion	88.1	89.7	91.4	86.4	3.3	
Parity 2						
N-intake	145.6	161.2	153.2	153.5	6.0	La*
Lysine intake	43.5	51.9	47.6	47.8	1.0	La***
N-retention litter	69.9	73.6	69.9	73.7	1.5	La* Pr*
N-retention sow	-12.7	-9.4	-11.6	-10.5	1.9	
N-excretion	88.3	96.9	94.9	90.3	5.1	
Parity 3						
N-intake	140.5	168.0	152.3	156.2	5.4	La**
Lysine intake	42.4	52.1	47.0	47.6	1.1	La***
N-retention litter	72.3	78.0	78.5	71.9	4.0	
N-retention sow	-16.6	-10.9	-17.8	-9.6	3.9	Pr*
N-excretion	84.8	100.8	91.6	94.1	2.9	La**

Pr*, Pr**, Pr*** = effect of pregnancy treatment with $P<0.05$, $P<0.01$, $P<0.001$
La*, La**, La*** = effect of lactation treatment with $P<0.05$, $P<0.01$, $P<0.001$

nitrogen retention was less negative than on pregnancy treatment C. This difference in nitrogen retention was only in the third parity significant. Nitrogen retention of sows became more negative with increasing parity number (Table 4.6).

Nitrogen excretion was on lactation treatment H significantly higher than on lactation treatment C in parity 3. Pregnancy treatment did not affect the nitrogen excretion.

Energy balance

ME intake of sows in Table 4.5 is somewhat underestimated, because energy losses in faeces and urine of the suckling piglets were included in those of the sows. Assuming that 0.55 of ingested milk energy in retained in piglets (Noblet and Etienne, 1987) and a metabolizability of milk energy of 0.91, it is estimated that the ME intakes in Table 4.5 must be multiplied with about 1.07 to get the actual ME intake of the sows. ME intake was on lactation treatment H was lower than on lactation treatment C in parity 2. Heat production was significantly higher on pregnancy treatment L than on pregnancy treatment C in parity 2. Heat production expressed per kg metabolic body weight decreased with increasing parity number (Table 4.6). This parity effect was only present on lactation treatment C and not on lactation treatment H (interaction between parity number and lactation treatment).

Mean energy retention in the litter was 548 $kJ.W^{-0.75}$. In parity 2 energy retention in the litter was on pregnancy treatment L significantly higher than on pregnancy treatment C. In parity 2 the highest energy retention per kg metabolic body weight was observed (Table 4.6).

Mean energy retention in the sow was -390 $kJ.W^{-0.75}$. Sows on lactation treatment H mobilized significant more energy than on lactation treatment C in the parities 2 and 3. Sows on pregnancy treatment L mobilized more energy than on pregnancy treatment C in parity 2.

Retained energy as protein in the sow ($RE_{P\text{-}SOW}$) followed the pattern of nitrogen retention in the sows (Table 4.4).

Retained energy as fat in the sow ($RE_{F\text{-}SOW}$) was more negative on lactation treatment H than on lactation treatment C. This effect was significant in the parities 2 and 3. The $RE_{F\text{-}SOW}$ was more negative on pregnancy treatment L than on pregnancy treatment C in parity 2. The proportion of energy mobilized as protein to total energy mobilization ($RE_{P\text{-}SOW}$ / RE_{SOW}) was significantly lower on lactation treatment H than on lactation treatment C in all parities. This ratio was also higher on pregnancy treatment C than on pregnancy treatment L, but this effect was only significant in parity 3. The ratio ($RE_{P\text{-}SOW}$ / RE_{SOW}) increased significantly from parity 1 to parities 2 and 3 (Table 4.6).

Table 4.5

Main treatment effects on the energy balance of sows during lactation : ME intake, heat production, retained energy in litter(RE_{LITTER}), retained energy in sow(RE_{SOW}), energy retained as fat (RE_F sow) and as protein ($RE_{P\text{-}SOW}$) in the sow all expressed in $kJ.W^{-0.75}$ and the ratio retained energy as protein to total retained energy ($RE_{P\text{-}SOW}$ / RE_{SOW}) * 100

	Lactation		Pregnancy		sed	significance
treatment	C	H	C	L		
<u>Parity 1</u>						
ME intake[1]	1301	1312	1296	1317	45	
Heat production[3]	1152	1174	1158	1167	32	
RE_{LITTER}	529	533	513	549	29	
RE_{SOW}	-369	-394	-370	-393	44	
$RE_{P\text{-}SOW}$	-42	-13	-34	-20	7	La***
$RE_{F\text{-}SOW}$	-327	-381	-335	-373	37	
($RE_{P\text{-}SOW}$ /RE_{SOW})*100	11	1	7	4	2	La***
<u>Parity 2</u>						
ME intake[1]	1353	1286	1296	1344	29	La*
Heat production[3]	1178	1177	1138	1217	29	Pr*
RE_{LITTER}	555	569	524	599	30	Pr*
RE_{SOW}	-370	-457	-361	-466	44	La* Pr*
$RE_{P\text{-}SOW}$	-36	-27	-33	-30	6	
$RE_{F\text{-}SOW}$	-334	-430	-328	-436	44	La* Pr*
($RE_{P\text{-}SOW}$ /RE_{SOW})*100	11	5	9	6	2	La**
<u>Parity 3</u>						
ME intake[1]	1277	1219	1236	1259	26	
Heat production[3]	1116	1150	1137	1130	31	
RE_{LITTER}	522	567	545	544	43	
RE_{SOW}	-359	-493	-443	-409	49	La*
$RE_{P\text{-}SOW}$	-45	-30	-48	-27	10	Pr*
$RE_{F\text{-}SOW}$	-313	-463	-394	-382	41	La**
($RE_{P\text{-}SOW}$ /RE_{SOW})*100	12	5	11	7	2	La** Pr**

Pr*, Pr**, Pr*** = effect of pregnancy treatment with $P<0.05$, $P<0.01$, $P<0.001$

La*, La**, La*** = effect of lactation treatment with $P<0.05$, $P<0.01$, $P<0.001$

[1] ME intake not corrected for faecal and urinary losses from piglets

[3] Heat production of the sow and litter together

Table 4.6.

Observed statistically significant parity effects (within sow comparison)

	Parity number			sed	significance	
	1	2	3		Pari[1]	interaction[2]
litter size	9.9	10.5	10.6	0.3	*	
mean live weight sow (kg)	173	193	208	1.8	***	
live weight gain litter(kg.d^{-1})	2.47	2.80	2.89	0.05	***	
N-retention litter (g.d^{-1})	62.9	72.1	74.1	1.3	***	Pari.La* [3]
N-retention sow (g.d^{-1})	-7.3	-11.7	-13.9	1.4	***	
Heat production[§] (kJ.$W^{-0.75}$.d^{-1}))	1181	1170	1129	14	**	Pari.la** [4]
RE_{LITTER} (kJ.$W^{-0.75}$.$d^{-1)}$	534	568	542	13	*	
($RE_{P\text{-}SOW}$ /RE_{SOW})*100	4	8	9	1	**	

[§] Heat production of the sow and litter together

[1] significance of parity effect * = $P<0.05$; ** = $P<0.01$; *** = $P<0.001$

[2] observed interaction between parity and lactation treatment (Pari.La)

[3] much stronger effect on lactation treatment H than on lactation treatment C

[4] parity effect only observed on lactation treatment C

Discussion

In this experiment, the effect of the level of nitrogen supply on nitrogen metabolism of lactating sows is closely related to the supply of amino acids. The pattern of essential amino acids in relation to lysine was similar in both diets (Table 4.7) and the proportional levels of the essential amino acids were at least as high as proposed by Whittemore and Morgan (1990).

With a mean litter size of 10.3 piglets and a mean daily gain per piglet of 265 g.d^{-1}, the daily litter gain was on a high level (2.72 kg.d^{-1}) compared with most literature. In the studies of Beyer (1986), Chen et al.(1978), O'Grady and Hanrahan (1975) and Noblet and Etienne (1986,1987) mean daily gain of piglets was close to or below 200 g.d^{-1}. Sohail et al. (1978) used a smaller litter size and Speer (1990) used a milk production level of 5 kg.d^{-1} for the calculation of amino acid requirements. These values indicates that high yielding sows with fast growing piglets were used in the present experiment.

Composition of weaned piglets (Table 4.3) is in line with the results of Noblet and Etienne (1986, 1987). However, fat content of weaned piglets in their experiment was lower and this was probably related to either a lower daily gain, to a shorter lactation period or to differences in genotype. Results of Wood and Grooves (1965) and of Manners and McCrea (1963) showed a higher fat content and a lower nitrogen content in weaned piglets. This can probably be explained by changes in genetic potential of piglets in the last decades.

Table 4.7.

Essential amino acids content in diets in relation to lysine supply (lysine = 100 %) in the diets and as proposed by Whittemore and Morgan (1990). The percentages are based on analyses in the diets, except for tryptophan

Diet	C	H	Whittemore and Morgan (1990)
Lysine	100	100	100
Threonine	76	77	64
Valine	101	101	71
Isoleucine	84	84	57
Tyrosine + Phenylalanine	155	157	100
Histidine	53	52	36
Cystine + Methionine	71	77	57
Tryptophan	22[1]	22[1]	20

[1] calculated from tabulated values

Nitrogen metabolism

Nitrogen and lysine intakes on lactation treatment H were significantly higher than on lactation treatment C in all parities (Table 4.4). This higher nitrogen/lysine supply had no significant effect on the daily gain of piglets nor a consistent effect on live weight losses of sows (Table 4.2). These two parameters seem to be less suitable to assess the nitrogen/lysine requirements for lactating sows fed more than 40 g lysine.d^{-1}.

Nitrogen retention in the litter was not affected by dietary treatments in parity 1. In parity 2 nitrogen retention in the litter was affected by the lactation treatment and the pregnancy treatment (Table 4.4). These effects were probably related to the relatively low birth weights of the piglets from sows with the combination of pregnancy treatment C and lactation treatment C in this parity. Piglets on the combination of these treatments had 150 to 200 g lower birth weight compared with the other combinations of treatments. These differences in birth weight were not significant, however.

Nitrogen balance of sows was affected by the lactation treatment. Table 4.4 indicates that the nitrogen balance is less negative when more nitrogen/lysine is supplied during lactation, however the effect was only significant in the first parity. Also a reduced nitrogen/lysine supply during pregnancy tended to less negative nitrogen balances during lactation. This effect of pregnancy treatment was only significant in parity 3. In general, the nitrogen balance technique tends to overestimate the nitrogen retention (Just et al., 1982). In the case of a negative nitrogen retention, the actual nitrogen balances should be lower than observed. In the present experiment nitrogen in out-going air and condensation water from the heat exchangers were also analysed to minimize the overestimation of the nitrogen balances of the lactating sows.

Estimated nitrogen and lysine requirements

A regression analysis between nitrogen intake (NI) and nitrogen retention in piglets (NR_{LITTER}) and nitrogen balance of sows (NR_{SOW}) gave the following equation in g/d^{-1}:

$$NI = 61.4(\pm 13.6) + 1.89(\pm 0.22)*NR_{SOW} + 1.59(\pm 0.21)*NR_{LITTER}\ (RSD = 11.6;\ \%acc = 60.1) \quad (1)$$

From this equation it can be calculated that 162 g N.d^{-1} must be supplied to first parity sows (NR_{LITTER} = 63 g N) to get a nitrogen balance equal to zero. For second parity sows (NR_{LITTER} = 74 g N) this was 179 g nitrogen.d^{-1} and for third parity sows (NR_{LITTER} = 78 g N) 185 g nitrogen.d^{-1}. These estimated nitrogen requirements are higher than the value from Speer (1990) and also higher than the values of Beyer (1986). The main reason for this discrepancy is the difference in (milk) production level.

Theoretically the nitrogen requirement can be calculated by assuming a maintenance requirement and an efficiency for the utilization of ingested nitrogen to milk nitrogen. The assumption for maintenance requirement (0.45 g N. kg$^{-0.75}$) and for efficiency for the utilization of ingested nitrogen to milk nitrogen (0.6) are from Everts and Dekker (1994b). The produced amount of milk nitrogen was calculated from the nitrogen retention in the litter assuming that 0.85 of ingested milk nitrogen is retained in piglets (Noblet and Etienne, 1987). This results in a theoretical nitrogen requirement for first parity sows of 145 g N.d^{-1} (body weight 173 kg, milk nitrogen 74 g). The calculated nitrogen requirement for second parity sows is 168 g N.d^{-1} (body weight 193, milk nitrogen 87 g) and for third parity sows 178 g N.d^{-1} (body weight 208 and milk nitrogen 92 g). These theoretical values are 7 to 17 g N lower than estimated from equation (1). In figure 4.1 corrected milk nitrogen ($NR_{LITTER}/0.85 + NR_{SOW}$) is plotted against NI. The calculation of corrected milk nitrogen assumes that nitrogen mobilized from the sow's body is used with an efficiency of 1 as observed by Everts and Dekker (1991) and that the efficiency of the utilization of ingested nitrogen to retained nitrogen in the sow is equal to the efficiency of ingested nitrogen to milk nitrogen (only in a few balances the sow retained a small amount of nitrogen).

The theoretical relation between NI and corrected milk nitrogen for a sow of 195 kg fits quite good to the observations. However, the observed points tend to show a smaller sloop than the theoretical line. This can indicate that some sows were fed above the required amount of nitrogen and that the requirements

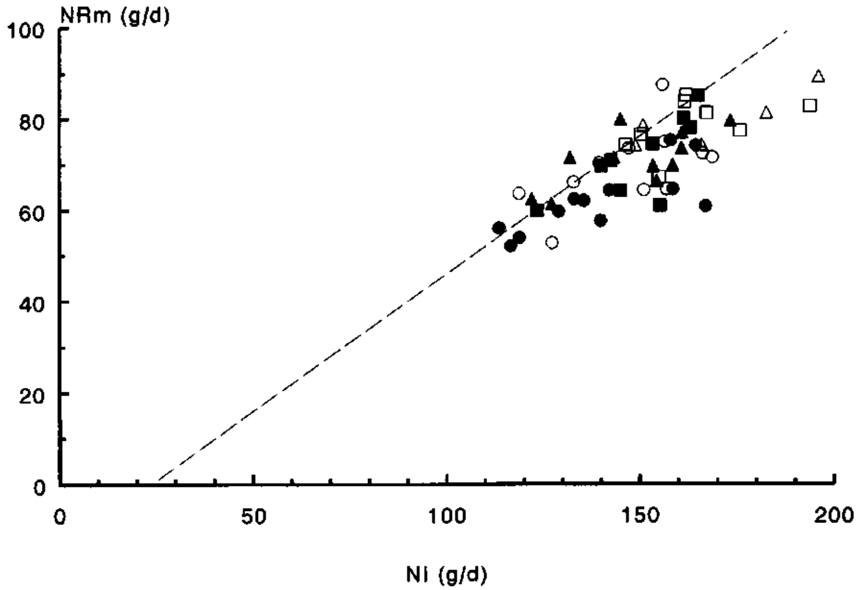

Figure 4.1

The relation between ingested nitrogen (NI) and corrected milk nitrogen production (NR_M). NR_M is calculated as NR_{LITTER}* 1.18 + NR_{SOW}. Results of sows on lactation treatment C are indicated with ●, ■ and ▲ for parity 1, 2 and 3, respectively. Results of sows on lactation treatment H are indicated with ○, □ and △ for parity 1, 2 and 3, respectively. The line ----- represents the theoretically calculated nitrogen requirement for a sow with a live weight of 195 kg, assuming a maintenance requirement of 0.45 g $N.W^{-0.75}$ and an efficiency of utilization of ingested nitrogen to milk nitrogen of 0.6.

based on equation (1) are slightly overestimated. However, this overestimation can be compensated by a somewhat lower efficiency of the utilization of mobilized nitrogen for milk nitrogen. A regression analysis between lysine intake and nitrogen retention in piglets (NR_{LITTER}) and nitrogen balance of sows (NR_{SOW}) gave the following equation in $g.d^{-1}$:

$$Lysine = 15.2(\pm 4.4) + 0.51(\pm 0.07)*NR_{SOW} + 0.52(\pm 0.07)*NR_{LITTER} \quad (RSD = 3.7;\ \%acc = 55.3) \quad (2)$$

From this equation it can be calculated that 48 g $lysine.d^{-1}$ must be supplied to first parity sows (NR_{LITTER} = 63 g N) to get a nitrogen balance equal to zero. For second parity sows (NR_{LITTER} = 74 g N) this was 54 g $lysine.d^{-1}$ and for third parity sows (NR_{LITTER} = 78 g N) 56 g lysine $.d^{-1}$. These levels are close to the levels as proposed by Wilkinson et al. (1982) on the basis of blood parameters, by Etienne et al. (1989) on the basis of maintenance of muscle mass and by Helms (1978) on the basis of nitrogen balances and regression.

With the use of tabulated digestibility coefficients, the presented requirements for lysine can also be expressed as faecal digestible lysine (CVB, 1984) by multiplying with 0.82 or to ileal digestible lysine (CVB, 1991) by multiplying with 0.77.

Relation between nitrogen intake and nitrogen excretion in faeces and urine

The relationship between nitrogen intake and nitrogen excretion in faeces and urine was linear:

N excretion = 0.6142 (± 0.004) * N-intake (RSD= 5.25 ; % acc. = 83.8). (3)

About 60 % of ingested nitrogen was excreted in faeces and urine. This indicates that during lactation the gross utilization of ingested nitrogen was about 40 % and this is higher than during pregnancy. Everts and Dekker (1994b) observed during pregnancy gross coefficients of utilization of ingested nitrogen between 0.21 and 0.35.

Irrespective to parity number the excretion of nitrogen during a reproductive cycle (pregnancy and 25 days of lactation) can be estimated by combining the data of Everts and Dekker (1994b) and the present data about nitrogen excretion. On pregnancy treatment C 5.5 kg N was excreted and on pregnancy treatment L 3.4 kg N. On lactation treatment C 2.2 kg N was excreted and on treatment H 2.4 kg. Nitrogen excretion on the combination of pregnancy treatment C and lactation treatment C was 7.7 kg N. Nitrogen excretion was slightly increased to 7.9 kg N by combining pregnancy treatment C with lactation treatment H. When pregnancy treatment L was combined with lactation treatment C, than nitrogen excretion was 5.6 kg N. Nitrogen excretion increased slightly to 5.8 kg, when pregnancy treatment L was combined with lactation treatment H. It is clear from these results that the reduction of the N supply during pregnancy is very effective to reduce N excretion during the reproductive cycle. The N excretion during lactation is relatively small and a change in supply during lactation has a small effect on the excretion during a reproductive cycle.

Energy metabolism

The effects of treatments on energy metabolism of lactating sows were rather moderate and not very systematic (Table 4.5). The most consistent effect of lactation treatment was on the ratio between retained energy as protein to total energy retention in sows. However, in this ratio the errors of the balance technique are cumulating: $RE_{P\text{-}SOW}$ has the errors of the N-balance measurement and RE_{SOW} has the cumulated errors of the energy balance. In spite of it, an increase in lysine supply decreased the ratio $RE_{P\text{-}SOW}/RE_{SOW}$. This means that a higher lysine supply reduced the nitrogen mobilization and increased fat mobilization. Pettigrew, Tokach, Crooker and Sower (1991) also observed that an increased lysine supply to lactating sows increased fat mobilization, using NEFA as an indicator. On one hand this can be explained by assuming that synthesis of milk protein from body stores is energetically more efficient than from ingested protein. On the other hand it can also be explained as an indication for a higher milk energy output, although in the present study no significant difference in retained energy in the piglets was observed between the lactation treatments.

Fat mobilization seems to be increased by nitrogen restriction during pregnancy, however statistical evidence is not present in all parities (Table 4.5). Nitrogen restriction during pregnancy increased fat deposition in the sows (Everts and Dekker, 1994b) and this seems to induce a higher fat mobilization during lactation resulting in more milk fat and thus fatter piglets (Table 4.3). Other ways to increase milk fat production and the fat content in piglets, are restricting energy intake during lactation (Noblet and Etienne, 1986) or increasing the fat content of the diet (Babinsky, 1992). These manipulations with body composition of the sow and nutrient supply resulted in a higher fat content of the weaned piglets without a significant effect on litter gain in most cases. However, when the lysine/supply is increased, then fat mobilization of the sow increases mostly without increasing the fat content of the piglets. This indicates that in this situation mobilized fat is used preferentially for metabolic processes in the sow and not for increasing milk fat as observed by Babinsky (1992).

The observed parity effects in Table 4.6 indicated that it is important to consider the parity number when requirements for lactating sows are designed. Older sows showed a higher live weight and a higher litter gain and mobilized relatively more nitrogen during lactation than younger sows.

Conclusion

From the results of this experiment it is concluded that a higher nitrogen/lysine supply during lactation decreased mobilization of sow's body protein without significant effects on the daily litter gain. The higher nitrogen/lysine supply during lactation increased fat mobilization of the sows. This extra mobilized fat was not retained in the piglets, but probably used for metabolic processes in the sows.

The nitrogen requirement for lactating sows was derived with regression analysis and estimated to be 162 - 185 g $N.d^{-1}$, depending on the parity number. A theoretically calculated nitrogen requirements for lactating sows assuming a maintenance requirement of 0.45 g $N.W^{-0.75}$ and an efficiency for the utilization of ingested nitrogen to milk nitrogen of 0.6 indicated slightly lower requirements.

With regression analysis the lysine requirement for lactating sows was estimated to be 48 to 56 $g.d^{-1}$, depending on the parity number of the sow. Based on tabulated values (CVB, 1991), this requirement is equivalent to 37 to 43 g ileal digestible lysine.

The present values are higher than literature and recommendations. This can be explained by the higher production rates and the new methodological approach in this experiment.

Nitrogen restriction during pregnancy had an effect on the performances during lactation (less nitrogen mobilization and fatter piglets at weaning), but there were no interactions observed between pregnancy treatment and lactation treatment. Nitrogen restriction during pregnancy seems to be much more effective to reduce the total nitrogen excretion in a reproductive cycle than a change in nitrogen content in the lactation diet.

Mobilization of body stores during lactation is related to body composition of the sow (e.g. parity effects) and to the nitrogen (lysine) content of lactation diet. Even when we are able to manipulate the body composition of the sow during the reproductive cycle, then the main question arises: what is an ideal body composition of a sow to guarantee a high reproductive performance and longevity.

Acknowledgements

We want to thank M.W.A. Verstegen and A.W. Jongbloed for their very useful comments on this manuscript. This research was partially financed by the Dutch Fund for Manure and Ammonia Research (FOMA).

References

Babinsky, L., 1992. Energy metabolism and lactation performance of primiparous sows as affected by dietary fat and vitamin E. Thesis, Agricultural University Wageningen. pp159

Beyer, M., 1986. Untersuchungen zum Energie- und Stoffumsatz von graviden und lactierende Sauen sowie Saugferkeln - eine Beitrag zur Präzisierung des Energie- und Proteinbedarfes. Promotionsarbeit, Forschungszentrum für Tierproduktion Dummerstorf-Rostock. pp 234.

Chen, S.Y., D'Mello, J.P.F., Elsley, F.W.H. and Taylor, A.G., 1978. Effect of dietary lysine levels on performance, nitrogen metabolism and plasma amino acid concentrations of lactating sows. *Animal Production* 27: 331-344

Centraal Veevoeder Bureau (CVB), 1977. [Data about chemical composition, digestibility and feeding value of feedstuffs] Veevoedertabel, Centraal Veevoederbureau, Lelystad

Centraal Veevoeder Bureau (CVB), 1984. [Preliminary table of digestible amino acids in feedstuffs for pigs] Voorlopige tabel verteerbare aminozuren in veevoedergrondstoffen voor varkens, januari 1984. Centraal Veevoederbureau, Lelystad

Centraal Veevoeder Bureau (CVB), 1986. [Nutrient requirements of livestock and feeding value of feedstuffs] Verkorte Tabel, augustus 1986. Centraal Veevoederbureau, Lelystad

Centraal Veevoeder Bureau (CVB), 1991. [Data about chemical composition, digestibility and feeding value of feedstuffs] Veevoeder Tabel, Centraal Veevoederbureau, Lelystad

Etienne, M., Noblet, J., Dourmad, J.Y. and Fortune, H., 1989. Étude du besoin en lysine des truies en lactation. *Journées Recherche Porcine en France* 21: 101-108

Everts, H. and Dekker, R.A., 1991. Effect of protein/lysine supply and of parity number on energy metabolism during pregnancy and lactation in sows. In: Energy metabolism in farm animals (Ed. Wenk, C. and Boessinger, M.) *EAAP publication* 58 : 317-320

Everts, H. and Dekker, R.A., 1994a. Balance trials and comparative slaughtering in breeding sows: description of techniques and observed accuracy. *Livestock Production Science* 37 : 339-352

Everts, H. and Dekker, R.A., 1994b. Effect of nitrogen supply on the retention and excretion of nitrogen and on energy metabolism of pregnant sows. *Animal Production* : in press

Just, A., Fernández, J.A. and Jørgensen, H., 1982. Nitrogen balance studies and nitrogen retention. In: Digestive physiology in the pig (Ed: Laplace, J.P., Corring, T., Rerat, A.) 27-29 October 1982, Jouy-en-Josas. *Les Colloques de l'INRA* 12: 111-122

Helms, W., 1978. Zur Verwertung von Futterproteinen definierter Zusammensetzung und Ergänzung beim laktierenden Schwein. Thesis, Göttingen pp 261

Manners, M.J. and McCrea, M.R., 1963. Changes in the chemical composition of sow reared piglets during the 1 first month of life. *British Journal of Nutrition* 17: 495-513

Noblet, J. and Etienne, M., 1986. Effect of energy level in lactating sows on yield and composition of milk and nutrient balance of piglets. *Journal of Animal Science* 63: 1888-1896

Noblet, J. and Etienne, M., 1987. Body composition, metabolic rate and utilization of milk nutrients in suckling piglets. *Reproduction Nutrition Developpement* 27: 829-839

O'Grady, J.F. and Hanrahan, T.J., 1975. Influence of protein level and amino acid supplementation of diets fed in lactation on the performance of sows and their litters. *Irish Journal of Agricultural Research* 14: 127-135

Pettigrew, J.E., Tokach, M.d., Crooker, B.A. and Sower, A.F., 1991. Energy-protein interactions in the lactating sow: Metabolites and milk synthesis. In: Energy metabolism in farm animals (Ed. Wenk, C. and Boessinger, M.) *EAAP publication* 58 : 349-352

Pettigrew, J.E., 1993. Amino acid nutrition of gestating and lactating sows. *Biokyowa Technical Review* 5:1-18

Speer, V.C., 1990. Partitioning nitrogen and amino acids for pregnancy and lactation in swine: A review. *Journal of Animal Science* 68: 553-561

Sohail, M.A., Cole, D.J.A. and Lewis, D., 1978. Amino acid requirements of the breeding sow 2. The dietary lysine requirement of the lactating sow. *British Journal of Nutrition* 40: 369-376

Whittemore, C.T. and Morgan, C.A., 1990. Model components for the determination of energy and protein requirements for breeding sows: a review. *Livestock Production Science* 26: 1-37

Wilkinson, R., Cole, D.J.A. and Lewis, D., 1982. Amino acid nutrition of the lactating sow: the requirement for dietary lysine. *Animal Production* 35: 15-23

Wood, A.J. and Grooves, T.D.D., 1965. Body composition studies on the suckling pig. 1. Moisture, chemical fat, total protein, and total ash in relation to age and body weight. *Canadian Journal of Animal Science* 45: 8-13

Chapter 5

Effect of protein supply during first pregnancy on body composition of sows and their products of conception

H. Everts and R.A. Dekker

Institute for Animal Science and Health
(ID-DLO) Branch Runderweg
P.O. Box 160 8200 AD Lelystad
The Netherlands

Submitted for publication to Livestock Production Science

Effect of protein supply during first pregnancy on body composition of sows and their products of conception

H. Everts and R.A. Dekker

Abstract

The effect of two different levels of nitrogen supply during pregnancy (treatment C 28.5 g N. kg^{-1} DM and treatment L 19.3 g N.kg^{-1} DM) on body composition of sows was studied at the same level of ME intake. By comparative slaughter body composition was analysed at mating ($n = 11$) and at day 108 of pregnancy ($n = 14$). From day 0 until day 85 of pregnancy 2.5 kg feed.d^{-1} was offered and from day 86 until slaughter 3.0 kg.d^{-1}.

Treatments did not affect fresh weight and chemical composition of products of conception (piglets, placentas, uterus and intra-uterine fluids) nor the amino acid pattern of protein of unborn piglets. On treatment L, maternal protein deposition was 22 g.d^{-1} lower than on treatment C, while maternal fat deposition was higher on treatment L. Protein content of fat-free maternal body, however, was not different between treatments and remained at the same level as observed at mating (220 g.kg^{-1}). Also water:protein ratio was similar in the maternal body at the two treatments (3.3).

It was concluded that the development of products of conception has a higher priority than the development of maternal body.

Conversion efficiency, after allowance for maintenance, of ingested ileal digestible essential amino acids into products of conception and maternal body was on treatment L for lysine 0.59 and for threonine 0.67 and on treatment C 0.46 and 0.44, respectively.

Keywords: sow, body composition, pregnancy, amino acids

Introduction

During first pregnancy the products of conception (piglets, placentas, uterus and intra-uterine fluids) are developed in a sow and in addition the sow grows to a more mature status. In balance trials only the sum of these two processes is measured, while with the comparative slaughter technique the consequences of these two processes can be measured separately. In some experiments the change in chemical body composition of gilts during the first pregnancy was compared with non-pregnant gilts (De Wilde, 1980a,b; Hovell et al., 1977; Lodge et al., 1979; Shields and Mahan, 1983; Walach-Janiak et al., 1986a). In other experiments the effect of different feeding levels on body composition of gilts (Walach-Janiak et al., 1986b; Hovell et al., 1977) and on the products of conception (Noblet et al., 1985) was investigated. The effect of protein supply (14.5 g N.d^{-1} vs 41 g N.d^{-1} at a ME supply of 25 MJ ME.d^{-1}) on body composition was studied by Shields et al. (1985) and the effect of energy supply (from 19.5 MJ ME.d^{-1} to 32.1 MJ ME.d^{-1}) on body composition was studied by Hovell et al. (1977). From the data of Walach-Janiak et al. (1986b), Shields et al. (1985) and Hovell et al. (1977) Figure 5.1 was derived using multiple regression. Figure 5.1 indicates that the effect of a decrease in protein supply at a high level of energy supply has less effect on maternal protein deposition than at a low level of energy supply.

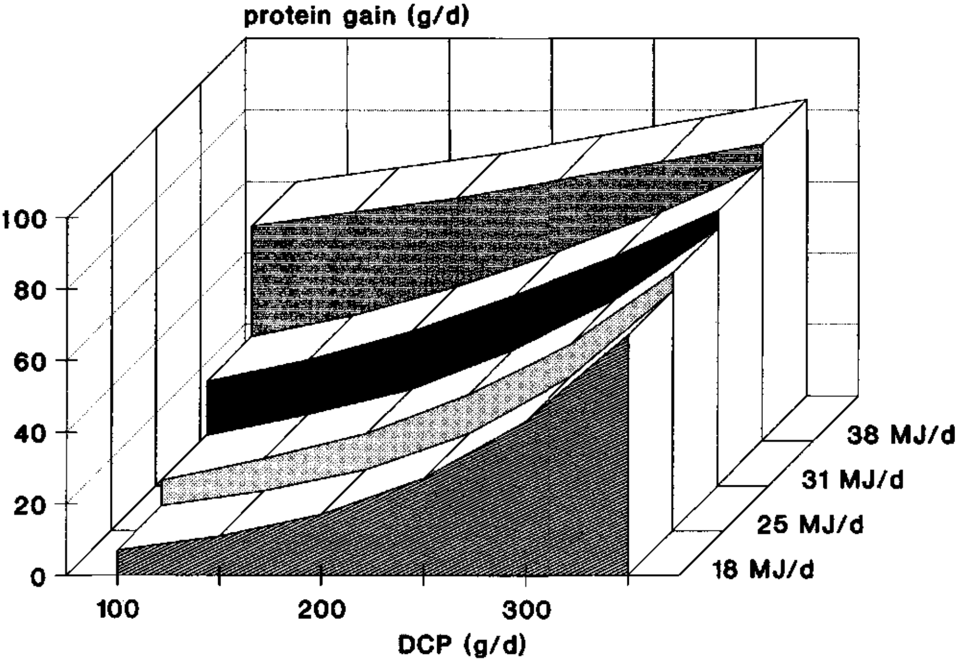

Figure 5.1

Mean protein gain in g.d^{-1} in the maternal body of the sow during first pregnancy in relation to the mean daily intake of digestible crude protein (DCP) and metabolizable energy (MJ ME)

When on a relatively high level of energy supply, nitrogen and lysine supply were restricted during pregnancy, a lower nitrogen retention in late pregnancy was observed in balance trials (Everts and Dekker, 1994b). From these data it was calculated theoretically, that mainly maternal deposition is affected.

The present experiment was designed to study the effect of a nitrogen and lysine restriction during pregnancy on the composition of the maternal body and of the products of conception. It was also aimed to measure the utilization of nitrogen, lysine and energy. All gilts were fed at the same high level of metabolizable energy (29 to 35 MJ ME. day^{-1}).

Material and methods

Animals

In total six groups of 10 half sisters (Large White*Dutch Landrace) were reared individually from a live weight of 25 kg to 125 kg on a time-fixed schedule aiming at a mean growth rate of 600 g.d^{-1}. At a mean live weight of 125 kg animals were artificially inseminated. At the moment of insemination 2 animals of each group (except one group of which only one animal was taken) were slaughtered and chemically analysed to measure their body composition (BC_{D0}; n = 11). After mating the remaining animals in each group were randomly allotted to one of the two treatments. At the end of the first pregnancy at least one animal per treatment in each group was slaughtered and analysed for body composition (BC_{D108}; n = 14).

Diets and feeding level

During pregnancy the animals on treatment C were fed a diet with 24.7 g N.kg^{-1} and 7.3 g lysine.kg^{-1} and on treatment L a diet with 16.7 g N.kg^{-1} and 4.9 g lysine.kg^{-1} . Both diets had a metabolizable energy content of 11.6 MJ.kg^{-1}. Analysed chemical composition of the diets is given in Table 5.1.

Table 5.1

Mean analysed chemical composition of the diets in dry matter in g.kg^{-1}, unless other units are indicated

Diet	L	C
Dry matter	866	867
Ash	74	80
Nitrogen	19.3	28.5
Crude fibre	71	71
Crude fat	32	36
Gross energy (MJ.kg^{-1})	17.9	18.1
Lysine	5.7	8.4
Cystine	2.1	2.9
Methionine	2.2	3.1
Threonine	4.3	6.3

Further details about the used ingredients and the manufacturing of the diets were given by Everts and Dekker (1994b). Feed allowances during pregnancy were 2.5 $kg.d^{-1}$ during day 1 to day 85 and 3.0 $kg.d^{-1}$ from day 86 to day 108. The animals were fed twice a day.

Determination of the body composition

Body composition of sows was measured by the comparative slaughter technique. The details of the method were described by Everts and Dekker (1994a). The contribution of hair to the total body composition was systematically excluded from all calculations by removing the hair during slaughter. From each animal the half carcass and the offal (empty gastrointestinal tract, internal organs, blood, eyes, ears, spinal cord, brain, small cuttings and the tail) were chemically analysed. From the pregnant animals the reproductive tract was removed and chemically analysed as two fractions : a.) the unborn litter (all piglets with 10 cm of umbilical cord) and b.) the reproductive tissues (uterus, placentas and intra-uterine fluids). These two fractions together are defined as the products of conception.

From six of animals -pooled over treatments- amino acid composition in the protein of the carcass and the offal was analysed. Amino acid composition in the total maternal body was calculated using the observed amounts of nitrogen in the offal and in the carcass and the amino acid composition of the two fractions. The amino acid composition of the unborn litter was determined in four litters per treatment.

Statistical analysis

Treatment effects on body composition were tested with analysis of variance. The model included the group number as a block effect to correct for differences in time and for differences between groups with a similar dietary treatment. For the statistical analysis of the chemical composition of the reproductive tissues and the unborn litter, the total number of piglets in the uterus was used as a co-variable in the model.

The deposition of nutrients in the maternal body was calculated as BC_{D108} - EC_{D0}, where BC_{D108} is the measured body composition at the end of pregnancy and EC_{D0} represents the estimated body composition at mating. The values for EC_{D0} were calculated with regression equations as derived from the measured body composition at mating (C_{D0}).

The number of observations of amino acid pattern in carcass and offal were too small to test treatment effects.

Results

Body composition at mating

Live weight, back fat thickness and body composition of the animals at mating are shown in Table 5.2. The amount of protein in the body had a low standard deviation, probably due to the time-fixed feeding schedule during the rearing period. The amount of fat in the body at mating had the highest coefficient of variation compared with the amounts of dry matter, water and protein. Fat-free empty body (FFEB) of the sows contained 219 g protein. kg^{-1}. Water to protein ratio was 3.33 and energy content of the empty body was 13.2 $MJ.kg^{-1}$.

Table 5.2

Chemical composition of sows at the start of the experiment (mating) in kg, unless other units are indicated

	Mean	sd
n	11	
Live weight	125.8	5.4
Empty body weight	114.7	4.4
Mean back fat thickness (mm)	13.35	0.68
Dry matter	50.9	3.6
Water	63.8	3.5
Ash	3.8	0.4
Protein	19.2	0.7
Fat	27.0	3.2
Energy (MJ)	1516.0	119.0
Ratio water:protein	3.32	0.14
Protein (g.kg EBW^{-1})	167.5	6.0
Fat (g.kg EBW^{-1})	234.8	25.8
Protein (g.kg $FFEBW^{-1}$)	219.1	8.6

EBW = empty body weight; FFEBW = fat-free empty body weight; sd = standard deviation

In order to predict body composition of the remaining animals at the moment of mating several multiple regression models were tested to relate the observed amounts of protein, fat and energy in the slaughtered animals at mating to live weight and back fat thickness at different positions on the back. In all regression models one animal with the lowest body weight had a disproportionate influence on the estimated parameters (high leverage) and therefore this observation was excluded from the data set. The best fitting equations are presented in Table 5.3.

Composition of products of conception

Chemical composition of the reproductive tract and unborn litter (number of piglets: 9.9 ± 2.2) showed no differences between the treatments (Table 5.7). Compared with the maternal deposition the products of conception contained a limited amount of protein and hardly any fat. In the unborn litter the water to protein ratio was about 8.7 and in the reproductive tract (uterus, placentas and intra-uterine fluids) about 11.0. The amino acid pattern of nitrogen in unborn piglets (Table 5.8) did not differ between treatments.

Table 5.7

Chemical composition of reproductive tissues (uterus, intra-uterine fluids, placentas and piglets) and of unborn piglets at day 108 of first pregnancy in kg, unless other units are indicated

treatment	C	L	sed	P values	
				npig	treatment
n	7	7			
<u>reproductive tissues</u>					
Weight	19.14	19.33	1.56	0.061	0.906
Dry matter	2.67	2.69	0.22	0.045	0.924
Water	16.47	16.64	1.35	0.065	0.904
Protein	1.73	1.73	0.14	0.059	0.956
Fat	0.19	0.21	0.03	0.171	0.584
Energy (MJ)	54.1	55.7	4.26	0.049	0.710
Ratio water:protein	9.50	9.71	0.27	0.945	0.464
Protein (g.kg^{-1} fresh)	90.6	88.9	2.26	0.995	0.470
Fat (g.kg^{-1} fresh)	9.8	10.7	1.74	0.623	0.619
<u>unborn piglets</u>					
Number of piglets	10.4	9.7	1.4	-	0.585
Weight	10.78	10.96	1.09	0.470	0.876
Dry matter	1.76	1.79	0.20	0.061	0.876
Water	9.02	9.17	0.90	0.45	0.877
Protein	1.05	1.05	0.11	0.060	0.959
Fat	0.09	0.09	0.01	0.140	0.728
Energy (MJ)	33.1	33.5	3.76	0.087	0.923
Ratio water:protein	8.57	8.79	0.16	0.554	0.190
Protein (g.kg^{-1} fresh)	97.7	95.4	1.51	0.529	0.161
Fat (g.kg^{-1} fresh)	8.5	8.3	0.25	0.035	0.509

npig = effect of number of piglets in the litter ; treatment = effect of treatment

Table 5.8

Level of amino acids in g.16 g N^{-1} in unborn piglets at day 108 of pregnancy

treatment	C	L	sed	significance
n	4	4		
asparagine	7.30	7.17	0.10	ns
threonine	3.47	3.35	0.05	ns
serine	4.44	4.34	0.08	ns
glutamine	11.44	11.34	0.25	ns
proline	6.12	6.31	0.23	ns
glycine	9.46	9.25	0.37	ns
alanine	5.99	5.96	0.17	ns
cystine	1.27	1.39	0.06	ns
valine	4.50	4.44	0.11	ns
methionine	1.42	1.46	0.03	ns
isoleucine	2.93	2.89	0.12	ns
leucine	6.34	6.15	0.14	ns
tyrosine	2.33	2.26	0.11	ns
phenylalanine	3.43	3.34	0.07	ns
histidine	2.35	2.28	0.04	ns
lysine	5.88	5.70	0.10	ns
arginine	6.75	6.51	0.16	ns

Conversion efficiency of amino acids and energy

For lysine, cystine+methionine and threonine the conversion efficiency of ingested amino acid into retained amino acid was calculated for both treatments as: retained amino acid in maternal body and products of conception divided by ingested ileal digestible amino acid minus the maintenance requirement (Table 5.9). Ileal digestibility of the amino acids was estimated from table values (CVB, 1991). For maintenance requirements of amino acids estimates of Pettigrew (1993) were used. It was assumed that the protein present in uterus, placentas and intra-uterine fluids (0.68 kg protein) has the same pattern of amino acids as the unborn piglets. The mean metabolic body weight was calculated according to Kotarbińska (1969). The conversion efficiency of the amino acids on treatment L was significantly higher than on treatment C.

The conversion efficiency for metabolizable energy was calculated in a similar way. Metabolizable energy content of the diets was measured in energy balance trials with pregnant sows (Everts and Dekker, 1994b) and a maintenance requirement of 393 kJ per kg metabolic weight (Everts and Dekker, 1991) was used in the calculations. The conversion efficiency on treatment L was higher than on treatment C, but the differences were not significant.

differences in the estimated body composition at the mating. Maternal deposition (Table 5.6) has an additional source of variance due to the prediction of the body composition at mating (Everts and Dekker, 1994a).

Maternal protein retention during pregnancy differed significantly between treatments (treatment C 8.0 kg and treatment L 5.66 kg protein; $P=0.002$) and also maternal fat deposition tended to be different (treatment C 18.4 kg and treatment L 22.2 kg fat; $P=0.099$). The protein and fat deposition on treatment C during pregnancy were intermediate to those of sows receiving 2.5 and 3.5 kg feed per day (Walach-Janiak et al., 1986a). De Wilde (1980ab) observed only a maternal protein deposition of 2.5 kg and a maternal fat deposition of less than 10 kg during the first 107 days of pregnancy. These much lower values can be explained by the low feeding level and the low protein content of the diets supplied.

The lower maternal body protein increment on treatment L is compensated by a higher fat deposition, because the amount of fat in the maternal body per kg EBW was significantly higher. The difference in protein increment of about 2.3 kg was compensated by about 3.8 kg of fat. Also Shields et al. (1985) showed that sows on a low protein diet deposited less protein and more fat than at on a high dietary protein level. Due to differences in feeding level during pregnancy, the absolute levels of maternal gain in their study are not comparable to our data. Hovell et al. (1979) showed that both protein and fat deposition increased after an increase in ME intake (from 19.5 to 32.1 MJ ME.day^{-1}), while protein intake was constant. This indicates that at the low energy supply protein deposition is limited by energy shortage and that dietary protein is used as an energy source.

The mean maternal protein gain as observed in the present study, fitted very well in Figure 5.1 (at the level of 31 MJ ME). This finding confirms, at least partially, that there is an interaction between protein and energy intake for maternal protein gain as observed from literature data (see introduction).

Assuming partial efficiencies of 0.53 for protein deposition and of 0.81 for fat deposition in pregnant sows (Everts and Dekker, 1991) it can be derived that deposition of one kg of protein is energetically about equal to one kg of fat. The observed ratio is higher (2.3 kg protein to 3.8 kg fat). This is probably due to a difference in energy required for maintenance (sow live weight on treatment L was lower than on treatment C).

Deposition in the reproductive tract

The amounts of protein in the reproductive tract and in the piglets were nearly equal to the results of De Wilde (1980a). Noblet et al. (1985) also showed similar values for the amounts of protein and energy in products of conception for sows fed 30 MJ ME.d^{-1}. In addition Beyer (1986) observed also similar levels of dry matter, protein, fat and energy in piglets at day 105 of pregnancy. It should be realized that all data are from first litter sows and that unborn piglets at day 108 of pregnancy do not have the same body composition as at birth.

Since there was no effect of dietary treatment on the products of conception, it can be concluded that the development of products of conception has a higher priority than maternal deposition during pregnancy. This conclusion is supported by the results of Walach-Janiak et al. (1986b), who observed no effect on weight nor on chemical composition of the products of conception when they varied the supply of feed for gilts from 1.5 to 3.5 kg per day (nitrogen supply increased from 38 to >100 g.d^{-1}).

The ratio of nitrogen retention in the products of conception to total nitrogen retention was on treatment C 0.22 and on treatment L 0.31. For energy the ratios for treatment C and L were similar (about 0.06). These values indicate that the amount of protein and of fat deposited in the developing foetal tissues are relatively small compared with the total retention of protein and energy during pregnancy. At day 108 of pregnancy the proportion of nitrogen and energy retention in the piglets compared with the retention in the total reproductive tissues was about 0.6.

The pattern of amino acids in the unborn piglets was similar to the results from newborn piglets as reported by Aumaitre and Dueé (1974). Becker et al. (1979) observed in piglets of day 105 higher levels of asparagine, glycine, alanine and tyrosine compared with our study. Williams et al. (1954) observed in newborn piglets in general higher levels of amino acids, especially for lysine (9 g lysine per 16 g N). The discrepancy with old literature sources may be partially explained by differences in methods for determination of amino acids (e.g. microbiological procedures).

Conversion efficiency for deposition

The conversion efficiencies, after allowance for maintenance, of certain ingested ileal digestible amino acids into retained amino acids are given in Table 5.9. The conversion efficiencies on treatment L are significantly higher for lysine (P=0.06), for cystine + methionine (P=0.02) and for threonine (P=0.01) than on treatment C. On treatment L the conversion efficiency for lysine was 0.59 and for threonine 0.67 and on treatment C 0.46 and 0.44, respectively. Pettigrew (1993) proposed a conversion efficiency, after allowance for maintenance, of ingested amino acids into retained amino acids of 0.45 for all amino acids. When the apparent digestibility of amino acids is 0.8 (as assumed by Pettigrew, 1993), then the conversion efficiency of ingested digestible amino acids will be 0.56 (=0.45/0.8). In Table 5.9 we observed higher efficiencies for lysine and threonine on treatment L.

Excretion of nitrogen was calculated as the difference between ingested and retained nitrogen. On treatment L the excretion of nitrogen was much lower than on treatment C. During the first 108 days of pregnancy sows on treatment L excreted 3.6 kg N and sows on treatment L 5.4 kg N. This difference between the treatments is related to the difference in nitrogen intake and the difference in nitrogen deposition.

The conversion efficiency, after allowance for maintenance, of ME into retained energy on treatment L was expected to be higher than on treatment C due to differences in fat deposition. The difference was, however, not significant.

The observed conversion efficiency was somewhat lower than calculated from the values for k_f and k_p as given by Close and Noblet (1985) with a comparable level of maintenance requirement. However, in our study the conversion efficiency was higher than calculated from the values for k_f and k_p as given by De Wilde (1980ab) and Walach-Janiak et al. (1986), but they observed also a higher maintenance requirement.

Conclusions

A decrease in nitrogen level in the diet during pregnancy from 28.5 to 19.3 g N. kg^{-1} in the dry matter at the same level of ME supply did not affect the fresh weight, the chemical composition of the products of conception nor the amino acid pattern in the protein in the unborn piglets. On the low level of nitrogen supply maternal protein deposition decreased and maternal fat deposition increased. The protein content of the fat-free maternal body did not differ between treatments and remained at the same level as observed at mating. Also the water:protein ratio remained similar in the maternal body during pregnancy. The conversion efficiency, after allowance for maintenance, of ileal digestible amino acids into retained amino acids was significantly higher on the treatment with the low nitrogen supply. The conversion efficiency, after allowance for maintenance, of ME into retained energy was higher (ns) on the treatment with the restricted protein supply, due to an increased level of fat deposition in the maternal body.

From the data it can be concluded that the development of the products of conception has a higher priority than the development of the maternal body. When the dietary supply allows the maternal body to gain weight, then protein deposition has a priority above fat deposition. However, when protein supply is restricted at a similar energy intake, then the young sow can only increase her fat mass.

The amounts of protein and fat in the body of a sow can be affected by nutrient supply. However, the process of deposition of protein in the maternal body seems to be regulated by strict rules. Especially the protein content in the fat-free body mass and the amino acid pattern in the body of sows show a small variation.

Acknowledgements

We want to thank M.W.A. Verstegen and A.W. Jongbloed for their useful comments on the manuscript. This research was partly financed by the Dutch Fund for Manure and Ammonia Research (FOMA).

References

Aumaitre, A. and Dueé, P.H., 1974. Composition en acides aminés des protéines corporelles du porcelet entre la naissance et l'âge de huit semaines. *Annales de Zootechnie* 23: 231-236

Becker, K., Farries, E., Pfeffer, E., 1979. Changes in body composition of pig fetuses during pregnancy. *Archiv für Tierernährung* 29: 561-568

Beyer, M., 1986. Untersuchungen zum Energie- und Stoffumsatz von graviden und laktierenden Sauen sowie Saugferkeln - ein Beitrag zur Präzisierung des Energie- und Proteinbedarfes. Promotionsarbeit. Dummerstorf-Rostock p. 234

Buraczewski, S., 1973. Views on the pig requirements for amino acids and new sources of these nutrients suitable for use in the feeding of pigs. In: *New developments on the provision of amino acids in the diets of pigs and poultry* Vol I: 73-97 [ECE/AGRI/4]

Close, W.H., Noblet, J. and Heavens, R.P., 1985. Studies on the energy metabolism of the pregnant sow. 2. Partition and utilization of metabolizable energy intake in pregnant and nonpregnant animals. *British Journal of Nutrition* 53: 267-279

CVB, 1991.[Data about chemical composition, digestibility and feeding value of feedstuffs] Veevoedertabel, Centraal Veevoederbureau, Lelystad

De Wilde, R.O., 1980a. Protein and energy retention in pregnant and non-pregnant gilts. I. Protein retention. *Livestock Production Science* 7: 497-504

De Wilde, R.O., 1980b. Protein and energy retention in pregnant and non-pregnant gilts. II. Energy retention. *Livestock Production Science* 7: 505-510

Everts, H. and Dekker, R.A., 1991. Effect of protein/lysine supply and parity number on energy metabolism during pregnancy and lactation in sows. In: Energy metabolism of farm animals (Ed. Wenk, C. and Boessinger, M.) *EAAP Publication* 58: 317-320

Everts, H. and Dekker, R.A., 1994a. Balance trials and comparative slaughtering in breeding sows: description of techniques and observed accuracy. *Livestock Production Science* 37: 339-352

Everts, H. and Dekker, R.A., 1994b. Effect of nitrogen supply on the excretion of nitrogen and on energy metabolism of pregnant sows. *Animal Production* : in press

Hovell, F.D.DeB., MacPherson, R.M., Crofts, R.M.J., Smart, R.I., 1977. The effect of pregnancy, energy intake and mating weight on protein deposition and energy retention of female pigs. *Animal Production* 25: 281-290

Kotarbińska, M., 1969. [Studies on energy metabolism in growing pigs]. *Wydawnictwo Wlasne Instytut Zootechniki*, p. 238

Lahrssen, M., 1988. Untersuchungen zu quantitativen und qualitativen Veränderungen in der Körperzusammensetzung laktierender Sauen und zur Verwertung des Proteins und der Energie für die Milchbildung. Thesis . Freien Universität Berlin Journal-Nr 1417: p123

Lodge, G.A., Friend, D.W. and Wolynetz, M.S., 1979. Effect of pregnancy on body composition and energy balance of the gilt. *Canadian Journal of Animal Science* 59: 51-61

Noblet, J. Close, W.H. and Heavens, R., 1985. Studies on the energy metabolism of the pregnant sow. 1. Uterus and mammary tissue development. *British Journal of Nutrition* 53: 251-265

Pettigrew, J.E., 1993. Amino acid nutrition of gestating and lactating sows. *Biokyowa Technical Review* 5: 1-18

Shields Jr., R.G. and Mahan, D.C., 1983. Effects of pregnancy and lactation on the body composition of first-litter female swine. *Journal of Animal Science* 57: 594-603

Shields Jr, R.G., Mahan, D.C. and Maxson, P.F., 1985. Effect of dietary gestation and lactation protein levels on reproductive performance and body composition of first-litter female swine. *Journal of Animal Science* 60: 179-189

Swanson, C.O., 1921. Effect of ration on the development of pigs. *Journal of Agricultural Research* 21: 279-341

Walach-Janiak, M., Raj, St. and Fandrejewski, H., 1986a. The effect of pregnancy on protein, water and fat deposition in the body of gilts. *Livestock Production Science* 15: 261-269

Walach-Janiak, M., Raj, St. and Fandrejewski, H, 1986b. Protein and energy balance in pregnant gilts. *Livestock Production Science* 15: 249-260

Whittemore, C.T. and Yang, H., 1989. Physical and chemical composition of the body of breeding sows with differing body subcutaneous fat depth at parturition, differing nutrition during lactation and differing litter size. *Animal Production* 48: 203-212

Williams, H.H, Curtin, L.V.,Abraham, J.,Loosli, J.K., and Maynard, L.A., 1954. Estimation of growth requirements for amino acids by assay of the carcass. *Journal of Biology and Chemistry* 208: 277-286

Chapter 6

Effect of protein supply during pregnancy and lactation on body composition of sows during three reproductive cycles

H. Everts and R.A. Dekker

Institute for Animal Science and Health
(ID-DLO) Branch Runderweg
P.O. Box 160, NL 8200 AD Lelystad
The Netherlands

Submitted for publication in Livestock Production Science

Effect of protein supply during pregnancy and lactation on body composition of sows during three reproductive cycles

H. Everts and R.A. Dekker

Abstract

The effect of two levels of nitrogen supply during pregnancy and of two levels of nitrogen supply during lactation on the development of body composition of sows during three reproductive cycles was investigated using the comparative slaughter technique (n = 11 at first mating; n = 23 after third weaning). Nitrogen content of the diets in dry matter was 28.5, 19.3 and 32.8 g N. kg^{-1} for diets C, L and H, respectively. Tested combinations of diets during pregnancy (first character) and lactation (second character) were: CC, CH, LC and LH. Animals remained on the same treatment during the whole experiment.

Treatments did not affect the amount of protein in the body nor the amino acid pattern of protein after three reproductive cycles. Pregnancy treatment affected the ratio water:protein significantly after the third weaning. Amounts of fat, dry matter and energy in the body after three reproductive cycles were affected by the level of protein supply during lactation. On treatments CH and LH the amounts of fat, dry matter and energy in the body were lower ($P<0.1$) than on the treatments CC and LC.

Body composition of sows was predicted from live weight (corrected for the products of conception) and back fat thickness at P2 using all available data (including measured body compositions at the end of first pregnancy, n = 14). With the derived equations the development of body composition during three reproductive cycles was predicted. During the first reproductive cycle deposition of protein and water was lower on treatments LC and LH than on treatments CC and CH. This was not completely compensated in the next two cycles. The overall trend in the present experiment showed an increasing live weight and a decreasing back fat thickness at P2 with increasing parity number, while the amount of fat hardly changed and the amount of energy increased slightly and the amount of protein and water increased considerably. This means that a feeding regimen that aims at a constant back fat thickness increases the amount of body fat.

Keywords: sows, body composition, back fat thickness, live weight, parity

Introduction

Body condition, live weight and fatness seem to influence reproductive performance of sows (Whittemore et al., 1988) and of women (Frisch, 1988). In sows visual body condition score has a relatively low correlation with back fat thickness (Whittemore et al., 1980) and gives no quantitative information about the actual body composition of the sow in terms of amounts of fat and protein. Live weight (LW) and back fat thickness (BFT) can predict the amount of fat and protein in young sows (King et al., 1986) and in older sows (Whittemore and Yang, 1989). However, data on chemical body composition of sows are scarce and are mainly based on experiments with gilts (Lodge et al., 1979; Hovell et al., 1977; De Wilde, 1980ab; Shields and Mahan, 1983; Shields et al., 1985; Walach-Janiak et al., 1986ab). Anatomical dissection of gilts and older sows was presented more often (Elsley et al., 1966; Heap and Lodge, 1967; Elsley et al., 1968; O'Grady et al., 1975; Whittemore et al., 1980; Etienne et al., 1982), but it does not quantify absolute amounts of fat and protein in the animal's body. Chemical body composition of older sows (parity >2) were given by Beyer (1986), Lahrssen (1988) and by Whittemore and Yang (1989). Beyer (1986) analysed pregnant sows in first, second and fourth parity at the end of pregnancy. The number of observations per dietary treatment, however, was very small ($n = 1$ to 3). In the experiment of Lahrssen (1988) the change in body composition during lactation was quantified on a fixed feeding regimen (up to 4.6 kg air dry material) in first and third parity sows. Whittemore and Yang (1989) investigated the effects of litter size during lactation (6 or 10 suckling piglets), of fatness of the sows (thin or fat sows) and of feeding level during lactation (3 or 7 $kg.d^{-1}$) on body composition at weaning after the 4th lactation. The combination of these experimental factors resulted in large contrasts between treatments.

The study reported here aimed to quantify the development of body composition during the first three parities. Firstly, the effect of different levels of protein supply during pregnancy and during lactation on body composition over three parities was studied. Secondly, equations were derived to predict body composition of sows from LW and BFT. Thirdly, we described with these equations the development of body stores during three parities.

Material and methods

Animals

Six groups of 10 half sisters (Large White*Dutch Landrace) were reared individually from a live weight of 25 kg to 125 kg on a time-fixed schedule aiming at a mean growth rate of 600 $g.d^{-1}$. At a mean live weight of 125 kg the animals were inseminated artificially. At the moment of insemination 2 animals of each group (except one group of which only one animal was taken) were slaughtered and chemically analysed for their body composition (BC_{D0}). After mating the remaining animals in a group were randomly allotted to one of two pregnancy treatments. At the end of the first pregnancy at least one animal per treatment in each group was slaughtered and analysed for its body composition (BC_{D108}; n = 14). During lactation the sows within pregnancy treatments were allotted to one of two lactation treatments. The animals remained on the same combination of pregnancy and lactation treatments for three parities. One week after the third weaning all remaining animals were slaughtered and chemically analysed (BC_{D435}; n = 23). The effect of the treatment during the first pregnancy is described separately by Everts and Dekker (199X).

Treatments

During pregnancy the sows were fed a control diet (treatment C_) or an experimental diet with a low nitrogen level (treatment L_) (Everts and Dekker, 199X). The feed allowance during pregnancy was 2.5 $kg.d^{-1}$ from day 1 to day 85 and 3.0 $kg.d^{-1}$ from day 86 to day 114. During lactation the sows were fed either the control diet (treatment _C) or a diet with an increased protein/lysine content (treatment _H). The feed allowance during lactation was 1 % of the body weight of the sow plus 0.4 kg per suckling piglet. Table 6.1 shows the chemical composition of the diets. In the experiment four combinations of treatments during pregnancy and during lactation were imposed: CC, CH, LC and LH (first character is pregnancy treatment and second character is lactation treatment).

Table 6.1
Mean analysed chemical composition of diets in g.kg DM^{-1} (energy: MJ.kg DM^{-1})

Diet	L	H	C
Pregnancy treatment	L_		C_
Lactation treatment		_H	_C
Dry matter	866	870	867
Ash	74	80	80
Nitrogen	19.3	32.8	28.5
Crude fibre	71	90	71
Crude fat	32	30	36
Gross energy	17.9	18.2	18.1
Lysine	5.7	10.3	8.4
Cystine	2.1	3.6	2.9
Methionine	2.2	4.4	3.1

Determination of body composition

Body composition of the sows was measured by comparative slaughter as described by Everts and Dekker (1994a). The contribution from hair to the total body composition was systematically excluded from all calculations by removing the hair during the process of slaughter. From each animal the left half of the carcass and the offal (empty gastro-intestinal tract, internal organs, blood, eyes, ears, spinal cord, brain, small cuttings and the tail) were chemically analysed. The amino acid composition was determined in the protein of the carcass and the offal from four animals.

Statistical analysis

The results were analysed by multiple regression using the model:

$$Y_{ijk} = \mu + G_i + P_j + L_k + P_j.L_k + \epsilon_{ijk} \qquad (1)$$

where

μ = mean
G_i = effect of group number
P_j = effect of pregnancy treatment (C_ or L_)
L_k = effect of lactation treatment (_C or _H)
$P_j.L_k$ = interaction between pregnancy and lactation treatment
ϵ_{ijk} = error component

No significant interactions between pregnancy and lactation treatments with regard to body components were found, therefore model (1) was simplified to :

$$Y_{ijk} = \mu + G_i + P_j + L_k + \epsilon_{ijk} \qquad (2)$$

Deposition of protein, water, fat and energy in the maternal body was calculated as BC_{D435} - EC_{D0}, where EC_{D0} represents the estimated body composition at first mating. The values for EC_{D0} were calculated with regression equations derived from the measured body composition at mating (BC_{D0}) as given by Everts and Dekker (199X).
The number of observations of amino acid pattern in carcass and offal were too small ($n=4$) to test for treatment effects.
Two regression models were tested to predict body composition from live weight corrected for the weight of unborn piglets, placentas, intra-uterine fluids and uterus (LWc) and BFT at the P2:

$$Y_{ij} = \text{Constant} + \beta_1 * LWc_i + \beta_2 * BFT_j + \epsilon_{ij} \qquad (3)$$

and

$$Y_{ij} = \text{Constant} + \beta_1 * LWc_i + \beta_2 * (LWc_i * \ln(BFT_j)) + \epsilon_{ij} \qquad (4)$$

where

Y_{ij} = observed amount (kg)
Constant = estimated intercept
β_1, β_2 = estimated coefficients
LWc_i = Live weight (kg, corrected for products of conception)
BFT_j = back fat thickness at P2 (mm)
ϵ_{ij} = error term

Results

Body composition at after the third weaning

Table 6.2 gives the body composition of the sows after the third weaning. Sows on pregnancy treatment C_ had a lower water to protein ratio than pregnancy treatment L_ ($P=0.054$). The protein content per kg empty body on treatment C_ was higher than on pregnancy treatment L ($P=0.064$). Lactation treatment _H resulted in a lower amount of fat in the body than lactation treatment _C ($P=0.065$). This difference in fat was also reflected by a difference in amount of dry matter ($P=0.063$) and in energy ($P=0.063$). Also, the fat content in the empty body was lower on lactation treatment _H ($P=0.054$) than on lactation treatment _C. Lean to fat ratio was higher on lactation treatment _H than on lactation treatment _C ($P=0.057$).

All animals had about 100 kg of water in their body. The variation in amount of protein was much smaller than the variation in the amount of fat. Energy content per kg EBW on treatments CC, CH, LC and LH was 12.1, 11.0, 12.5 and 11.45 MJ, respectively.

The amino acid pattern in the carcasses and the offal of the sows indicated no large differences between the treatment combinations. The number of observations, however, was small. With the observed amounts of N in the carcass and in the offal the amino acid pattern of the sow's body was calculated and is presented in Figure 6.1. For comparison also the amino acid pattern of first parity sows (Everts and Dekker, 199X) is given in Figure 6.1, which shows only minor differences.

Table 6.2

Chemical composition of the body of sows one week after the end of the third lactation

Treatment	CC	CH	LC	LH	rsd	P values	
						trtPr	trtLa
Live weight(kg)	186.3	179.1	188.1	181.0	13.3	0.743	0.226
EBW(kg)	173.6	166.9	174.7	168.1	13.0	0.838	0.243
Dry matter(kg)	72.4	65.1	73.9	66.7	8.6	0.681	0.063
Water(kg)	101.2	101.8	100.8	101.4	6.6	0.893	0.842
Protein(kg)	29.9	29.7	28.8	28.6	1.9	0.168	0.729
Fat(kg)	34.6	28.3	37.7	31.4	7.4	0.331	0.065
Energy(MJ)	2099.	1836.	2188.	1925.	308.	0.504	0.063
Ratio water/protein	3.39	3.43	3.52	3.56	0.16	0.054	0.483
Protein(g.kg EBW^{-1})	172.3	178.2	164.6	170.5	9.2	0.064	0.175
Fat(g.kg EBW^{-1})	198.0	168.0	215.0	184.0	33.9	0.267	0.054
Protein(g.kg FFEBW^{-1})	215.1	214.2	209.7	208.8	7.7	0.112	0.704
Ratio lean/fat[#]	3.83	4.76	3.61	4.53	1.06	0.619	0.057

EBW = empty body weight; FFEBW = fat-free empty body weight; rsd = residual standard error; trtPr = effect of treatment during pregnancy ; trtLa = effect of treatment during lactation; [#] lean = protein + water

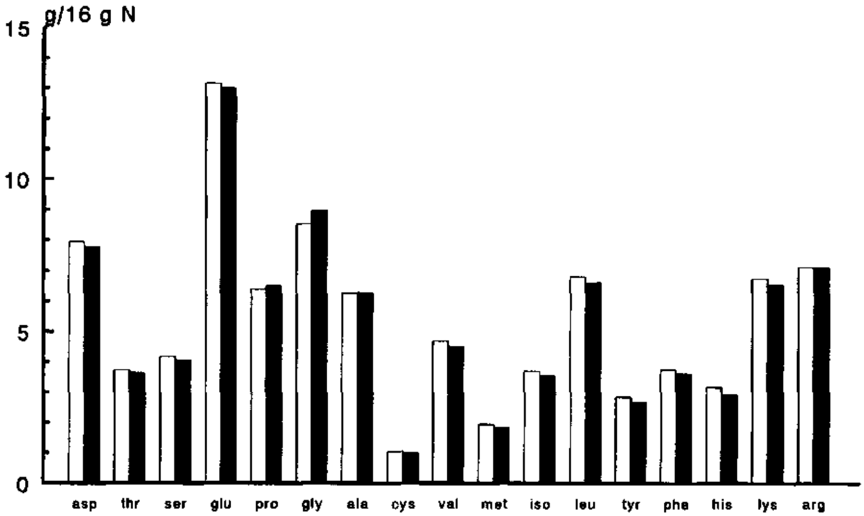

Figure 6.1

Amino acid pattern in the body of sows (g.16 g N^{-1}). ☐ = First parity sows. ■ = third parity sows

Deposition during three reproductive cycles

The difference between estimated body composition at mating and observed body composition at the end of third lactation represents the deposition during three parities. Body composition of the animals at mating and the equations to predict the body composition at mating were reported earlier (Everts and Dekker, 199X). The calculated deposition during three parities has a relatively high coefficient of variation due to additional variance from the estimate of the body composition at mating (Everts and Dekker, 1994a). Table 6.3 shows the results. Mean empty body weight (EBW) increased with 51 to 57 kg without a significant treatment effect. Mean water deposition was about 36 kg. The protein deposition in sows on pregnancy treatment C_ was about 1.25 kg higher than on pregnancy treatment L_ (difference not significant). The lactation treatment affected the amount of deposited fat and energy in the same way as in the total body.

Table 3.

Deposition in the sows from first mating to a week post weaning of the third litter calculated as BC_{435}-EC_0

Treatment	CC	CH	LC	LH	rsd	P values	
						trtPr	trtLa
EBW (kg)	56.9	50.9	57.3	51.2	11.9	0.943	0.244
Water (kg)	36.0	36.9	35.5	35.5	6.0	0.843	1.000
Protein (kg)	10.5	10.3	9.2	9.1	1.8	0.124	0.775
Fat (kg)	7.6	2.6	10.2	5.2	6.2	0.334	0.082
Energy (MJ)	584	367	655	438	269	0.540	0.078

EBW = empty body weight

EC_0 = estimated body composition at mating

BC_{435} = body composition a week after the end of the third lactation

Prediction of body composition from live weight and back fat thickness

Using all available slaughter data (at first mating, at the end of first pregnancy and after the third lactation) equations were derived to predict the body composition from LWc and BFT at P2. The results of the models (3) and (4) are presented in Table 6.4. From the results of model (3) it can be calculated that an increase of 1 kg LWc without any change in BFT at P2 represents 110 g fat and 175 g protein and 615 g water. The remaining 100 g is assumed to be 25 to 30 g ash and about 65 g gut fill and some glycogen. The figure of 65 g for gut fill is more or less similar to the increase of EBW with 0.935 per kg LWc as observed in regression equation (5):

$$EBW = -2.04 + 0.935 * LWc \; (\%acc. = 97.5 \; ; RSD = 4.24) \qquad (5)$$

An increase of 1 mm of BFT at P2 without any change in LWc results in an increase of 1.98 kg of fat and a decrease of 0.38 kg of protein and a decrease of 1.64 kg of water. Model (4) gave for water, fat and energy a small improvement in percentage of variance accounted for and a somewhat lower RSD.

Table 6.4

Prediction of body components in sows from body weight corrected for the weight of the products of conception (LWc) and back fat thickness at P2 (BFT)

Model: $Y = C + \beta_1 * LWc + \beta_2 * BFT$ (Model 3)

Y	C	(sd)	β_1	(sd)	β_2	(sd)	% acc	RSD
Water (kg)	+6.88	3.71	+0.615	0.023	-1.693	0.149	93.9	4.04
Protein (kg)	+1.67	1.32	+0.175	0.008	-0.377	0.053	90.8	1.43
Fat (kg)	-10.40	2.80	+0.110	0.017	+1.997	0.112	92.1	3.05
Energy (MJ)	-408.0	116	+8.885	0.732	+68.06	4.65	93.0	126

Model: $Y = C + \beta_1 * LWc + \beta_2 * LWc * \ln(BFT)$ (Model 4)

Y	C	(sd)	β_1	(sd)	β_2	(sd)	% acc	RSD
Water (kg)	-13.57	3.80	+0.959	0.044	-0.137	0.012	94.2	3.92
Protein (kg)	-2.97	1.41	+0.252	0.016	+0.031	0.004	90.6	1.45
Fat (kg)	14.4	2.87	-0.306	0.033	+0.166	0.009	92.6	2.96
Energy (MJ)	440.0	117	-5.38	1.37	+5.69	0.370	93.6	121

(sd) = standard deviation; % acc = percentage variance accounted for; RSD = residual standard error

Development of body stores during three parities

The development of the LWc during three parities showed some non-significant differences between the treatment combinations. At the end of pregnancy 1 sows on treatment C_ had a higher LWc. After the third lactation the sows on treatment with diet C during lactation (_C) had the highest LWc. Figure 6.2a shows the overall trend of LWc during three parities.

BFT at P2 also showed non-significant differences between the treatments. At the end of the first parity sows on treatment C_ tended to a lower BFT at P2 than sows on treatment L_. After the third lactation sows with treatment _C tended to a higher BFT at P2 than sows with treatment _H. The overall trend in Figure 6.2b indicates that BFT at P2 measured at the end of pregnancy decreased with parity number.

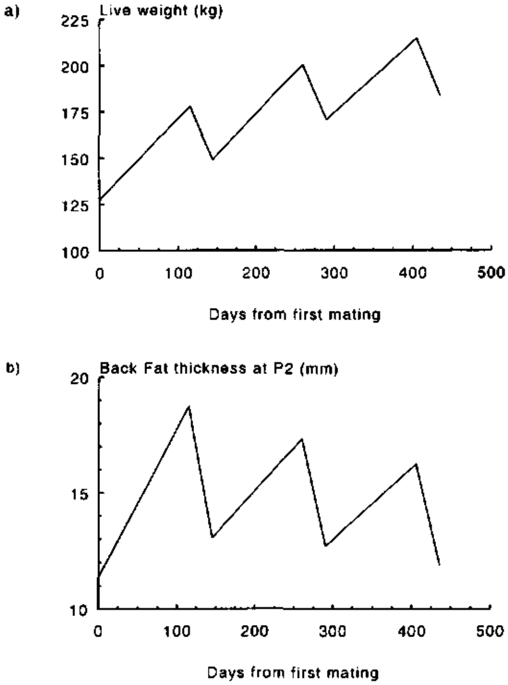

Figure 6.2
Mean live weight (a) corrected for the products of conception (LWc, kg) and b) back fat thickness (b) at P2 (BFT, mm) during three reproductive cycles

With the equations according to model (3) in Table 6.4 the body composition was predicted using the observed values for LWc and BFT. The results per treatment are shown in Table 6.5 and the overall trends (mean of all treatments) are shown in Figure 6.3. During the first reproductive cycle (mating for first pregnancy to mating for second pregnancy) the sows on treatment C_ gained more protein and water than the sows on treatment L_. During the second and third reproductive cycles (from mating to mating for the next pregnancy) there were no significant differences between the treatments. Compared with the first reproductive cycle the sows deposited in general less fat and energy in the second and third reproductive cycle.

Table 6.5

Changes in body composition during three successive reproductive cycles estimated from model (3) (see Table 6.4) from moment of mating to the mating for the next reproductive cycle

Treatment	CC	CH	LC	LH	rsd	P values	
						trtP	trtL
First reproductive cycle							
Protein (kg)	4.4	4.5	2.3	2.3	1.9	0.012	0.957
Fat (kg)	5.0	3.6	6.0	7.3	5.1	0.339	0.962
Water (kg)	15.0	15.6	7.5	7.3	6.6	0.010	0.961
Energy (MJ)	313	260	299	347	205	0.737	0.952
Second reproductive cycle							
Protein (kg)	3.3	4.4	4.9	3.3	2.6	0.720	0.698
Fat (kg)	3.8	-0.4	1.9	0.9	4.6	0.713	0.243
Water (kg)	11.4	15.8	17.2	11.7	9.1	0.695	0.756
Energy (MJ)	236	100	200	121	212	0.841	0.263
Third reproductive cycle							
Protein (kg)	2.1	0.5	2.4	3.2	2.6	0.292	0.752
Fat (kg)	-1.9	2.3	0.7	-1.8	4.6	0.937	0.757
Water (kg)	8.0	1.6	8.5	11.5	9.4	0.296	0.742
Energy (MJ)	-20	104	90	12	198	0.780	0.854

rsd = residual standard error; trtPr = effect of treatment during pregnancy ; trtLa = effect of treatment during lactation

When the mean body composition at the end of each pregnancy is compared for the three parity numbers (Figure 6.3), then the mean increase of amount of water, protein, fat and energy in the body measured at the end of pregnancy was from parity 1 to parity 2 +16.3 kg, +4.5 kg, -0.2 kg and +108 MJ, respectively. From parity 2 to parity 3 these values were +10.4 kg, +2.9 kg, -0.6 kg and +51 MJ. The mean increase of the amount of fat, protein, water and energy per parity at the end of pregnancy was +13.4 ± 3.5 kg, +3.7 ± 1.0 kg, -0.4 ± 2.8 kg and +80 ± 120 MJ, respectively.

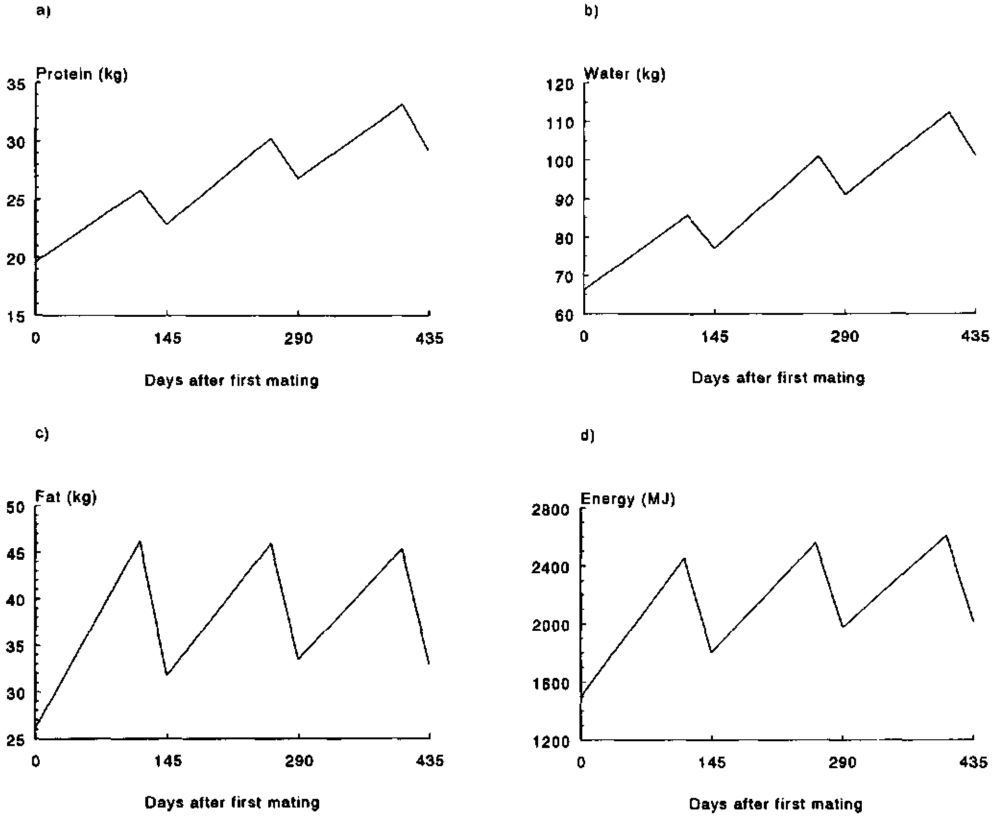

Figure 6.3
Estimated mean amounts of protein (a), water (b) and fat (c) in kg and energy (d) in MJ in the body of sows during three reproductive cycles

Discussion

Body composition and deposition

Mean amounts of protein in the body after the third lactation (Table 6.3) were similar with the value of 28.9 kg (± 2.7) as observed by Lahrssen (1988). Whittemore and Yang (1989) observed after the fourth lactation amounts of protein in the body from 32.4 to 39.8 (sows with 10 suckling piglets). Our sows retained 2.3 to 4.9 kg protein in their body per parity (Table 6.5) and the overall mean value was 3.7 kg protein (Figure 6.3). Comparable values were observed by Beyer (1986) and Lahrssen (1988). In the experiment of Whittemore and Yang this value ranged between 3 and 5 kg.

Between treatment C_ and L_ the difference in total retained protein in the body was about 1.25 kg after three parities (Table 6.3). This is less than the difference in retained protein in the body during the first pregnancy of 2.3 kg (Everts and Dekker, 199X). This indicates that sows on the low protein diet during pregnancy had the possibility to compensate during the following lactation and the next two reproductive cycles. The difference between the lactation treatments was much smaller (0.2 kg).

There was also a small, but significant, effect of pregnancy treatment on the water to protein ratio. Sows on the low protein diet during pregnancy retained 0.1 to 0.2 kg more water per kg protein. Due to this difference also the protein content in the empty body and in the fat-free empty body (FFEB) showed lower values on treatment L_ than on treatment C_. This effect was not due to differences in the amino acid pattern between the treatments. The amino acid pattern of protein in the body of the third parity sows was quite similar to the pattern at first parity (mating and end of first pregnancy). Probably, within one week after weaning the water balance of the sows is not yet returned to normal values. Lahrssen (1988) also observed a much higher water to protein ratio (3.67) in newly weaned sows than at the end of pregnancy (3.38). In her experiment also the protein content of the FFEB of the sows was affected. The present data indicate that the required time to reach a steady water to protein ratio is dependent on the level of protein supply during pregnancy.

The amount of fat in the body after the third lactation (Table 6.2) was high compared with the level of 17.5 kg as observed by Lahrssen (1988) at the same moment. Whittemore and Yang (1989) observed comparable or even higher levels of body fat after the fourth lactation compared with our data.

The lactation treatment had mainly an effect on the amount of fat in the body. The sows on treatment _H with a higher protein supply contained 6.3 kg less fat than the sows on treatment _C. This confirms the results from balance trials during lactation, where a higher protein/lysine supply was associated with a higher fat mobilization (Everts and Dekker, 1991). This difference in amount of fat was also reflected in a difference in amount of dry matter, energy in the body, the fat content in the empty body and the lean to fat ratio. The mean amount of fat at the end of pregnancy decreased with 0.4 kg per parity (figure 6.3). Lahrssen (1988) observed a reduction of 1.2 kg fat per parity with increasing parity number, whilst Whittemore and Yang (1989) observed an increase of fat amount per parity ranging between 0 and 6 kg per parity.

Prediction of body composition from live weight and back fat thickness.

Compared with equations of Whittemore and Yang (1989) the present equations had small residual standard errors. In both experiments an increase in BFT at a constant LWc reduced the lean mass and increased the fat mass. A change of 1 mm BFT at P2 represents in the present experiment an increase of 1.99 kg and a reduction in lean tissue (water + protein) of about 2.0 kg. The coefficients for changes in BFT at P2 were lower in the experiments of King et al. (1986) and of Whittemore and Yang (1989) than in the present experiment. The data set of King et al. (1986) was mainly based on young animals with a relatively high level of back fat thickness (ranging from 16 to 37 mm at P2). The data set of Whittemore and Yang was based on both young and old sows with back fat thicknesses ranging between 5 and 19 mm at P2. In the present data set the back fat thickness at P2 ranged between 8 and 26 mm.

The equations for the prediction of the amount of fat in the body from King et al. (1986), Whittemore and Yang (1989) and equations according to models (3) and (4) are compared in Figure 6.4.

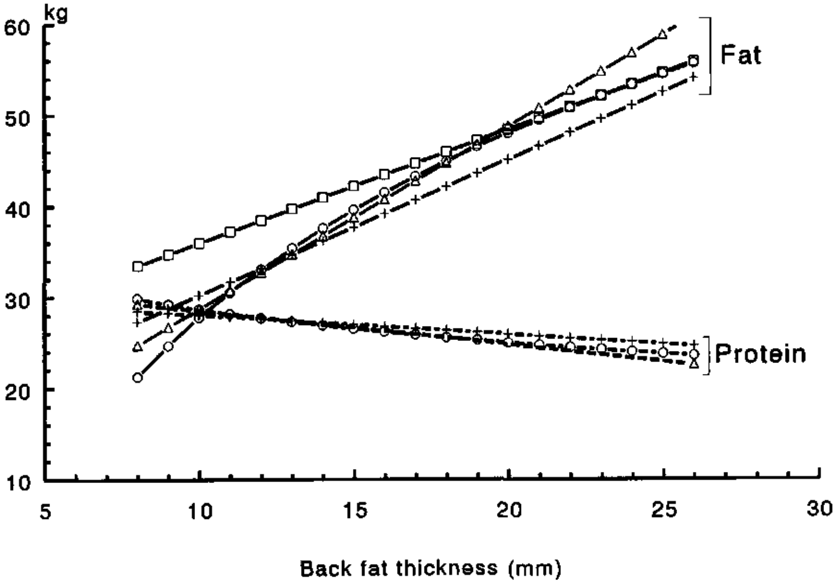

Figure 6.4

Comparison of prediction equations for amount of fat and protein in the body from live weight (175 kg) and back fat thickness. Fat (kg): □——□ = King et al. (1986); +——+ = Whittemore and Yang (1989); ▵——▵ = model (3); ○——○ = model (4); Protein (kg): +······+ = Whittemore and Yang (1989); ▵······▵ = model (3);○······○ = model (4)

At a live weight of 175 kg (corrected for the weight of the products of conception) the predictions of the amount of fat are quite similar when BFT at P2 is in the range of 16 to 23 mm (taking the errors into account). At low BFT the equation of King et al. (1986) seems to predict higher amounts of fat than the other equations. At the high levels of BFT model (3) seems to predict more fat than the other equations. When the equations are compared at a lower live weight then the range of BFT with similar predictions from all equations is shifted to lower levels of BFT. When the equations are compared at a higher live weight then the ranges of BFT with similar predictions from all equations is shifted to higher levels of BFT. The prediction of the amount of protein showed hardly any differences between the equations of Whittemore and Yang (1989) and model (3) or (4).

Besides methodological differences in measuring the back fat thickness and possible genetic differences in the distribution of fat depots in sows, it is theoretically assumable that back fat thickness in a small sow has an other meaning than in a large sow (deviation from linearity). When live weight is highly correlated with the size and/or conformation of an animal, then the combination of live weight and back fat thickness can predict body composition accurately. The coefficients for live weight and back fat thickness are dependent on the ranges for live weight and ranges in back fat thickness in the different data sets.

Development of the body composition in relation to parity number

Only in the first parity pregnancy treatment affected protein deposition (Table 6.5). The results suggest that protein deposition on the treatments CC and CH decreases with parity number from about 4.5 to 2.1 or 0.5 kg. The sows on treatments LC and LH can compensate by additional protein deposition in the second and third reproductive cycle. For fat and energy no significant differences between treatments were observed. There was a high residual error for these components predicted from the equations, but it is clear that deposition of fat and energy tends to decrease with parity number.

The overall trends for LWc, BFT at P2, water, protein, fat and energy in Figures 6.2 and 6.3 indicate that a decrease in BFT at P2 does not mean a decrease in fat mass. The increase in LWc was mainly due to an increase of water and protein. The energy content increased mainly due to the increased protein mass. Although large variations in composition of the body are observed, water and protein content seem to increase more than fat content with increasing age of the sows. This is in line with the results from Lahrssen (1988) and Whittemore and Yang (1989).

Conclusions

The level of protein supply during pregnancy affected the amount of protein in the body of sows significantly during the first parity and the protein supply during lactation affected the amount of fat in the body significantly at the end of the third lactation. It is suggested that a low dietary protein supply in first parity sows can be compensated in subsequent parities. However, after three parities the compensation was not yet completely. The amino acid pattern of protein remained constant with increasing parity number.

The amount of water showed the same pattern as the amount of protein. One week after the third lactation the water to protein ratio seems not to be stabilized. This process seems to be related to the protein supply during pregnancy.

During three reproductive cycles the course in the amount of fat in the body of sows showed a different pattern than that in body protein. On the applied feeding regimen the deposition of fat during pregnancy is mobilized during lactation, except for the first parity. A high protein supply during lactation induced a higher fat mobilization and this results in a lower amount of fat in the body after the third lactation.

For prediction of the body composition of sows live weight and back fat thickness seem to be good predictors. However, the observed ranges in live weight and back fat thickness in the data set can affect the estimated coefficients for live weight and back fat thickness.

In the present experiment back fat thickness at P2 tended to decrease with parity number, while the amount of fat hardly changed. This indicates that a feeding regimen that aims to stabilize back fat thickness at a constant level increases the amount of fat in the body.

Reliable equations to predict body composition can be helpful to answer the question about the ideal body composition of a sow for optimal reproductive performance and longevity.

Acknowledgements

We want to thank M.W.A. Verstegen and A.W. Jongbloed for their useful comments on the manuscript. This research was partly financed by the Dutch Fund for Manure and Ammonia Research (FOMA).

Chapter 7

Nitrogen excretion by breeding sows in relation to some reproduction characteristics: predictions by a model

H. Everts

Institute for Animal Science and Health
(ID-DLO) Branch Runderweg
P.O.Box 160 8200 AD Lelystad
The Netherlands

Quantification of different measures to reduce nitrogen excretion from breeding sows

On first sight it seems attractive to express the excretion of nitrogen per sow per year. However, this way of expression is only valid when the production of the number of weaned piglets per sow per year remains constant. When a measure affects both excretion of nitrogen and level production, then expression of excretion per sow per year can easily lead to incorrect conclusions. Therefore, it is better to express the excretion per weaned piglet.
To calculate the mean nitrogen excretion per weaned piglet (NEX_p) a model was designed. In this model the total nitrogen input and output are calculated during one reproductive cycle of a herd of 100 sows, including rearing of the gilts. NEX_p is calculated as (total nitrogen excretion of the herd)/(total number of weaned piglets). The following inputs (F1..F8) for the model were used as constants:

F1. Amount of feed to rear a piglet of 8 kg to a gilt of 120 kg is 325 kg with a mean nitrogen content of 26.4 g N. kg^{-1} (Coppoolse et al., 1990). To replace one sow 1.3 animals are reared to allow a sharp selection. The reared gilts not used for replacement of sows are sold.

F2. Amount of feed during one pregnancy for a sow is 295 kg (CVB, 1988). For gilts the amount of feed is 0.25 $kg.d^{-1}$ less, resulting in 266 kg.

F3. Amount of feed consumed during the lactation period of 28 days is 150 kg for sows (Everts, 1991) and 135 kg for gilts. The amount of feed consumed during lactation is corrected for number of suckling piglets with the equation 0.4*(nwp-10)*21, where nwp is the number of weaned piglets and the use 21 days assumes that it takes a week before the maximum feed intake is realized. For gilts this correction equation is 0.4*(nwp-9)*21.

F4. Amount of feed after weaning is 3 $kg.day^{-1}$ during the first 10 days and thereafter 2.5 $kg.day^{-1}$. The total number of non-productive days is calculated as: (365/farrowing index)-115-28

F5. Litter size (alive + stillborn) is related to parity number as observed by Everts (1991). Litter size and parity number are given in Appendix 7.1.

F6. Mean weaning weight of piglets is assumed to be 8 kg. Weaned piglets contain 23.8 g $N.kg^{-1}$ according to Noblet and Etienne (1986). The amount of ingested creep feed was not taken into account.

F7. Mean live weight of stillborn piglets and of piglets that died during lactation is estimated to be 2.5 kg and these piglets contain 22.5 g $N.kg^{-1}$.

F8. Live weight of gilts at mating is 125 kg and the development of live weight in relation to parity number is given in Appendix 7.1. The culled sows contain 26.1 g $N.kg^{-1}$ (Whittemore et al., 1989). It is assumed that reared gilts not used for replacement have the same amount of nitrogen per kg.

The following inputs (V1..V5) for the model were investigated for their effect on NEX_p. Firstly, an input value is indicated which represents a common figure in the Netherlands and then the range is indicated to test the effect on NEX_p.

V1. Mortality of the piglets {(stillborn + died during suckling period)/(born alive + stillborn)}: fixed value = 0.17 (Everts, 1991); range: 0.05 - 0.20. The macerated and mummified piglets are excluded.

V2. Number of born piglets (alive + stillborn) per farrowing: fixed value = 11.8 (Everts, 1991); range: 11.0 - 14.0. These values are valid for a herd with a yearly replacement percentage of 48. When the yearly replacement percentage changes, then also litter size is changed due to the relation between parity number and litter size as indicated at point F5.

V3. Farrowing index: fixed value = 2.1 (Everts, 1991); range: 2.0 - 2.4. The farrowing index is defined as the mean number of farrowings per sow per year. A change in farrowing index also represents an effect on feed intake during a reproductive cycle by changing the number of non-productive days.

V4. Yearly replacement percentage: fixed value = 48 (Baltussen et al., 1988); range: 20 - 50. The yearly replacement percentage is the number of replaced sows by young gilts divided by the total number of productive sows in the herd multiplied by 100%. The distribution of the number of sows per parity present in a herd (Appendix 7.1) is calculated according to the culling pattern of sows as indicated by Everts (1991).

V5. Mean nitrogen content of diet fed during pregnancy and non-productive days: fixed value: 25.6 g $N.kg^{-1}$; range: 16 - 26 g $N.kg^{-1}$. Nitrogen content in the lactation diet was kept at a constant level of 25.6 g $N.kg^{-1}$.

Results and discussion

Using all fixed inputs in the model and omitting the contribution from the rearing period of the sows, the ingested amount of nitrogen and the excreted amount of nitrogen per sow per year are very close to the values of Coppoolse et al. (1990) as shown in Table 7.1. Jongbloed and Lenis (1993) also calculated a nitrogen excretion of 22.4 kg N per sow per year.

Table 7.1.
Ingested excreted nitrogen per sow per year in kg.

Source	Coppoolse et al. (1990)	Present calculations[§]
Ingested kg N	27.8	27.9
Excreted kg N	22.7	22.6

[§] Contribution from the rearing of the sow excluded

Using all fixed inputs the model indicates that per weaned piglet of 8 kg and with an age of 28 days 1627 g N is consumed by the sow. From this total amount of consumed N about 16 % was needed for rearing, 60 % for pregnancy and 24 % for lactation. Total retained nitrogen was 337 g per weaned piglet. From the total amount of retained N about 29 % was retained in reared gilts, 12 % in sows, 56 % in the weaned piglet and 3% in dead piglets.
The efficiency of utilization of ingested nitrogen to retained nitrogen was 0.207. This efficiency is somewhat higher than the value that can be calculated from the data of Coppoolse et al. (1990). The main reason for the difference is that in the present calculations the rearing of the gilts is included.
The main effects of a change in the investigated reproduction characteristics are summarized in Table 7.2. For the calculation of these effects a linear relationship is assumed. However, for some characteristics it could be shown that a non-linear relationship showed a slightly better fit.

Effect of mortality of piglets on NEX_p

A decrease of mortality of piglets causes a reduction of NEX_p (Figure 7.1). The effect of piglet mortality on NEX_p is non-linear. A mean effect of a reduction in mortality of 1 % decreased NEX_p by 13 g N per weaned piglet. The three main reasons for piglet mortality are starvation, crushing by the sow and stillbirths (Dyck and Swierstra, 1989). In most cases mortality is related to a low birth weight. Birth weights can be increased by a higher feeding level in late pregnancy (Cromwell et al., 1989). This effect seems to be more an effect of

Table 7.2.

Linear relations between some reproduction characteristics and nitrogen excretion per weaned piglet in g (NEX_p) according to the model Y = C + β_1 * X

Y		C	β		X	%acc	RSD
NEX_p	=	1067.8	+ 13.2	*	Mortality percentage (%)	99.6	5.3
NEX_p	=	1170.6	+ 2.6	*	Yearly replacement percentage (%)	94.6	7.7
NEX_p	=	2431.9	- 97.0	*	Litter size (born alive + stillborn)	99.3	10.7
NEX_p	=	2341.9	-499.6	*	Farrowing index	99.6	4.9
NEX_p	=	308.7	+ 38.3	*	Nitrogen content pregnancy diet ($g.kg^{-1}$)	100.0	0.0

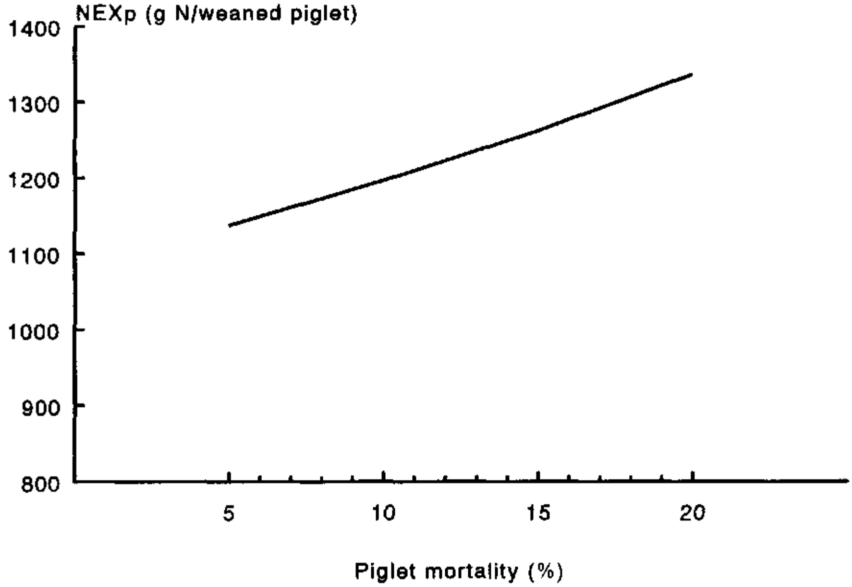

Figure 7.1

The effect of piglet mortality (%) on NEX_p (g)

energy (Henry and Etienne, 1978) than of protein (Lavorel et al., 1981). Piglet mortality can also be reduced by feeding supplemental fat (Seerley et al., 1981).

Other measures to reduce piglet mortality are related to the hygienic conditions at parturition, the micro climate for piglets, the housing system and feeding of sows during lactation.

There are indeed possibilities to reduce piglet mortality, but the observed effects are in most cases relatively small. Even when mortality can be decreased with several percentage units, the effect on NEX_p will be small.

Effect of yearly replacement percentage on NEX_p

The effect of decreasing the yearly replacement percentage in a herd is shown in Figure 7.2. There is a slight decrease in NEX_p with a decreasing yearly replacement percentage. The mean decrease in NEX_p is only 2.6 g N per percent decrease in yearly replacement percentage of the sows. This small effect is mainly due to a decrease in total nitrogen retention. This total nitrogen retention is the sum of nitrogen retention in the weaned piglet and nitrogen retention in the reared gilts and in the culled sows. With a yearly replacement percentage of 48 % 136 g nitrogen is retained in the reared gilts and culled sows per weaned piglet. When the yearly replacement percentage is decreased to 20 %, then only 65 g nitrogen is retained in the reared gilts and culled sows per weaned piglet. This decrease in nitrogen retention in reared gilts and culled sows with a decreasing yearly replacement percentage is the explanation for the small effect on NEX_p (2.6 g N per % unit).

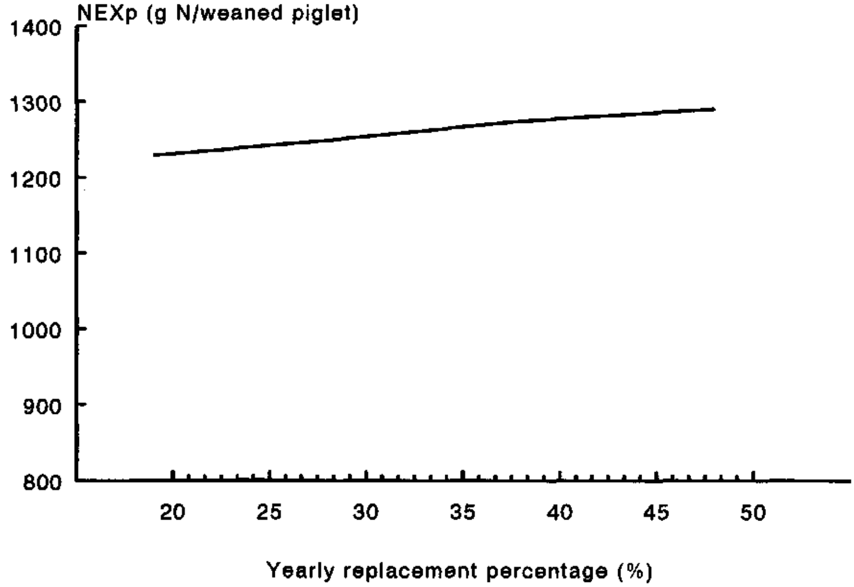

Figure 7.2
The effect of yearly replacement rate (%) on NEX_p (g)

The reasons for culling are mainly leg problems, reproduction failures and selection (Everts, 1991). A lower incidence of leg problems and reproduction failures can lower the yearly replacement percentage considerably and increase longevity of sows. However, the replacement policy in a herd is also determined by the preferred selection level in the herd and by economic considerations. In a herd with low priority for selection, it is on the basis of the cumulative cost price per piglet attractive to let sows produce at least 7 litters (Kroes and van Male, 1979). This is equivalent to a yearly replacement percentage of 30 to 35 %.

Effect of litter size on NEX_p

The effect of increasing the litter size from 11 to 14 piglets (born alive + stillborn) per litter is shown in Figure 7.3. This effect is non-linear: the decrease in NEX_p is 113 g when litter size increased from 11 to 12 and the decrease in NEX_p is 83 g when litter size increased from 13 to 14 piglets. This value is in line with the results of Jongbloed and Lenis (1993), who observed a decrease in

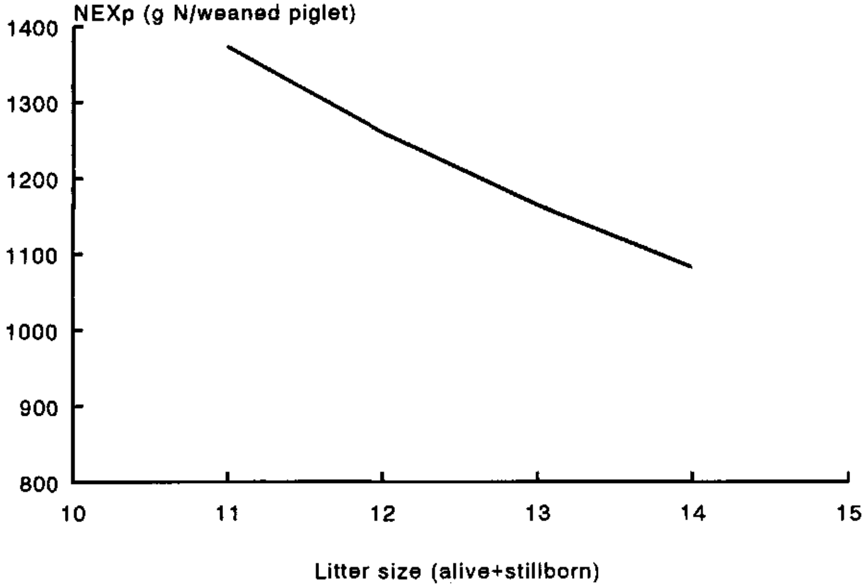

Figure 7.3
The effect of litter size on NEX_p (g)

NEXp of 78 g N per extra weaned piglet. In the range of 11 to 14 piglets the mean decrease in NEX_p was 97 g per extra weaned piglet.

Litter size can be increased by genetic selection, however the progress will be slow. Another way to increase litter size is the reduction of embryonic mortality. A low feeding level (1.2 times maintenance) in the first weeks of pregnancy can reduce embryonic mortality in gilts (Dyck and Strain, 1983). However, for sows hardly any significant evidence is presented.

Progress in litter size can be expected on the long term by genetic improvement and on the short term probably by adapting the feeding level in early pregnancy (at least in gilts).

Reduction of NEX_p by increasing litter size is effective, but a fast increase in litter size is not expected.

Effect of farrowing index on NEX_p

The effect of an increase in farrowing index is presented in figure 7.4. This effect was non-linear: an increase in farrowing index from 2 to 2.1 reduced

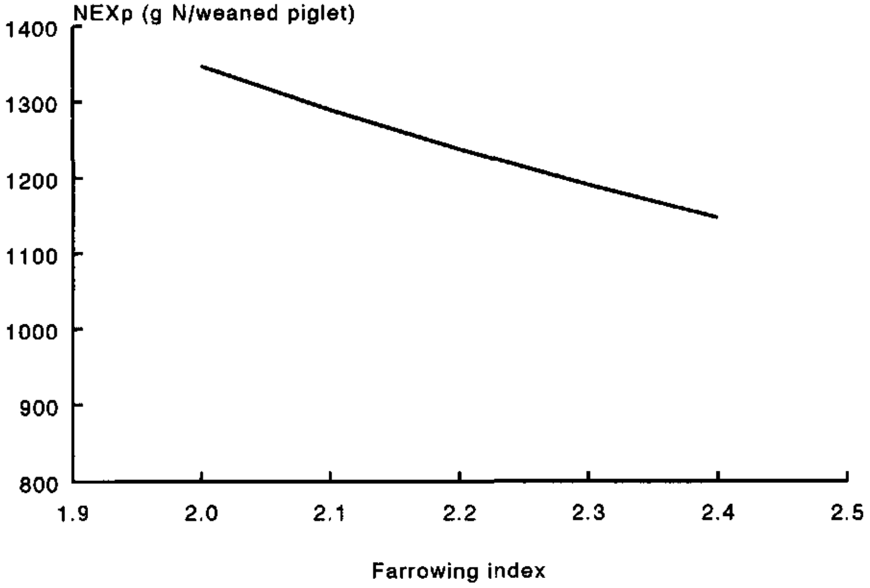

Figure 7.4
The effect of farrowing index on NEX_p (g)

NEX_p with 57 g and an increase of the farrowing index from 2.3 to 2.4 decreased NEX_p with 43 g. In the range of 2.0 to 2.4 the mean effect of an increase of the farrowing index with 0.1 represents a decrease of 50 g in NEX_p.
A further increase of the farrowing index above 2.4 requires shortening of the lactation period. The length of the interval between farrowings is equal to the sum of the length of the pregnancy period, the lactation period and the time between weaning and next pregnancy. Te Brake (1978) indicated that a lactation length between 21 and 25 days has the highest economic profit. Also Varley (1982) concluded that a decrease of lactation length to a 21 day period can increase the annual sow productivity. To decrease the interval between weaning and next pregnancy the problem of the post-weaning anoestrus must be solved. Fahmy et al. (1979) concluded that improvements in the weaning to oestrus interval of sows can be reached by improving the management. Foxcroft (1992) suggested that manipulation of the suckling intensity is more effective than manipulation of nutrient intake. A farrowing index of 2.58 can be reached with a pregnancy length of 115 days, a lactation length of 21 days and an interval of 5 days between weaning and next pregnancy. Non-productive days due to culling of sows are not included in the calculation of this highest possible farrowing index.

Effect of nitrogen content in the diet on NEX_p

The effect of a reduction of the nitrogen content of the pregnancy diet in Figure 7.5 indicates that NEX_p decreases with 38 per g $N.kg^{-1}$ less in the diet. The effect was linear in the range from 16 to 26 g $N.kg^{-1}$. Compared with the other measures, this seems a powerful and effective method to decrease NEX_p. With this method it is possible to excrete less than 1000 g N per weaned piglet. A similar effect of lowering the nitrogen content in the diet was calculated by Jongbloed and Lenis (1993).
Efficiency of utilization of ingested protein to retained protein was increased from 0.2 to 0.27 when nitrogen content of the pregnancy diet decreased from 26 to 16 $g.kg^{-1}$. However, the main assumption for this measure is that the production level of the sow does not change and that the body composition of sows and of weaned piglets remain the same.
A further decrease in NEX_p it is possible by a further lowering of the nitrogen content of the pregnancy diet. Also the nitrogen level of diet used during the rearing period and the lactation period can be decreased. However, the (further) decrease in nitrogen content of the diets has its limits. The level of essential amino acids supply should at least be equal to the requirements. Realization of a sufficient amino acid supply in combination with a low nitrogen content in the diet can be achieved by the use of synthetic amino acids in the diets for rearing, pregnancy and lactation (Lenis, 1989). The use of synthetic amino acids is only

attractive when the price is reasonable and the production process of synthetic amino acids does not consume much energy nor causes pollution.

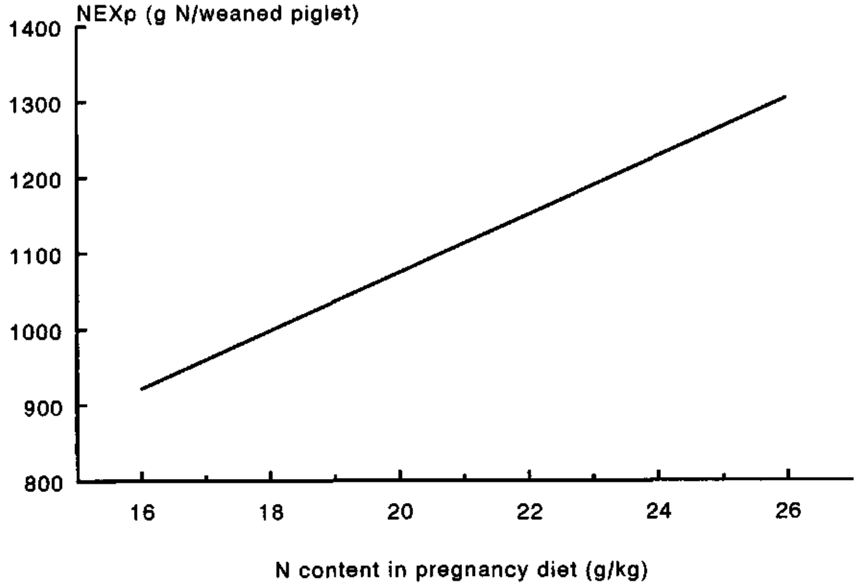

Figure 7.5
Effect of nitrogen content in the diet during pregnancy (g N.kg^{-1}) on NEX$_p$ (g)

Conclusions

In the calculations presented, only the effects of different reproduction characteristics on the nitrogen excretion were investigated. NEX$_p$ is only moderately affected by farrowing index and yearly replacement percentage. The effects of reduction of piglet mortality and the increase of litter size can influence NEX$_p$. However, a fast improvement in these characteristics is not expected. Even when the positive effects of all these characteristics on NEX$_p$ are combined, then their effect is smaller than the effect of decreasing the nitrogen content of the pregnancy diet. A combination of a replacement percentage of 32 %, a piglet mortality of 10 %, an index of 2.3 and increase of litter size with 0.5 piglet has an equivalent effect on NEX$_p$ as the reduction of the nitrogen level in the pregnancy diet to 19 g N.kg^{-1}. The reduction of the nitrogen level in the pregnancy diet is the most promising and easiest measure to reduce NEX$_p$ on the short term. Measures to increase litter size and to decrease piglet mortality can also play an important role to reduce NEX_p.

The highest reduction can be realized, when the reduction of the nitrogen level during pregnancy is decreased in combination with optimal values for the investigated characteristics as shown in Table 7.3.

The NEX_p can then be reduced to about 700 g per weaned piglet and the efficiency of ingested protein to retained protein is increased to 0.295. This efficiency remains low compared with growing pigs. The main reason for this discrepancy is the low feeding level of sows during pregnancy in combination with a moderate protein retention. Even in an ideal situation the excretion per weaned piglet remains considerably high. However, for production of pork weaned piglets are indispensable.

Table 7.3

The effect of the combination of improvement of the reproduction characteristics and nitrogen content of pregnancy diet on nitrogen excretion per weaned piglet in g (NEX_p) and on nitrogen efficiency (N-eff = N retained/ N ingested).

Farrowing index	Replacement percentage	Litter size	Piglet mortality (%)	N content pregnancy diet ($g.kg^{-1}$)	NEX_p	N-eff
2.2	48	11	17	26	1333	0.206
2.3	48	11	17	26	1282	0.213
2.3	**38**	11	17	26	1252	0.206
2.3	**38**	**13**	17	26	1062	0.223
2.3	**38**	**13**	**10**	26	986	0.229
2.3	**38**	**13**	**10**	**16**	698	0.295

References

Baltussen, W.H.M., Altena, H., Bakker, C.M., and van Rijnberk, D., 1988. [Farms with pigs] CADV/LEI, Rosmalen

Coppoolse, J., van Vuuren, A.M., Huisman, J.,Janssen, W.M.M.A., Jongbloed, A.W., Lenis, N.P., Simons, P.C.M., 1990. [Excretion of nitrogen, phosphorus and potassium by livestock, now and tomorrow] DLO, Wageningen, 131 pp

Cromwell, G.L., Hall, D.D., Clawson, A.J., Combs, G.E., Knabe, D.A., Maxwell, C.V., Noland, P.R., Orr Jr, D.E., Prince, T.J., 1989. Effects of additional feed during late gestation on reproductive performance of sows: a cooperative study. *Journal of Animal Science* 67: 3-14

CVB, 1988. [Nutrient requirements of livestock and feeding value of feedstuffs] Verkorte Tabel voedernormen landbouwhuisdieren en voederwaarde veevoeders. Centraal Veevoederbureau in Nederland, Lelystad

Dyck, G.W. and Strain, J.H., 1983. Post mating feeding level effects on conception rate and embryonic survival in gilts. *Canadian Journal of Animal Science* 63: 579-585

Dyck, G.W. and Swierstra, E.E., 1989. Causes of piglet death from birth to weaning. *Canadian Journal of Animal Science* 67: 543-547

Everts, H., 1991. The effect of feeding different sources of crude fibre during pregnancy on the reproductive performance. *Animal Production* 52: 175-184

Fahmy, M.H., Holtmann, W.B. and Baker, R.D., 1979. Failure to recycle after weaning, and weaning to oestrus interval in crossbred sows. *Animal Production* 29: 193-202

Foxcroft, G.R., 1992. Nutritional and lactational regulation of fertility in sows. *Journal of Reproduction and Fertility* (Suppl). 45: 113-125

Henry, Y. and Etienne, M., 1978. Alimentation énergétique du pork. *Journée Recherche Porcine en France* 10: 119-166

Jongloed, A.W. and Lenis, N.P., 1993. Excretion of nitrogen and some minerals by livestock. In: Nitrogen flow in pig production and environmental consequences (Ed. Verstegen, M.W.A., den Hartog, L.A., van Kempen, G.J.M. and Metz, J.H.M.) *EAAP Publication* 69: 22-36

Kroes, Y. and van Male, J.P., 1979. Reproductive lifetime of sows in relation to economy of production. *Livestock Production Science* 6: 179-183

Lavorel, O., Fekete, J., Bouard, J.P., Leuillet, M., 1981. Influence du niveau azoté de gestation sur les performances a long terme des truies et des porcelets en élevage intensif. *Journée Recherche Porcine en France* 13: 109-124

Lenis, N.P., 1989. Lowering nitrogen excretion in pig husbandry by feeding: current and future possibilities. *Netherlands Journal of Agricultural Science* 37: 61-70

Noblet, J. and Etienne, M., 1986. Effect of energy level in lactating sows on yield and composition of milk and nutrient balance of piglets. *Journal of Animal Science* 63: 1888-1896

Seerley, R.W., Snyder, R.A. and McCampbell, H.C., 1981. The influence of sow dietary lipids and choline on piglet survival, milk and carcass composition. *Journal of Animal Science* 52: 542-550

Scholman, G.J. and Dijkhuizen, A.A., 1989. Determination and analysis of the economic optimum culling strategy in swine breeding herds in Western Europe and the USA. *Netherlands Journal of Agricultural Science* 37: 71-74

Te Brake, J.H.A., 1978. An assessment of the most profitable length of lactation for producing piglets of 20 kg body weight. *Livestock Production Science* 5: 81-94

Varley, M.A., 1982. The time of weaning and its effects on reproductive function. In: Control of pig reproduction (Editors Dole, D.J.A. and Foxcroft, G.R.) Butterworth Scientific, London.

Whittemore, C.T. and Yang, H., 1989. Physical and chemical composition of the body of breeding sows with differing body subcutaneous fat depth at parturition, differing nutrition during lactation and differing litter size. *Animal Production* 48: 203-212

Appendix 7.1.

Litter size (alive + stillborn), live weight of sows and number of sows present in the herd in relation to parity number.

Parity number	Litter size (total)	Live weight (kg)	Number sows in herd of 100 sows yearly replacement percentage[‡]		
			48	38	28
1	10.3	125	22.8	18.2	13.6
2	11.5	155	17.1	14.5	11.6
3	12.2	175	13.7	11.8	9.9
4	12.7	195	11.4	10.0	8.9
5	12.5	205	9.3	8.7	8.3
6	12.5	225	8.4	8.2	7.8
7	12.2	245	7.3	7.7	7.5
8	12.0	265	5.2	6.8	7.2
>8	11.8	285	4.8	14.1	25.2

[‡] Yearly replacement on a basis of 2.1 litter per sow per year

Chapter 8

General discussion

Introduction

In the various approaches to obtain a more sustainable pig production, more attention has to be paid to optimalization of pig production rather than to maximalization, which has been practised sofar. Sustainability can be described in many ways and uniform criteria are difficult to formulate (de Wit et al., 1994). Jongbloed and Lenis (1992) discussed several aspects of animal production in relation to environmental pollution. One of the aspects of sustainable pig production is an optimal utilization of ingested nutrients into the desired products during a long period. For sows this means an efficient utilization of ingested nitrogen into weaned piglets and the sow's body. In addition the sow should produce a high number of weaned piglets during her life. Indirectly, this includes minimalization of excretion of nitrogen from breeding sows. However, it must be realized that also other aspects are needed for the concept of sustainability such as the well being of animals and economic profit for farmers.

Instead of maximalization of pig production we should focus on optimalization of pig production with respect to the ratio between input and output. One of the important aspects in pig nutrition is the utilization of ingested nutrients. With respect to possible environmental pollution in relation to animal production the utilization of nitrogen needs to be increased. For sows the amount of excreted nitrogen per weaned piglet is a good parameter to judge the utilization of dietary nitrogen. From the tested measures in the model calculation in Chapter 7 it was concluded that reduction of the nitrogen content of the diet during pregnancy is an effective and easy way to reduce nitrogen excretion per weaned piglet.

To calculate the efficiency of utilization of ingested nitrogen into retained nitrogen it is necessary to characterize a diet in terms of nitrogen content. Of course, the nutritional (protein) value of a diet can be much better expressed in terms of digestible protein, amino acid composition and ileal digestible amino acids.

In the present investigations the effect of lowering the nitrogen supply to pregnant sows was studied in a long term experiment (5 years). In relation to possibility for lowering the nitrogen supply during pregnancy a number of aspects, which can be studied, were introduced in Chapter 1. In the next part of the general discussion various aspects of nitrogen nutrition will be discussed. At the end of this chapter a new feeding strategy for pregnant and lactating sows is presented. This feeding strategy is combined with a proposal for recommended allowances for energy, nitrogen and ileal digestible lysine.

Effect of nitrogen supply during pregnancy on products of conception and maternal body composition.

In the calculations from Chapter 7 it has been assumed that both the amount of retained nitrogen in the products of conception and the sow's body composition are unaffected by the level nitrogen supply. However, these two assumptions are questionable. In Chapter 5 the effect of nitrogen supply during the first pregnancy on the composition of the products of conception was investigated using the comparative slaughter technique. No differences in amounts of nitrogen in reproductive tissues (uterus, fluids, placentas and piglets) were observed on day 108 of pregnancy as result of considerable difference in dietary nitrogen input (in late pregnancy 50 g N.d^{-1} compared with 74 g N.d^{-1}). Also, the amount of nitrogen deposited in the piglets was similar at the two levels of nitrogen supply. This indicates that 50 g N.d^{-1} in late pregnancy was sufficient for normal development of the products of conception. This amount of nitrogen should contain 11 g of ileal digestible lysine and the other amino acids can be proportional to lysine as indicated by Whittemore and Morgan (1990). According to the balance trials in late pregnancy sows at the low level of nitrogen supply had a positive nitrogen balance of 18 g N.d^{-1} (Chapter 3). Noblet et al. (1985) estimated that about 14 g N.d^{-1} is deposited in the gravid uterus (about 12 piglets) and mammary tissue during this phase of pregnancy (day 105 - day 112). Thus about 4 g N.d^{-1} could be considered as retained in the maternal body.

From experiments with extreme low levels of nitrogen supply (<7 g N.d^{-1}) it is clear that the development of the products of conception has a high priority (Pond, 1973; Atinmo et al., 1974; Hammel et al., 1976; Leuillet et al., 1979; Pond et al., 1991). However, in their experiments birth weight of piglets from sows with such an extreme low nitrogen supply decreased to about 0.75 of the piglets from sows on the control treatment. Duée (1976) indicated that a dietary N supply of about 30 g.d^{-1} is sufficient for normal foetal development. Vanschoubroek and Van Spaendonck (1973) indicated that a dietary supply of 46 g N.d^{-1} is needed for sows in late pregnancy, which also allows some maternal growth. Speer (1990) calculated that 35 g N.d^{-1} is needed during the whole pregnancy for a first litter sow. This level of N supply was based on a moderate maternal growth in addition to the development of the products of conception at a feeding level of 1.8 kg feed.d^{-1} during the whole pregnancy period.

From the results of our balance trials and the comparative slaughter experiments of first parity sows it became clear that the development of the maternal protein mass was reduced, when the mean nitrogen supply during pregnancy was decreased from 67 g N.d^{-1} to 45 g N.d^{-1}. From the balance trials it was concluded that the depression in maternal protein gain occurred mainly in late pregnancy. The comparative slaughter measurements showed that the maternal protein deposition on the low nitrogen treatment was 0.71 of the control treatment, while the nitrogen supply on the low nitrogen treatment was 0.67 of the control treatment.

From our experiments it can be concluded that the assumption that the nitrogen retention in the products of conception is not affected by lowering the nitrogen supply to the sow to a level of 45 g $N.d^{-1}$ is valid. The body composition of sows at the end of the first pregnancy, however, is affected and therefore the assumption of no effect of nitrogen supply on maternal retention is not valid.

Dietary nitrogen supply is closely linked to amino acid supply. The proportion of amino acids related to lysine in the diets C and H were equal or higher than suggested by Whittemore and Morgan (1990) and Pettigrew (1993) (Table 8.1). Pettigrew (1993) indicated that the proportion of some essential amino acids in relation to lysine depended on the live weight of the sow and the lean tissue growth during pregnancy.

Table 8.1.

The proportion of some essential amino acids in relation to lysine as proposed by Whittemore and Morgan (1990) and Pettigrew (1993) and in our diets (values are expressed as total amino acid)

	Whittemore and Morgan (1990)	Pettigrew(1993)	Diet C	Diet L	Diet H
Lysine	100	100	100	100	100
Threonine	64	62-66	76	74	77
Isoleucine	57	47-49	84	73	84
Methionine + cystine	57	56-71	71	76	77
Tryptophan	20	13-16	22#	20#	22#

calculated values

In the Netherlands feed evaluation of essential amino acids is based on ileal digestible amino acids (CVB, 1991). The tabulated values are derived from experiments with growing pig. It is assumed that the ileal digestibility of amino acids are similar for growing pigs and for sows. Therefore the results of the comparative slaughter experiment were used to study the efficiency of utilization of ileal digestible amino acids into retained amino acids.

When maintenance requirements of ileal digestible amino acids are assumed according to Pettigrew (1993) of 39 $mg.W^{-0.75}$ for lysine, 49 $mg.W^{-0.75}$ for cystine + methionine and 41 $mg.W^{-0.75}$ for threonine, we could calculate from our comparative slaughter experiment the utilization of supplied ileal digestible amino acids, above maintenance requirement, into deposition in products of conception and maternal body. This was on the low level of protein supply for lysine 0.59, for cystine + methionine 0.47 and for threonine 0.67. Values for tryptophan were not measured and values for isoleucine could not be calculated due to lack of tabulated ileal digestibility coefficients in the Dutch feedstuff table (CVB, 1991). The values for efficiency on the higher nitrogen supply level were significantly lower (lysine 0.46, cystine + methionine 0.34 and threonine 0.44) than on the low nitrogen supply level. This indicates that the dietary supply of amino acids on the high nitrogen supply treatment was substantially above the required amounts. Pettigrew (1993) used an efficiency for the utilization of dietary threonine, above maintenance requirement, into retained threonine of 0.45. He applied this figure for all other amino acids. If a mean ileal digestibility of amino acids of 0.8 is assumed, then the efficiency of utilization of ileal digestible amino acids into retained amino acids should be equal to 0.45/0.8 = 0.56. The present estimates for the utilization of ileal digestible lysine and threonine are somewhat higher on the low level of protein supply. For an optimal use of essential amino acids the calculation of the requirements for ileal digestible amino acids should be based on a high efficiency of the utilization of ingested ileal digestible amino acids, above maintenance requirement, into retained amino acids. Therefore, it is suggested to use for sows the same efficiency as for growing pig (0.7, TMV, 1991).

Nitrogen supply during lactation in relation to the nitrogen supply during pregnancy.

When the low nitrogen level in the diet was supplied during pregnancy, a lower nitrogen deposition in the maternal body during pregnancy was observed. Thus, the protein mass in the body of these sows is lower at farrowing compared with the control sows. Sows with a high performance level during lactation are using protein from their body stores. If sows have to compensate for the reduced protein growth during pregnancy, then it seems attractive to supply these sows with more protein during lactation to prevent that these sows are even more retarded in their protein growth. In our experiment the effect of additional dietary protein/ lysine during lactation is seen most clearly in the first lactation; mobilization of nitrogen was lower compared with the control treatment (-13.3 vs -4.1 g $N.d^{-1}$). This effect was also observed in second and third parity sows, however to a much smaller extent.

The nitrogen supply during pregnancy significantly affected the nitrogen balance of the lactating sows in the third lactation only. The observed values suggest that sows with a low level of nitrogen supply during pregnancy tend to mobilize less protein during lactation. On the basis of the results of the balance trials performed during lactation (Chapter 4) it seems possible to reduce nitrogen mobilization during lactation by feeding extra nitrogen during this lactation period without affecting the growth rate of the piglets. From a regression analysis between lysine intake, nitrogen balance of the sow and the nitrogen retention in the litter the ileal digestible lysine requirement for lactating sows was estimated to be 37 to 43 $g.d^{-1}$, depending on the parity number and litter size. The present estimates are close to the estimates of Etienne et al. (1989) based on the maintenance of muscle mass and Wilkinson et al. (1982) on the basis of blood parameters.

Effects of nitrogen supply on energy metabolism during pregnancy and lactation

From the balance trials and the comparative slaughter trials during pregnancy it was concluded that a reduced protein gain was associated with a higher fat gain during pregnancy when the same amount of ME was supplied. In the parities 2 and 3 this effect was not found. The ME for production in these parities decreased due to a higher proportion of total ME needed for maintenance. The differences in nitrogen retention between the low and normal nitrogen supply were smaller in the parities 2 and 3 than in parity 1. When a maintenance requirement for metabolizable energy (ME) of 393 kJ $ME.W^{-0.75}$ (Everts and Dekker, 1991) and k_p of 0.6 and k_f of 0.8 (Noblet and Etienne, 1987) are assumed, then the present data (ME intake related to observed nitrogen and energy balance) fit to these estimates. The maintenance requirement was derived from the same animals and was relatively low. It should be noted, however, that in our experiment the sows were kept at an ambient temperature of 20° C and they were very well adapted to the respiration chambers and were very quiet. This may be the reason for a low maintenance requirement estimate.

It was observed that sows with the low nitrogen supply during pregnancy tended to produce fatter piglets at weaning. The sows on this treatment were also fatter at the end of first pregnancy. Therefore, the composition of the mobilized tissues in the sow seems to be related to the body composition of the sow. However, the evidence for this relation is not always clear.

The development of body composition of sows during the three successive parities indicates that sows became leaner with increasing parity number (increasing protein mass and a more or less constant amount of fat; Chapter 6). During lactation sows are increasing the ratio between energy mobilized as protein to total energy mobilized ($RE_{P\text{-}SOW}/RE_{SOW}$) with increasing parity number (Chapter 4). This indicates that multiparous sows mobilize proportionally more protein than primiparous sows. This supports the hypothesis that the body composition of the sow is related to the composition of mobilized tissues in the sow during the lactation period.

When more lysine was supplied during lactation, then an increased fat mobilization was observed during lactation (Chapter 4). Such an effect was also observed by Pettigrew et al. (1991) by supplying more lysine to lactating sows.

The higher fat mobilization in the sows was not accompanied by fatter piglets at weaning. Thus the extra amount of mobilized fat is probably used for metabolic processes in the sow. This can be explained by assuming that the conversion of mobilized protein into milk protein is a more efficient process than the conversion of dietary protein into milk protein.

It is concluded that the nitrogen supply during pregnancy has an impact on energy metabolism especially in first litter sows and that the mobilization of body stores during lactation is related to the body composition of the sows and to the nitrogen (lysine) supply during lactation.

The development of body composition of sows during 3 parities

When sows are fed a nitrogen-deficient diet during successive parities their protein body mass can be depleted. However, in our investigations the applied levels were high enough to guarantee a considerable increase in protein body mass. Sows at first mating had 19.2 kg protein in the body, at the end of first pregnancy this was 25.1 kg on the low protein diet and 27.9 kg on the high protein diet during pregnancy. After the third lactation body protein mass was increased to a mean level of 29 kg. The way to reach this amount of protein in the body differed between the dietary treatments. The scale of the experiment did not allow serial slaughtering after each pregnancy and each lactation. Therefore, we estimated the body composition of the sows at different stages of their reproductive life by using prediction equations based on live weight and back fat thickness (Chapter 6). Taking into account the low accuracy of these figures, it is clear that within the scope of the present studies sows can reach the same amount of protein in their body on the long term independent of the protein supply during pregnancy. The development to this amount of body protein, however, is affected by the protein supply during pregnancy. Both the comparative slaughter method and the balance trials indicated that sows tend to shift their protein gain to a later parity, when protein supply is limited during first pregnancy.

The maximum amount of protein in the body was estimated for the sows on the different treatments by fitting a curve with the calculated amounts of protein in the body of the sows as a dependent variable and the age of the sows as an independent variable. For this calculation mean values of the body composition were used. Firstly, we assumed that 0.17 kg of protein is present in the piglet with a birth weight of 1.5 kg (Chapter 2). As a next step we used the predicted body composition at mating and at the end of first, second and third pregnancy (Chapter 6). These data were fitted according to the model:

$$\text{Body protein (kg)} = A + B \times e^{(-k * age)} \qquad (1)$$

In this model A gives the estimated maximum value for body protein (age = ∞). The sum of A + B gives the estimated value for body protein at an age of 0 days. The age is expressed in days after birth. The results are presented in Table 8.2 and Figure 8.1 and they indicate a maximum amount of 40 kg body protein on treatment CC. On the treatments with a low nitrogen supply during pregnancy the maximum amount of protein in the body was calculated to be about 36 kg. A high protein supply during lactation increased the maximum protein amount from 39.6 to 41.9 kg on treatment CH and from 35.3 to 36.6 kg on treatment LH. The level of 42 kg is comparable to the protein mass in 4th parity sows as observed by Whittemore and Yang (1989).

When also the amounts of protein at the end of the first, second and third lactation are included in the calculations, then the estimated amounts of protein in adults sows are at a lower level on all treatments (Table 8.2 and Figure 8.2). A mean value of about 35 kg body protein was found. The differences in the estimated amounts of body protein between the dietary treatments were smaller and not significant when the estimates of protein mass at the end of lactation were included.

Based on these observations the following concept was developed. A breeding sow has a biological need to have a protein body store of at least 35 kg in her body and she is trying to realize this according to a certain pattern. This can be hampered by a limited protein supply during pregnancy and/or a high mobilization of protein during lactation. Compensation can be realized by

Table 8.2

Equations to predict the maximum and mean protein mass in sows according to the model: body protein (kg) = A + B*exp$^{(-k*age)}$ where age is expressed in days.

treatment	A	B	k	%acc
Maximum amount of body protein (only protein mass at the end of pregnancy):				
CC	39.6 ± 1.7	-39.6	0.00306	99.9
LC	35.3 ± 0.5	-35.2	0.00397	100.0
CH	41.9 ± 1.3	-41.8	0.00246	100.0
LH	36.6 ± 2.3	-36.6	0.00322	99.7
Mean amount of body protein (protein mass at the end of pregnancy and of lactation):				
CC	36.1 ± 4.5	-36.1	0.00319	94.7
LC	34.8 ± 3.4	-34.8	0.00396	96.1
CH	35.2 ± 5.2	-35.1	0.00305	93.4
LH	33.0 ± 3.2	-32.9	0.00358	95.6

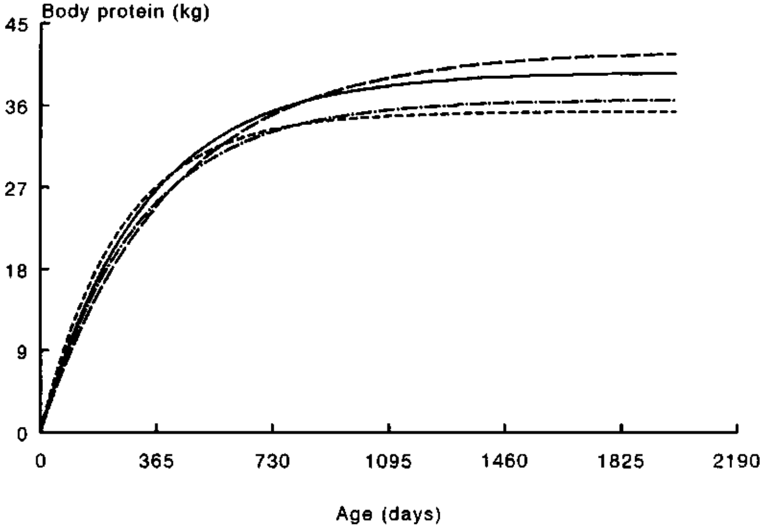

Figure 8.1

Prediction of the protein mass in the body of sows based on the equations of Table 8.2 using only the protein mass at the end of pregnancy. Treatments: CC = —— ; LC = · · ·; CH = — — ; LH = — · —

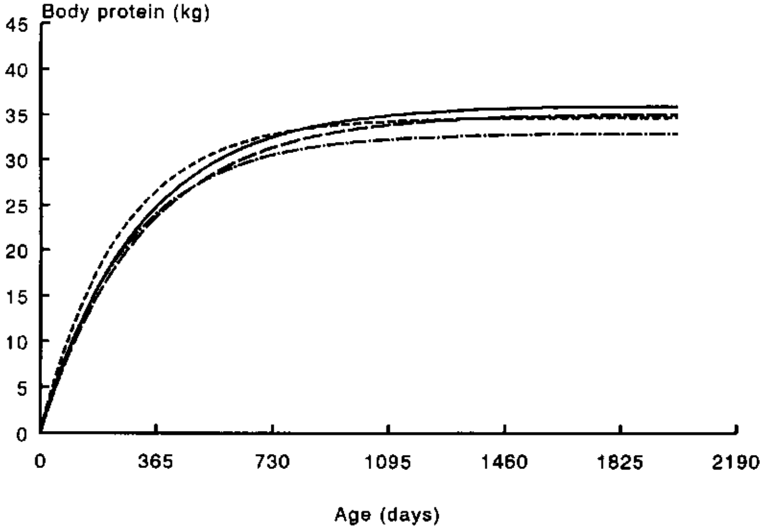

Figure 8.2

Prediction of the protein mass in the body of sows based on the equations of Table 8.2 using the mean protein mass at the end of pregnancy and at the end of lactation. Treatments: CC = —— ; LC = · · ·; CH = — — ; LH = — · —

increasing the protein gain during pregnancy, by increasing the efficiency of protein gain or by decreasing the mobilization during lactation. When only small litters are reared in combination with a high feeding level during lactation the protein mass of sows will increase towards a high level (Whittemore and Yang, 1989) and will halt when the adult size is reached. However, the adult size of the protein mass in the sow is not known. Also data about possible differences between different breeds are unknown.

For fat the situation seems to be totally different. Body fat can be seen as a store for energy when energy intake exceeds the need for maintenance and growth of products of conception, milk production or protein gain. It can be depleted in all situations of energy shortage. The body fat store can be depleted to a large extent, as was shown in our experiment where some sows had a very low percentage of fat in the body after three reproductive cycles (11 % of the empty body).

A small amount of fat together with a high amount of protein in the body can have a negative effect on reproduction (Everts and Šebek, 1992). However, evidence for a relationship between body stores and reproduction performance from literature is not very convincing. In humans it is well known that in young girls a certain amount of fat in relation to protein or lean mass is needed to start reproductive activity and that menstrual cycling can be stopped by extreme development of muscle mass (body building) (Frisch, 1988). The same may be valid for young sows. However, in sows with a higher parity number a large variation in the lean to fat ratio can be observed (<3 to >5; Whittemore and Yang, 1989). The effect of differences in the lean to fat ratio on reproductive performance of these sows is unknown. Therefore, studies are needed to know the development of the body composition of sows in relation to reproductive performance.

The prediction of body composition from live weight and back fat thickness seems an easy way to prevent large scale serial slaughtering of sows. However, these equations seem to have their limitations, because the derived coefficients could not be validated by other independent data sets. Prediction errors can be related to differences between breeds (Rozeboom et al., 1994) or to differences in the method of measuring back fat thickness.

Effect of nitrogen supply during pregnancy and lactation on the performance and longevity of sows.

The number of data in the present investigations are too small to derive evidence for an effect of protein restriction during pregnancy on performance and longevity. In a large scale experiment on the Experimental Farm for Pig Production at Sterksel, where more or less similar dietary protein levels during pregnancy were tested, no statistical evidence was observed for a reduced technical performance and longevity of the sows which were given a lower protein supply during pregnancy (Everts et al., 1991a). Interpretation of these data, however, is difficult because the effect of dietary protein supply was confounded with other imposed experimental factors (weaning age and water supply).

On the Experimental Farm for Pig Production at Raalte in a large scale experiment the effect of a higher protein/lysine supply during lactation was tested (Everts et al., 1991b). In this trial all sows received a commercial diet during pregnancy with 24.5 g $N.kg^{-1}$. The technical results between the diets hardly differed. Only the percentage of culled sows after the first parity was significantly higher on the treatment with a high lysine supply. The difference in culling percentage was mainly due to higher incidence of reproductive failures.

From these two large scale experiments no clear effect of dietary treatment on reproductive performance was observed. In young sows, however, a high lysine supply during lactation in combination with a high nitrogen supply during pregnancy seems to have a negative effect on their reproductive performance.

The most important question remains: what is an ideal body composition of the sow to guarantee a high production level during a long (re)productive life time?

Effect of protein supply on nitrogen excretion

From the balance trials during pregnancy and lactation data on total N excretion were derived by assuming that the period during mid pregnancy (the balance period) is representative for the pregnancy period between day 0 and day 85. Moreover, we assumed that the data from the balance trials in late pregnancy are valid for the last month of pregnancy. When a farrowing frequency of 2.25 is assumed, then nitrogen excretion can be calculated in kg $N.sow^{-1}.year^{-1}$. These values are presented in Table 8.3 for the different treatments.

In addition nitrogen excretion during three parities was calculated from the results of the comparative slaughtering experiment. In this calculation a small correction was applied for stillborn piglets. Subsequently, the mean nitrogen excretion per reproductive cycle was calculated and by using the same farrowing frequency of 2.25 the nitrogen excretion per sow per year was derived (Table 8.3).

Nitrogen excretion based on the balance trials was lower than on the basis of comparative slaughtering. This can be due to overestimation of the nitrogen retention in balance trials (Just et al., 1978). In our experiments, however, precautions were taken to minimize the losses by analysing ammonia in the outgoing air and in condensation water of the heat exchangers. The main reason for the discrepancy is probably that the measured balances during pregnancy are not completely representative for the whole pregnancy period. Nevertheless,

Table 8.3

Nitrogen excretion per sow per year in kg N calculated from balance trials and from comparative slaughtering

Method: Treatment	Balance trials	Comparative slaughtering
CC	20.3	22.2
CH	20.7	23.4
LC	14.5	16.0
LH	15.2	17.3

within both methods a similar reduction in N excretion was observed between the treatments. Lowering the nitrogen supply during pregnancy itself reduced N excretion by about 28 %. When more protein was fed during lactation in combination with a low nitrogen supply during pregnancy then the reduction in N excretion was about 24 %.

From the studies reported in Chapter 7 it was concluded that the nitrogen excretion should be expressed per weaned piglet. In the present experiment the mean number of weaned piglets was 10.3. With the assumed farrowing frequency of 2.25 this is 23.2 weaned piglets per sow per year. The reduction in nitrogen excretion per piglet was 6.0/23.2 = 0.259 kg N. A difference in nitrogen content between the two treatments was 8 g N per kg fresh diet. Thus a decrease of 1 g $N.kg^{-1}$ in the diet is equivalent to 259/8 = 32 g N excreted per weaned piglet. This value is somewhat lower than the value of 38 g N as calculated in Chapter 7. For the calculations with the model in Chapter 7 it was assumed that a decrease in nitrogen supply during pregnancy did not affect the N retention in sow. The balance trials during pregnancy and comparative slaughter experiment, however, showed a reduced maternal nitrogen retention during pregnancy on the treatment with a low nitrogen supply. Therefore, the observed effect of the nitrogen content of the pregnancy diet on nitrogen excretion is somewhat smaller than the effect calculated with the model in Chapter 7.

The overall efficiency of nitrogen utilization increased from 0.20 to 0.25 by decreasing the mean nitrogen supply during pregnancy by 33 %. However, the overall efficiency of nitrogen utilization remains low on both treatments. This is mainly related to a relatively low feeding level during the pregnancy period as compared with lactating sows. During pregnancy most of the feed is used for maintenance of the sow. In balance trials with lactating sows an efficiency of the utilization of ingested nitrogen was 0.4. Thus the impact of the maintenance requirement on the efficiency of utilization of ingested nitrogen is much stronger in pregnant sows than in lactating sows.

Implications for the feeding strategy of sows

From the results presented so far two completely different feeding strategies can be proposed:

The first strategy is based on the fact that sows have a biological drive to reach a certain protein mass in their body. To fulfil this drive sows must be fed during the first three parities with a protein-rich diet during pregnancy and lactation. A high protein supply during pregnancy guarantees the maximal maternal protein deposition. In addition a high protein supply during lactation minimizes the mobilization of protein. By variation in the supply of dietary energy the amount of body fat can be regulated. During pregnancy this is easier to realize than during lactation because of the limited feed intake capacity during lactation in young sows. The fast development of the protein mass in the sows also requires a large amount of fat. This is especially important when we consider that the young sows need a similar lean to fat ratio (< 3) as observed in humans (Frisch, 1988). After the third parity sows can be fed according to their requirements for maintenance and during pregnancy for the development of products of conception and during lactation for milk production only, thus without mobilization of body stores. Such a feeding strategy results in sows with a high body weight. A high live weight means a high maintenance requirement for energy and protein. This has a negative effect on the efficiency of utilization of ingested energy and nitrogen and, therefore, it can contribute more to environmental pollution. During the first three parities there are no possibilities to reduce the nitrogen excretion apart from avoiding an excessive surplus. When the productive life time of sows remains at 2.38 years (TEA-2000, CBK-plus, 1993), this feeding strategy does hardly contribute to a reduction in nitrogen excretion due to the small number of reproductive cycles after the third parity.

An additional problem of this feeding strategy may be that the maximum protein mass does not need to be similar for all genetic lines of sows.

The second strategy is based on a slow development of the protein mass. When nitrogen is supplied on a level of, for example, 0.85 of the required amounts to express the maximum capacity of nitrogen retention, the efficiency of utilization of ingested nitrogen can be increased. In growing pigs such a strategy depresses the growth performance. For sows the growth performance is not as important as in fattening pigs. Only when sows have a lower reproductive performance on such a feeding strategy, this argument is valid.

An additional advantage of such a feeding strategy is that live weight of sows can be on a much lower level compared with that in the first feeding strategy. Also required amount of body fat in order to reach the desired lean to fat ratio is reduced. A possible development of body stores is proposed in Table 8.4.

Calculated energy and amino acid requirements for two feeding strategies.

The development of the maternal body (Table 8.4) can be used to calculate the energy and ileal amino acid requirements of sows during pregnancy and lactation. The assumptions needed for the calculation of the requirements for pregnant sows are reported elsewhere (Everts et al., 1994). The main difference between the present calculation and the recommendations of the CVB is the development of maternal tissues. Recommendations of the CVB are based on an observed development of sows in practice, while the present calculations are based on a much slower rate of development of sows (Table 8.4).

Table 8.4
Proposed development of body composition of sows during 6 parities

	LW[1] (kg)	P2[2] (mm)	Protein (kg)	Water[3] (kg)	Fat (kg)	other[4] (kg)	lean[5]/fat (kg/kg)
First mating	120	11.4	18.4	62.6	25.5	13.5	3.2
End pregnancy 1	155	14.4	23.4	79.6	35.4	17.4	2.9
Start pregnancy 2	137.5	12.5	20.9	71.1	29.4	15.5	3.1
End pregnancy 2	167.5	15.6	24.9	84.7	39.1	18.8	2.8
Start pregnancy 3	152.5	14.1	22.9	77.9	34.6	17.1	2.9
End pregnancy 3	177.5	17.2	25.9	88.1	43.5	20.0	2.6
Start pregnancy 4	165.0	15.6	24.4	83.0	39.0	18.6	2.8
End pregnancy 4	185.0	16.8	27.4	93.2	43.6	20.8	2.8
Start pregnancy 5	172.5	15.3	25.9	88.1	39.1	19.4	2.9
End pregnancy 5	192.5	16.4	28.9	98.3	43.6	21.7	2.9
Start pregnancy 6	180.0	14.9	27.4	93.2	39.1	20.3	3.1
End pregnancy 6	200.0	16.1	30.4	103.4	43.7	22.5	3.1

[1] LW = live weight corrected for the development of the products of conception in the uterus
[2] P2 = Back fat thickness at P2
[3] assumed ratio water to protein 3.4
[4] ash (3.5 % of live weight), gut fill (6.75 % of live weight) and glycogen (1 % of live weight)
[5] lean tissue calculated as protein + water

The most important assumptions for the calculations can be summarized as follows:

- maintenance requirement : 440 kJ ME. $kg^{-0.75}$; 0.039 g lysine.$kg^{-0.75}$
- efficiency : $k_p=0.6$, $k_c=0.5$, $k_f=0.8$, $k_l=0.7$, $k_r=0.8$; the efficiency of utilization of ileal digestible lysine above maintenance into retained lysine is 0.7; the efficiency of mobilized amino acids into milk protein is 0.9

- sow's body contains 6.6 g lysine per 100 g protein; foetal protein contains 5.9 g lysine per 100 g protein
- the growth of the uterus content during pregnancy is 20 kg (11 piglets, mean birth weight 1.5 kg) for a first litter sow and 25 kg (12.5 piglets, mean birth weight 1.5 kg) for older sows. Newborn piglets contain 3.6 MJ energy per kg and 115 g protein per kg. The composition of the fluids and placentas and their development is according to Noblet et al. (1985)
- lactation length 25 days; mean milk production first litter sows 9 kg and older sows 10 kg; one kg milk contains 5 MJ energy , 50 g protein and 3.5 g lysine; mobilization of protein and fat according to Table 8.4

The equations of Noblet et al. (1985) predict the weight and chemical composition of the products of conception during pregnancy. With these equations the retention in the products of conception can be calculated in relation to the stage of pregnancy. With the efficiencies as indicated above it is possible to calculate the requirements for the development of the products of conception. Table 8.5 shows the ME, nitrogen and ileal digestible lysine requirements at the start (d0) and at the end (d115) of pregnancy, the mean requirement during pregnancy and during lactation. The ileal digestible lysine is representing the amino acid requirement. The requirement for the other amino acids can be derived as proportional to lysine as indicated by Whittemore and Morgan (1990) or can be derived by calculating the requirement for each amino acid separately. This last method can lead to more variation in the proportion of essential amino acids in relation to lysine as shown by Pettigrew (1993).

Table 8.5

Calculated recommended allowances of ME ($MJ.d^{-1}$), nitrogen ($g.d^{-1}$) and ileal digestible lysine ($g.d^{-1}$) for sows with a development of the body composition as proposed in Table 8.4

	ME				Nitrogen				i.d. Lysine			
	Pregnancy			Lact.	Pregnancy			Lact.	Pregnancy			Lact.
Parity	d0	d115	mean	mean	d0	d115	mean	mean	d0	d115	mean	mean
1	22	32	26	70	26	49	36	118	5.0	13.8	7.4	38
2	23	33	27	81	26	50	36	134	4.6	13.8	7.0	45
3	24	33	27	83	26	51	36	140	3.8	13.2	6.3	46
4	24	33	27	83	27	52	36	141	3.8	13.2	6.3	47
5	24	33	28	84	28	52	37	142	3.8	13.2	6.4	47

When the ME content of the diet is 12.55 MJ ME.kg^{-1}, then mean feed intake during lactation should be about 6 kg.d^{-1} for first parity sows with 10 suckling piglets and up to 7 kg.d^{-1} for older sows with 11 suckling piglets. Daily piglet gain is assumed to be 250 g.d^{-1}.

The energy supply during pregnancy is close to values as tested by Schneider and Bronsch (1977ab), who designed a feeding strategy to stabilize the body weight of sows at a level of about 160 kg. In their experiment they could maintain the body weight at the aimed level and still maintain a good reproductive performance. The feed intake during lactation was aimed at a high level, however, they did not give data on actual feed intake. The protein supply was at a relatively high level of 28.3 g N per kg feed.

Mahan (1977, 1979) tested at a low feeding level during pregnancy (1.8 kg.d^{-1}) different combinations of protein levels during pregnancy and lactation (*ad lib* feeding). The combinations of a low protein diet during pregnancy (50 to 90 g protein per kg) and a high protein level during lactation (180 to 200 g protein per kg) resulted in a lower performance than a constant protein level in the diet (140 g protein per kg) during pregnancy and lactation. It must be considered that in this experiment both energy and lysine supply in late pregnancy were lower than needed for a normal development of the products of conception. No data about body composition were given.

It is important to indicate the main difference between the experiments reported in literature and the concept derived from experiments presented in this thesis. In literature different feeding levels (kg.d^{-1}) were tested with a constant composition of the diet or differences in dietary composition were tested at the same feeding level (kg.d^{-1}). In the present concept energy and protein(amino acids) supply are independent of each other. This can be realized by feeding the sows with a mixture of an energy-rich diet and a protein-rich diet in changing proportions during the progress of pregnancy and lactation (multi-phase feeding). This seems easy, but is rather complicated, because a adequate supply of the other nutrients (e.g. minerals, vitamins, trace elements and essential fatty acids) is also needed.

When it is assumed that the sows will consume the proposed amounts of feed during lactation, then the total required amount of feed per sow per reproductive cycle can be decreased by 5 % in this concept. The efficiency of utilization of ingested nitrogen into retained nitrogen is 0.275 in this concept and the excretion of nitrogen per weaned piglet is 850 g N per weaned piglet.

However, the present concept must be tested to validate the development of body composition, the effect on reproductive performance, the effect on nitrogen excretion and the ability of sows to consume enough feed during lactation.

It can be concluded that this feeding strategy seems an attractive way for a further increase of the efficiency of the utilization of ingested nitrogen. For this feeding strategy sows with a relatively low adult body weight can be preferred to sows with a high adult body weight.

Conclusions

From the present investigations it is clear that there are possibilities to reduce the excretion of nitrogen by breeding sows considerably. When the nitrogen supply remains above the level where the development of the products of conception is affected, then the effect of manipulation the nitrogen supply is reflected in the maternal protein gain. When nitrogen supply exceeds the potential capacity of deposition, all extra nitrogen is excreted.

An ideal development of the body of the sow during successive parities can be defined as a development which enables the sow to realize a good reproductive performance and longevity.

To obtain a sustainable pig production an optimalization of the production of weaned piglets is needed. It is, therefore, of interest to use sows with a low live weight to reduce the costs for maintenance (both protein and energy). When sows are fed below the required amounts to express the maximum capacity of retention, then the efficiency of utilization can become more optimal and this leads to a lower excretion in faeces and urine and is consequently less harmful for the environment. Especially, during the pregnancy period such a strategy can be used. This also requires that voluntary feed intake during lactation reaches a sufficient level. Research is needed to quantify the effects of such a feeding strategy on reproductive performance and longevity.

References

Atinmo, T., Pond, W.G., Barnes, R.H., 1974. Effect of maternal energy vs. protein restriction on growth and development of progeny in swine. *Journal of Animal Science* 39: 703-711

Centraal Veevoeder Bureau (CVB), 1991. Veevoeder Tabel, Centraal Veevoederbureau, Lelystad

Duée, P.H., 1976. Chronologie de l'apport azote pendant le cycle de réproduction chez la truie. *Annales de Zootechnie* 25: 199-212

De Wit, J., Oldenbroek, J.K., van Keulen, H. and Zwart, D., 1994. Criteria for sustainable livestock production: a proposal for operationalization. *Agricultural Systems*: in press.

Etienne, M., Noblet, J., Dourmad, J.Y. and Fortune, H., 1989. Étude du besoin en lysine des truies en lactation. *Journées Recherche Porcine en France* 21: 101-108

Everts, H. and Dekker, R.A., 1991. Effect of protein/lysine supply and of parity number on energy metabolism during pregnancy and lactation in sows. In: Energy metabolism of farm animals (Ed. Wenk, C. and Boessinger, M.). *EAAP publication* 58: 317-320

Everts, H., Šebek, L.B.J., Hoofs, A., 1991a. Het effect van twee-fasen-voedering op de technische resultaten van zeugen in vergelijking met één-fase-voedering. Varkensproefbedrijf "Zuid- en West Nederland" te Sterksel. *Proefverslag* P1.75

Everts, H., Plagge, J.G., Šebek, L.B.J., 1991b. Het effect van het lysine/eiwitgehalte in het voer voor lacterende zeugen op de prestaties van de zeugen en hun biggen. Varkensproefbedrijf "Noord- en Oost Nederland" te Raalte. *Proefverslag* P1.67

Everts, H. and Šebek, L.B.J., 1992. Effect of lysine supply during lactation on reproductive performance of sows. In: *Proceedings of the International Pig Veterinary Society Congress* The Hague 17-20 august 1992: p 611

Everts, H., Blok, M.C., Kemp, B., van der Peet-Schwering, C.M.C., Smits, C., 1994. Normen voor dragende zeugen. Uitgangspunten en factoriële afleiding van de behoefte aan energie en darmverteerbare aminozuren voor dragende zeugen. *Documentatie Rapport CVB* no. 9

Frisch, A., 1988. Fatness and Fertility. *Scientific American* 258: 70-77

Hammell, D.L., Kratzer, D.D., Cromwell, G.I. and Hays, V.W., 1976. Effect of protein malnutrition of the sow on reproductive performance and on postnatal learning and performance of the offspring. *Journal of Animal Science* 43B: 589-597.

Jongbloed, A.W. and Lenis, N.P., 1992. Alteration of nutrition as a means to reduce environmental pollution by pigs. *Livestock Production Science* 31: 75-94

Just, A., Fernández, J.A. and Jørgensen, H., 1982. Nitrogen balance studies and nitrogen retention. In: Laplace, J.P., Corring, T., Rerat, A. (Editors), *Digestive physiology in the pig* 27-29 October 1982, Jouy-en-Josas. *Les Colloques de l'INRA* 12: 111-122

Leuillet, M., Etienne, M, Salmon-Legagneur, E., 1979. Consequences d'une tres forte restriction azotée a differentes periodes de la gestation de la truie sur le développement des foetus. *Annales de Biologie Animale Biochemie Biophysique* 19: 217-223

Mahan, D.C., 1977. Effect of feeding various gestation and lactation dietary protein sequences on long term reproductive performance in swine. *Journal of Animal Science* 45: 1061-1072

Mahan, D.C., 1979. Effect of dietary protein sequence on long term sow reproductive performance. *Journal of Animal Science* 49: 514-521

Noblet, J., Close, W.H., Heavens, R.P. and Brown, D., 1985. Studies on the energy metabolism of the pregnant sow. 1. Uterus and mammary tissue development. *British Journal of Nutrition* 53: 251-265

Noblet, J. and Etienne, M., 1987. Metabolic utilization of energy and maintenance requirements in pregnant sows. *Livestock Production Science* 16: 243-257

Pettigrew, J.E., Tokach, M.d., Crooker, B.A. and Sower, A.F., 1991. Energy-protein interactions in the lactating sow: Metabolites and milk synthesis. In: Energy metabolism in farm animals (Ed. Wenk, C. and Boessinger, M.) *EAAP publication* 58 : 349-352

Pettigrew, J.E., 1993. Amino acid nutrition of gestating and lactating sows. *Biokyowa Technical Review* 5:1-18

Pond, W.G., 1973. Influence of maternal protein and energy nutrition during gestation on progeny performance in swine. *Journal of Animal Science* 36: 175-181

Pond, W.G., Maurer, R.R. and Klindt, J., 1991. Fetal organ response to maternal protein deprivation during pregnancy in swine. *Journal of Nutrition* 121: 504-509

Rozeboom, D.W., Pettigrew, J.E., Moser, R.L., Cornelius, S.G. and El Kandelgy, S.M., 1994. In vivo estimation of body composition of mature gilts using live weight, back fat thickness, and deuterium oxide. *Journal of Animal Science* 72: 355-366

Schneider, D. and Bronsch, K., 1977a. Untersuchungen zur Energieversorgung der Zuchtsau. I. Formulierung eines Modelles für tragende Sauen mit Konstanz der Lebendmasseentwicklung im Bereich von 160-180 kg. *Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde* 38: 43-51

Schneider, D. and Bronsch, K., 1977b. Untersuchungen zur Energieversorgung der Zuchtsau. II. Überprüfung eines Modelles zum Energiebedraf tragender Sauen im Langzeitversuch *Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde* 38: 43-51

Speer, V.C., 1990. Partitioning nitrogen and amino acids for pregnancy and lactation in swine: A review. *Journal of Animal Science* 68: 553-561

TMV, werkgroep. 1991. Informatiemodel Technisch Model Varkensvoeding. *Proefverslag* P 1.66. Proefstation voor de Varkenshouderij, Rosmalen

Vanschoubroek, F. and Spaendonck, R. van 1973. Faktorieller Aufbau des Protein- und Aminosäurenbedrafs tragender Sauen. *Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde* 31: 71-91

Whittemore, C.T. and Morgan, C.A., 1990. Model components for the determination of energy and protein requirements for breeding sows: a review. *Livestock Production Science* 26: 1-37

Whittemore, C.T. and Yang, H., 1989. Physical and chemical composition of the body of breeding sows with differing body subcutaneous fat depth at parturition, differing nutrition during lactation and differing litter size. *Animal Production* 48: 203-212

Wilkinson, R., Cole, D.J.A. and Lewis, D., 1982. Amino acid nutrition of the lactating sow: the requirement for dietary lysine. *Animal Production* 35: 15-2322

Summary

Summary

Besides factors like optimal housing and management, an optimal feeding strategy is an essential factor to enable a sow to express her (genetical) potential productivity. The feed for sows is one of the most important input factors for piglet production. For a sustainable animal production nutrients should be converted with an optimal efficiency into the desired products. To reach a high efficiency of the utilization of nutrients it is attractive to feed sows as close as possible to their requirements. One of the most influential nutrients is protein (N*6.25), because it supplies the animal with essential and non-essential amino acids. A supply of dietary nitrogen above the optimal required amounts results in unnecessary excretion of nitrogen and therefore in an enhanced risk for pollution of the environment. During pregnancy nitrogen is required for maintenance, the development of the products of conception and growth of the maternal body mass of the sow. During lactation nitrogen is required for maintenance and milk production. Nitrogen supply during lactation often remains below the required amounts due to an insufficient feed intake.

In the past decades it was common practice to feed sows the same diet during pregnancy and lactation. In such a case sows are fed above the nitrogen requirement during pregnancy due to the relatively high nitrogen requirement during lactation. For feeding closer to the nitrogen requirement at least two different diets are needed. One diet with a low nitrogen content during pregnancy and an other diet with a higher nitrogen level during lactation. The consequences of such a feeding strategy was investigated in this thesis. Special attention was paid to the effect of a low nitrogen supply during pregnancy on development of the products of conception and on development of the maternal body. Also the consequences for nitrogen requirement during lactation, energy metabolism, efficiency of the utilization of ingested nitrogen and nitrogen excretion were investigated.

In this thesis two levels of nitrogen supply during pregnancy and two levels of nitrogen supply during lactation were studied in a 2 x 2 factorial design using different techniques during three parities.

In Chapter 2 the technique of balance trials during mid and late pregnancy and during lactation is described for breeding sows. During pregnancy the balance trial is done in a similar way as with the growing pig. The total retention over a short period is the result of a balance trial. However, information about the distribution of retained nitrogen and energy (fat) between that in the products of conception and that in the maternal body can not be obtained with this technique.

In balance trials with lactating sows the balance of the sow and her piglets was

measured together. To avoid problems related to the measurement of milk production and milk composition, litter gain was calculated from daily live weight gain of the litter and the chemical composition of piglet gain. The chemical composition of piglet gain was derived from live weight and body composition of the piglets at birth and at weaning. The balance of the sow was than calculated as the total balance (sow + litter) minus retention in the litter.

Losses of nitrogen due to ammonia evaporation were also measured because the balance trials were performed in respiration chambers (measuring ammonia in out-going air and in nitrogen in water from the heat exchangers).

Besides the balance technique also the comparative slaughter technique was used to get information about retention of nutrients and body composition of the sows. The advantage of the comparative slaughter technique is that it gives information about the retention in the different compartments of an animal. This technique, however, does not give information on the pattern of daily retention during pregnancy or lactation.

Of both techniques the accuracy and the contribution of the different sources of variance to the standard deviation of retention were studied. It was shown that the standard deviation of balance trails during lactation is much higher than in balance trials during pregnancy. With the comparative slaughter technique it was shown that standard deviation of retention is affected by the variance due to the estimation of the body composition at the start of the experiment. It was concluded that between-animal variance is the main source of variance.

The balances were not measured continuously during the time between the different moments of slaughter. Therefore, it was not possible to compare the retention measured with both techniques directly. From the results it was concluded that the balance trial had a smaller standard deviation of retention than the comparative slaughter technique when retention is measured over a limited period (< 3 months).

In Chapter 3 the effect of nitrogen supply during pregnancy on nitrogen retention and excretion was studied using the balance technique. It was shown that the nitrogen supply during mid pregnancy (40 g $N.d^{-1}$ compared with 62 g $N.d^{-1}$) had hardly any effect on nitrogen retention. Nitrogen excretion, however, was reduced by 40 %. In late pregnancy the difference in nitrogen supply significantly affected the nitrogen retention. On the low nitrogen supply (50 g $N.d^{-1}$) nitrogen retention was about 18 g $N.d^{-1}$ and on the high level of nitrogen supply (74 g $N.d^{-1}$) about 25 g $N.d^{-1}$. This lower nitrogen retention on the low protein diet was compensated by a higher fat gain in the first parity. The level of nitrogen retention of about 18 g $N.d^{-1}$ is higher than the estimated amount of daily nitrogen retained in the products of conception in late pregnancy. The nitrogen excretion in late pregnancy was decreased by 35 % on the low level of protein compared with the high level of protein supply. It is concluded that there are possibilities to reduce nitrogen excretion considerably during pregnancy.

Values derived from literature for maintenance requirement of nitrogen (0.45 g $N.kg^{-0.75}$) and efficiency of the utilization of ingested nitrogen, after allowance for maintenance, into retained nitrogen (0.6) were in line with the results.

With the comparative slaughter technique it was shown that nitrogen intake had no effect on the fresh weight and chemical composition of the products of conception (piglets, placentas, uterus and intra-uterine fluids) nor on the amino acid pattern of the protein in the unborn piglets at day 108 of the first pregnancy (Chapter 5). The results of the comparative slaughter experiment also confirmed the effect of nitrogen supply during pregnancy on maternal nitrogen retention and maternal fat deposition. Protein content of the fat-free maternal body remained at the same level as at mating (220 $g.kg^{-1}$). Also the ratio of water to protein in the maternal body remained constant during pregnancy.

Conversion efficiency, after allowance for maintenance, of ingested ileal digestible lysine into products of conception and maternal body was 0.59 on the low level of nitrogen supply. For threonine this value was 0.67. On the higher level of nitrogen supply the conversion efficiency was much lower for both lysine (0.46) and threonine (0.44).

Nitrogen excretion was calculated as the difference between ingested and retained nitrogen (comparative slaughter technique during the first pregnancy). The nitrogen excretion on the low level of nitrogen supply was 33 % lower than on the high level of nitrogen supply. This level of reduction was comparable to that derived from the balance trials during pregnancy.

In Chapter 4 the effects of nitrogen supply during the lactation period and of the nitrogen supply during the preceding pregnancy period were investigated. The nitrogen level in the lactation diets (24.7 g $N.kg^{-1}$ compared with 28.5 g $N.kg^{-1}$) had no effect on daily piglet gain during a 25 days lactation period. It was shown that a low level of nitrogen supply during pregnancy tended to a higher energy content in weaned piglets. A high nitrogen supply during lactation decreased nitrogen mobilization and increased fat mobilization of the sow.

The effect of parity number was tested by making within-sow comparisons after correction for differences in litter size. It was shown that piglets from second and third parity sows had a higher daily gain than piglets from first litter sows. Nitrogen mobilization of sows increased with parity number.

From the results the daily nitrogen requirement for lactating sows was estimated to be 162 g to 185 N $g.d^{-1}$, depending on the parity number and litter size. This estimated nitrogen requirements is closely related to the composition and digestibility of the used diets.

In this experiment the effect of nitrogen supply was closely related to the supply of amino acids. Therefore, the daily requirement for ileal digestible lysine was estimated to be 37 to 43 $g.d^{-1}$, depending on the parity number and litter size. The present requirements for nitrogen and lysine are higher than those in literature and current recommendations. These higher estimates can be

explained by the higher production rates and the new methodological approach in this experiment.
The gross utilization of ingested nitrogen was about 0.4, which was substantially higher than observed during pregnancy (0.21 - 0.35).

In Chapter 6 the effect of nitrogen supply during pregnancy and lactation on body composition of sows during three reproductive cycles was investigated.
After three parities sows were slaughtered to investigate the long term effect of nitrogen supply during pregnancy and lactation. The nitrogen supply during pregnancy and lactation did not affect the amount of protein in the body of the sows nor the amino acid pattern of the protein after the third weaning. The amounts of fat and energy in the body of the sows after three reproductive cycles were lower on a high level of nitrogen supply during lactation.
In order to study the development of the body composition during the three reproductive cycles more closely, equations were derived to predict body composition from live weight (corrected for the products of conception) and back fat thickness at P2 using all available data ($n=48$). With these equations development of body composition was predicted during the three investigated reproductive cycles. During the first reproductive cycle deposition of protein and water was lower in sows on the treatment with the low level of nitrogen supply during pregnancy. This effect was not completely compensated for in the next two reproductive cycles. The overall trend showed that sows, irrespective of treatment, had increased live weight and decreased back fat thickness with increasing parity number. The amount of protein and water in the body increased considerably during the three reproductive cycles, while the amount of fat remained more or less constant. This means that a feeding strategy aiming at a constant back fat thickness will increase the amount of fat in the body.

In Chapter 7 the influence of some important reproductive characteristics on nitrogen excretion by breeding sows was investigated using a theoretical model. For a correct comparison it was concluded that the nitrogen excretion must be expressed per weaned piglet and not per sow per year.
The nitrogen excretion per weaned the piglet was only moderately affected by increasing the farrowing index and by decreasing the yearly replacement percentage of the sows. A reduction of piglet mortality and an increase in litter size reduced nitrogen excretion per weaned piglet considerably. However, a fast improvement in these characteristics is not expected in the near future. Even when the possible positive effects of these characteristics on nitrogen excretion per weaned piglet are combined, then their effect is smaller than the effect of decreasing the nitrogen content of the pregnancy diet to a level of 18 g $N.kg^{-1}$.
It was concluded that reduction of the nitrogen level in the pregnancy diet is the most promising and easiest measure to reduce nitrogen excretion per weaned

piglet on the short term. Theoretically, the amount of nitrogen excreted per weaned piglet can be reduced to a level of 700 g N per weaned piglet, when the reproduction characteristics are optimal and the pregnancy diet contains only 16 g $N.kg^{-1}$. The gross efficiency of ingested nitrogen into retained nitrogen is then about 0.3. This efficiency remains low compared with growing pigs. The main reasons for this low efficiency are the low feeding level of sows during pregnancy and the moderate capacity of sows to retain nitrogen.

In the general discussion the following main conclusions were drawn:

- a nitrogen supply of 50 g $N.d^{-1}$ in late pregnancy guarantees a normal development of the products of conception, but the maternal nitrogen deposition is lower than with a nitrogen supply of 74 g $N.d^{-1}$;
- to calculated an optimal level of essential amino acids, an efficiency of the utilization of ingested ileal digestible amino acids (above the maintenance requirement) of 0.7 is suggested;
- a higher nitrogen supply during lactation reduced nitrogen mobilization and increased fat mobilization during lactation;
- sows on a low nitrogen supply during pregnancy have less protein in the body at the end of their first pregnancy, but they try to compensate this in the following reproductive cycles;
- the maximum amount of protein in the body of an adult sow is estimated to be about 42 kg for a Great Yorkshire * Dutch Landrace crossbred sow;
- prediction of the body composition from live weight (corrected for the products of conception) and back fat thickness is a possible way to avoid large scale serial slaughtering of sows;
- reducing the nitrogen level in the pregnancy diet (from 24.7 g $N.kg^{-1}$ to 16.7 g $N.kg^{-1}$) decreased nitrogen excretion with 25 % ;

From the results presented, a feeding strategy for breeding sows is proposed. When sows are fed below the required amount of nitrogen to express their maximum capacity of retention, the efficiency of utilization can be optimized. The additional advantage of such a feeding strategy is the fact that live weight of sows can be kept on a relatively low level. The proposed feeding level aims at a live weight of 180 kg and a back fat thickness at P2 of 15 mm at the start of the sixth pregnancy. The required amounts of ME, nitrogen and ileal digestible lysine for this feeding strategy were calculated for the first six reproductive cycles. With these data it was calculated that the gross efficiency of ingested nitrogen into retained nitrogen was 0.275. Furthermore, the nitrogen excretion per weaned piglet is about 850 g N. In the present feeding strategy energy and protein (amino acids) supply are independent of each other. This can be realized by feeding sows with a mixture of an energy-rich diet and a protein-rich diet in changing proportions during the progress of pregnancy and during lactation (multiphase feeding). This seems easy, but is rather complicated because an adequate supply of all other nutrients (e.g. minerals, vitamins, trace elements and essential fatty acids) must be guaranteed. This proposed feeding strategy should be tested to validate the development of body composition and to study the effects on reproductive performance and longevity.

Samenvatting

Samenvatting

Voor de zeugenhouderij is, naast optimale verzorging, management en fokkerij, een optimale voeding van groot belang om de zeug in staat te stellen haar potentiële produktiecapaciteit te kunnen verwezenlijken. Het zeugenvoer is één van de belangrijkste "inputs" voor de produktie van gespeende biggen. Voor een duurzame dierlijke produktie is het van belang om de toegevoerde nutriënten met de hoogst mogelijke efficiëntie te om te zetten in het gewenste produkt. Om een hoge benuttingsgraad van de nutriënten te bereiken, is het aantrekkelijk zeugen zo goed mogelijk naar hun behoefte te voeren. Eiwit is één van de belangrijkste nutriënten, omdat daarmee het dier voorzien kan worden van essentiële en niet-essentiële aminozuren. Een eiwitgift boven de behoefte leidt tot een hogere stikstofuitscheiding en kan daarmee een extra belasting van het milieu tot gevolg hebben. Gedurende de draagtijd is er eiwit nodig voor onderhoud, ontwikkeling van de baarmoederinhoud en groei van de zeug zelf (maternale groei). Tijdens de lactatieperiode is er eiwit nodig voor onderhoud en melkproduktie. Vaak blijft de eiwitvoorziening in de lactatie achter bij de behoefte vanwege een onvoldoende voeropname.

In de afgelopen decennia was het in de praktijk gebruikelijk om zeugen voer met dezelfde samenstelling te verstrekken tijdens dracht en lactatie. Vanwege de relatief hoge behoefte tijdens de lactatie, worden de zeugen dan tijdens de draagtijd ver boven de eiwitbehoefte gevoerd. Het gebruik van één voersoort voor dragende en lacterende zeugen heeft derhalve een aanzienlijke stikstofuitscheiding naar het milieu tot gevolg. Om beter naar de eiwitbehoefte te kunnen voeren zijn er minstens twee voersoorten noodzakelijk. Tijdens de draagtijd is een voer met een laag eiwitgehalte gewenst en tijdens de lactatie een voer met een hoger eiwitgehalte.

Het effect van het verlagen van het eiwitgehalte in het voer voor dragende zeugen op de ontwikkeling van de baarmoederinhoud, de ontwikkeling van de lichaamssamenstelling van de zeugen, de eiwitbehoefte tijdens de lactatie, de energiestofwisseling, de efficiëntie van de benutting van het opgenomen eiwit en de stikstofuitscheiding werd in dit proefschrift onderzocht.

In het onderzoek werden twee niveaus aan eiwitvoorziening tijdens de draagtijd en twee niveaus aan eiwitvoorziening tijdens de lactatie onderzocht in een 2 x 2 factoriële proef gedurende drie opeenvolgende reproduktiecycli.

Eerst wordt in hoofdstuk 2 de techniek van balansproeven met zeugen tijdens de dracht en de lactatie uitgebreid beschreven. De balansmetingen tijdens de draagtijd zijn goed vergelijkbaar met de balansmetingen bij groeiende vleesvarkens. In balansproeven kan de aanzet gedurende een korte periode gemeten worden. Balansproeven geven echter geen antwoord op de vraag of de aanzet nu plaatsvindt als baarmoederinhoud of als maternaal weefsel.

In de balansmetingen met lacterende zeugen werd de balans gemeten van de zeug en de zogende biggen samen. Omdat het meten van de melkproduktie en de melksamenstelling niet eenvoudig is, werd ervoor gekozen om de aanzet in de toom te berekenen aan de hand van de dagelijkse groei van de biggen en de groeisamenstelling van de biggen. Deze groeisamenstelling werd berekend met behulp van het gewicht en de chemische samenstelling van biggen bij de geboorte en bij het spenen. De balans van de zeug zelf kan dan berekend worden zonder verdere aannames.
Mogelijke verliezen in de vorm ammoniak werden ook gemeten door de proeven uit te voeren in respiratiekamers. Daarbij werd zowel de uitgaande lucht als het condenswater onderzocht.
Naast de balansmetingen is ook gebruik gemaakt van de vergelijkende slachttechniek. Deze techniek is geschikt om zowel de aanzet in het lichaam als de lichaamssamenstelling te bepalen. Het voordeel van deze techniek is dat ook de aanzet in de verschillende lichaamscompartimenten apart bepaald kan worden. Het nadeel is echter dat het patroon van de aanzet in de tijd niet bepaald kan worden.
Zowel van de balansmetingen als van de vergelijkende slachttechniek zijn de nauwkeurigheid en de bijdragen van de verschillende variatiebronnen aan de standaardafwijking van de retentie onderzocht. Het bleek dat de standaardafwijking van de gemeten aanzet in balansproeven tijdens de lactatieperiode veel groter is dan in balansproeven tijdens de draagtijd. Bij de vergelijkende slachttechniek bleek de schatting van de lichaamssamenstelling aan het begin van de dracht een extra bron van variatie te vormen. De geschatte tussen-dier variatie leek echter de grootste bron van variatie te zijn. Omdat de balans niet gedurende het hele experiment werd gemeten, was het niet mogelijk de aanzet volgens de balanstechniek te vergelijken met de aanzet volgens de vergelijkende slachttechniek. Op grond van de gemeten nauwkeurigheid werd geconcludeerd dat balansproeven met fokzeugen een kleinere standaardafwijking van de aanzet geven dan de vergelijkende slachttechniek, wanneer de aanzet wordt gemeten gedurende een beperkte tijdsduur (< 3 maanden). Voor het bepalen van de aanzet in het lichaam gedurende een langere tijdsduur geeft de vergelijkende slachttechniek een kleinere variatie.

In hoofdstuk 3 werd het effect van de stikstofgift tijdens de dracht op de stikstofaanzet en -uitscheiding onderzocht met behulp van de balanstechniek. Het bleek dat beperking van de stikstofgift tijdens het midden van de dracht (40 g N.d^{-1} ten opzichte van 62 g N.d^{-1}) nauwelijks effect had op de stikstofaanzet, maar dat de stikstofuitscheiding met ongeveer 40 % afnam. In de laatste weken van de dracht bleek de stikstofgift de stikstofaanzet wel te beïnvloeden. Bij een laag stikstofaanbod (50 g N.d^{-1}) was de stikstofaanzet ongeveer 18 g N.d^{-1} en bij een hoog stikstofaanbod (74 N.d^{-1}) ongeveer 25 g N.d^{-1}. De lagere stikstofaanzet ging gepaard met een hoger vetaanzet in de eerste dracht. De gemeten stikstofaanzet van 18 g N.d^{-1} bij het lage stikstofaanbod is echter nog hoger dan de in de literatuur aangegeven dagelijkse stikstofaanzet in de baarmoederinhoud. Met andere woorden er vond bij het lage stikstofaanbod nog stikstofaanzet plaats in de maternale weefsels in de laatste weken van de dracht. De stikstofuitscheiding was bij het lage stikstofaanbod ongeveer 35 % lager dan bij het hoge stikstofaanbod. De gevonden reductie in stikstofuitscheiding geeft aan dat er een aanzienlijke besparing in stikstofuitscheiding bij dragende zeugen mogelijk is.

De resultaten van dit onderzoek bevestigden de vooraf aangenomen waarden voor de onderhoudsbehoefte (0,45 G N. kg$^{-0,75}$) en voor de efficiëntie waarmee opgenomen stikstof (boven de onderhoudsbehoefte) wordt aangezet (0,6).

Met de vergelijkende slachttechniek werd aangetoond dat de stikstofopname geen effect had op het gewicht en de chemische samenstelling van de baarmoederinhoud (ongeboren biggen, placenta's, baarmoeder en vruchtwater). Ook werd er geen effect gevonden op het aminozuurpatroon van het eiwit in de ongeboren biggen op dag 108 van de eerste dracht (hoofdstuk 5).

De vergelijkende slachttechniek bevestigde ook het effect van de stikstofgift gedurende de dracht op de maternale stikstof- en vetaanzet in de eerste dracht. Het eiwitgehalte in het vet-vrije maternale lichaam (220 g.kg^{-1} vet-vrij lichaamsgewicht) bleek aan het einde van de eerste dracht vrijwel gelijk te zijn aan dat op het moment van dekken. Ook de verhouding tussen water en eiwit in het maternale lichaam bleek niet te veranderen tijdens de dracht.

Er kon berekend worden dat bij het lage stikstofaanbod 59 % van de opgenomen darmverteerbaar lysine, na correctie voor de onderhoudsbehoefte, werd aangezet in de baarmoederinhoud en maternale weefsels. Voor threonine was dit 67 %. Bij het hoge stikstofaanbod bleek dit voor lysine 46 % en voor threonine 44 % te zijn.

Aan de hand van de vergelijkende slachtproef werd ook de stikstofuitscheiding berekend als het verschil tussen de opgenomen stikstof en de aangezette stikstof. De stikstofuitscheiding bij het lage stikstofaanbod was 33 % lager dan bij het hoge stikstofaanbod. De mate van de besparing in stikstofuitscheiding kwam goed overeen met de gegevens van de balansmetingen tijdens de dracht.

In hoofdstuk 4 werd het effect van het stikstofaanbod tijdens de lactatie onderzocht. Het stikstofgehalte in het lactatievoer (24.7 g N.kg^{-1} ten opzichte van 28.5 g N.kg^{-1}) had geen effect op de groeisnelheid van de zogende biggen gedurende een 25-daagse zoogperiode. Een laag eiwitaanbod tijdens de dracht tendeerde tot een hogere energie-inhoud van de biggen bij het spenen. Een hoog stikstofaanbod tijdens de lactatie had een geringere stikstofmobilisatie en een grotere vetmobilisatie van de zeugen tot gevolg.

Het effect van het worpnummer op de resultaten werd onderzocht door binnenzeug vergelijkingen te maken. Het bleek dat de biggen van oudereworps zeugen (na correctie voor verschillen in worpgrootte) een hogere groeisnelheid hadden dan de biggen van eersteworps zeugen. Ook de stikstofmobilisatie van lichaamsreserves nam toe met een toenemend worpnummer.

Op basis van de resultaten werd de stikstofbehoefte van lacterende zeugen geschat. Afhankelijk van het worpnummer varieerde de stikstofbehoefte tussen de 162 en 185 g N.d^{1}. Deze behoefteschatting wordt echter voor een belangrijk deel bepaald door de samenstelling en verteerbaarheid van het gebruikte voeders In dit experiment was de stikstofgift nauw gerelateerd aan de aminozuurgift. De berekende behoefte aan darmverteerbaar lysine voor lacterende zeugen bedroeg 37 tot 43 g.d^{-1}, afhankelijk van het worpnummer en het aantal biggen. Deze behoefte aan stikstof en aan lysine is hoger dan aangegeven in de literatuur en dan de gangbare normen. Dit kan verklaard worden door de hogere groeisnelheid van de biggen en ook door het gebruik van een andere onderzoeksmethode.

De bruto benutting van opgenomen stikstof was tijdens de lactatie ongeveer 0,4 en dit is hoger dan de benutting zoals waargenomen tijdens de dracht (0,21 tot 0,35).

In hoofdstuk 6 is het effect van het stikstofaanbod tijdens de dracht en de lactatie op de lichaamssamenstelling van zeugen gedurende drie reproduktiecycli onderzocht. Na de derde lactatie werden zeugen geslacht en chemisch geanalyseerd om het lange termijn effect van het stikstofaanbod te kunnen bepalen. Het stikstofaanbod had geen significant effect op de hoeveelheid lichaamseiwit of het aminozuurpatroon van het eiwit na de derde lactatie. De hoeveelheid vet en energie in het lichaam van de zeugen na drie reproduktiecycli was bij een laag stikstofaanbod tijdens de lactatie groter dan bij een hoog stikstofaanbod tijdens de lactatie.

Om de ontwikkeling van de lichaamssamenstelling beter te kunnen bestuderen, werden er formules ontwikkeld die aan de hand van het lichaamsgewicht (gecorrigeerd voor de baarmoederinhoud) en de spekdikte op de P2 positie de hoeveelheden eiwit, water, vet en energie in het lichaam kunnen schatten. Voor de afleiding van deze formules werden alle beschikbare gegevens gebruikt ($n=48$). De resultaten gaven aan dat bij een laag stikstofaanbod tijdens de dracht de eiwit- en wateraanzet in de eerste reproduktiecyclus achter bleef bij die van de dieren met een hoger stikstofaanbod. Deze achterstand werd in de volgende reproduktiecycli wel grotendeels, maar niet volledig, goedgemaakt.

Bij de toegepaste voerstrategie bleek het lichaamsgewicht van de zeugen, ongeacht de toegepaste behandelingen, toe te nemen met het worpnummer, terwijl de spekdikte (gemeten aan het einde van de dracht) afnam met het worpnummer. De hoeveelheid eiwit en water in het lichaam namen aanzienlijk toe met het worpnummer, terwijl de hoeveelheid vet min of meer constant bleef. Dit betekent dat een voerstrategie die zich richt op een gelijk blijvende spekdikte een toename van de hoeveelheid vet in het lichaam tot gevolg heeft.

In hoofdstuk 7 is door middel van een theoretisch model onderzocht wat een verandering in een aantal belangrijke reproduktiekenmerken voor effect heeft op de stikstofuitscheiding. Het bleek voor een zuivere vergelijking noodzakelijk om de stikstofuitscheiding per gespeende big uit te rekenen in plaats van per zeug per jaar. De modelberekeningen lieten zien dat stikstofuitscheiding per gespeende big maar in beperkte mate afhankelijk was van de worpindex en van het vervangingspercentage van de zeugen. Het sterftepercentage van de biggen en de worpgrootte hadden wel een aanzienlijk effect op de stikstofuitscheiding per gespeende big. Daarbij moet echter wel opgemerkt worden dat er op korte termijn geen spectaculaire afname van de biggensterfte of toename van de worpgrootte verwacht mag worden. Zelfs wanneer alle onderzochte reproduktiekenmerken zich gunstig zouden ontwikkelen, dan is het totale effect daarvan kleiner dan het effect wat bereikt kan worden met het verlagen van het stikstofgehalte in het voer voor dragende zeugen tot een niveau van 18 g $N.kg^{-1}$. De conclusie uit deze modelberekeningen is dan ook dat een verlaging van het stikstofgehalte in het voer voor dragende zeugen een veelbelovende en gemakkelijke manier is om de stikstofuitscheiding per gespeende big op korte termijn te verminderen. Theoretisch is het mogelijk de stikstofuitscheiding per gespeende big terug te brengen tot een niveau van ongeveer 700 g N per gespeende big. Dit niveau van stikstofuitscheiding wordt bereikt bij een optimale reproduktie in combinatie met een voer voor dragende zeugen dat 16 g $N.kg^{-1}$ bevat. De opgenomen stikstof wordt dan voor ongeveer 30 % benut. Dit is in vergelijking met groeiende vleesvarkens nog steeds een vrij lage benuttingsgraad van opgenomen stikstof. De belangrijkste redenen voor deze lage benuttingsgraad zijn het relatief lage voerniveau van zeugen en de beperkte capaciteit van zeugen om stikstof aan te zetten.

In de algemene discussie (hoofdstuk 8) werden de volgende conclusies getrokken:

- een stikstofaanbod van 50 g $N.d^{-1}$ in de laatste fase van de dracht garandeert een normale ontwikkeling van de baarmoederinhoud, maar dit stikstofaanbod beperkt wel de maternale eiwitaanzet in vergelijking met een aanbod van 74 g $N.d^{-1}$;
- voor een optimaal gebruik van essentiële aminozuren wordt voorgesteld om een efficiëntie van 0,7 aan te houden voor de benutting van opgenomen darmverteerbare aminozuren (na correctie voor de onderhoudsbehoefte) in aangezette aminozuren;
- een hogere stikstof-/lysine-voorziening tijdens de lactatieperiode vermindert de eiwitmobilisatie en verhoogt de vetmobilisatie tijdens deze periode;
- zeugen met een laag stikstofaanbod tijdens de dracht hebben aan het einde van hun eerste dracht minder eiwit in het lichaam dan zeugen met een hoog stikstofaanbod. De zeugen trachten deze achterstand in de volgende reproduktiecycli wel te compenseren;

- de maximum hoeveelheid eiwit in het lichaam van een volwassen zeug wordt geschat op 42 kg voor een GY*NL zeug
- de voorspelling van de lichaamssamenstelling uit het lichaamsgewicht (gecorrigeerd voor de baarmoederinhoud) en de spekdikte is een mogelijkheid om de noodzaak voor grootschalige, vergelijkende slachtproeven te verminderen
- door het stikstofgehalte in het voer voor dragende zeugen te verlagen (van 24.7 g $N.kg^{-1}$ tot 16.7 g $N.kg^{-1}$) wordt de stikstofuitscheiding met ongeveer 25 % verminderd zowel per zeug per jaar als per gespeende big

Uit de gepresenteerde gegevens wordt tenslotte een voerstrategie voor zeugen afgeleid. Door zeugen onder de stikstofbehoefte voor een maximale eiwitaanzet te voeren, kan de benuttingsgraad van de opgenomen stikstof geoptimaliseerd worden. Het bijkomende voordeel van een dergelijke voerstrategie is dat het lichaamsgewicht van de zeugen relatief laag blijft. De voorgestelde voerstrategie streeft naar een lichaamsgewicht van 180 kg en een spekdikte (P2) van 15 mm aan het begin van de zesde dracht. De benodigde hoeveelheden ME, stikstof en darmverteerbaar lysine, volgens deze voerstrategie, werden berekend voor zes op eenvolgende worpnummers, zowel voor de dracht als voor de lactatie.
Uit deze gegevens werd een bruto benutting van de opgenomen stikstof berekend van 27,5 % en een stikstofuitscheiding van 850 g N per gespeende big. In de voorgestelde voerstrategie zijn het energieaanbod en het aanbod aan eiwit(aminozuren) onafhankelijk van elkaar. Dit kan bereikt worden door zeugen te voeren met een mengsel van een energievoer en een eiwitvoer in wisselende verhoudingen (multifasen voedering). De verhouding tussen deze twee voeders verandert met het vorderen van de draagtijd, tijdens de lactatie en met het toenemen van het worpnummer. Een dergelijk voersysteem lijkt eenvoudig, maar is toch vrij gecompliceerd, omdat er ook steeds een voldoende voorziening van andere nutriënten (zoals mineralen, vitamines, spoorelementen en essentiële vetzuren) gegarandeerd moet worden.
De voorgestelde voerstrategie zou onderzocht moeten worden om de gewenste ontwikkeling van de lichaamssamenstelling te valideren en om de effecten van deze voerstrategie op de reproduktieprestaties en levensduur vast te stellen.

Curriculum Vitae

Hendrik Everts is op 6 januari 1952 geboren in de gemeente Dwingeloo. Na het behalen van diploma gymnasium-*β* op het Christelijk Lyceum te Zeist in 1970, ging hij diergeneeskunde studeren aan de Rijksuniversiteit te Utrecht. Daar slaagde hij in 1974 voor het doctoraalexamen en in 1977 voor het dierenartsexamen. Na een aantal maanden gewerkt te hebben in een dierenartsenpraktijk in Valkenswaard, werd de militaire dienstplicht vervuld. In september 1978 werd hij aangesteld als wetenschappelijk onderzoeker bij het Instituut voor Veevoedingsonderzoek te Lelystad. Het werkterrein betrof zowel de energie- en eiwitstofwisseling van zeugen als van schapen. Een belangrijk deel van het onderzoek uitgevoerd met zeugen wordt in dit proefschrift beschreven. Sedert januari 1994 is het Instituut voor Veevoedingsonderzoek op gegaan in het Instituut voor Veehouderij en Diergezondheid, alwaar hij thans als wetenschappelijk onderzoeker werkt.