B. Kemp

Investigations on breeding boars to contribute to a functional feeding strategy.

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. H.C. van der Plas,
in het openbaar te verdedigen
op dinsdag 3 oktober 1989
des namiddags te vier uur in de aula
van de Landbouwuniversiteit te Wageningen.

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. L.A. den Hartog. Proefstation voor de varkenshouderij

Stellingen

1. Het aantal door een beer geproduceerde spermacellen per tijdseenheid is mede afhankelijk van de hoogte van de voergift.
(dit proefschrift)

2. De energiekosten van dekken zijn voor beren zo laag dat er bij het samenstellen van een voederstrategie geen rekening mee hoeft te worden gehouden.
(dit proefschrift)

3. Bij het opstellen van een voederstrategie voor reproducerende beren dient men, meer dan voorheen gebruikelijk was, rekening te houden met de groei van de beer.
(dit proefschrift)

4. Het verstrekken van een voeder (EW=1) met meer dan 0.68% lysine en 0.44% methionine en cystine ter verbetering van de prestaties van reproducerende beren is onder normale omstandigheden zinloos.
(dit proefschrift)

5. Het stelselmating controleren van de staltemperaturen en dienovereenkomstig aanpassen van de voergift kan een daling in de spermaproduktie zeker ten dele voorkomen.
(dit proefschrift)

6. Het is voor K.I.verenigingen van groot belang meer inzicht te krijgen in de kwaliteit van het door de beren geleverde sperma.

7. Vooral gedurende de laatste fase van de doctoraalstudie Zoötechniek zouden studenten meer geconfronteerd moeten worden met de maatschappelijke en ethische implicaties van het zoötechnisch handelen.

8. De Nederlandse Maatschappij ter bevordering der Tandheelkunde bevordert door haar vestigingsbeleid vooral de reeds gevestigde tandheelkunde.

9. Vaak wordt bij het Jiu Jitsu (Zachte kunst) het "zachte" van de kunst vergeten.

Proefschrift B. Kemp,
Investigations on breeding boars to contribute to a functional feeding strategy.
Wageningen, 3 oktober 1989.

Aan mijn ouders en
Chantal.

Voorwoord

Dit proefschrift is het resulaat van onderzoek gedaan bij de vakgroep Veevoeding van de Landbouwuniversiteit. Een deel van de proeven werd uitgevoerd in samenwerking met de vakgroep Veehouderij en/of één van de diverse varkens K.I.-verenigingen. Zonder de hulp van een groot aantal mensen zou de uitvoering van dit onderzoek onmogelijk zijn geweest.
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GENERAL INTRODUCTION

In 1987, about 33000 breeding boars (compared to 1361 x 10^3 sows) were kept in The Netherlands. In total 1379 from these boars were used for Artificial Insemination. The A.I. Centres took care of 45 % of the total of natural matings and inseminations. Assuming the same conception rate for A.I. and natural mating one can calculate that on an average one A.I. boar was used for the fertilization of 444 sows, while a natural mating boar fertilized 24 sows. These data make clear that compared to a total pig population in the Netherlands in 1987 of about 14.3 million, the population of breeding boars is relatively small. This small group (and especially those boars used for A.I.), however, is of great importance for pig production.

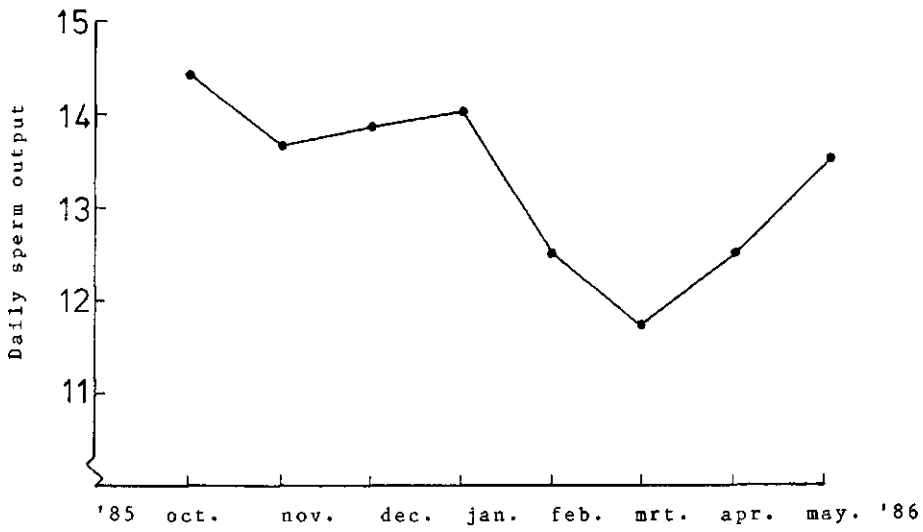
Breeding boars are selected on the basis of production characteristics such as growth, feed conversion ratio and slaughter quality. When boars are in the reproduction phase they should have good reproductive traits like strong libido, large number of produced sperm cells and a good fertilizing capacity of the semen. These traits can vary largely. Nooren (1988) found a variation coefficient in number of produced sperm cells per ejaculateat A.I. Centres of 40%. All kinds of factors like type of breed, age of the boar, mating or semen collection frequency, season, heat stress and social environment were found to influence semen quality and quantity (Kennedy and Wilkins, 1984; Cameron, 1988).

One of the factors which influence the reproductive characters is nutrition. There are few data in literature regarding the nutritive needs of boars to optimize reproductive characters. The feed requirements of boars as given in the tables of the A.R.C (1981), I.T.P (1982), D.L.G. (1984) and N.R.C. (1988), are mainly based on sow data. In this thesis some aspects of the energy and protein requirements of breeding boars are investigated. The experiments described in this thesis are done to develop a feeding strategy which will fit more closely the nutritive needs of breeding boars.

In chapter I a literature review is given on the influence of the energy and protein intake on the reproductive characters: libido, number of produced sperm cells and fertilizing capacity of the sperm cells.

From the literature review it becomes clear that there is lack of agreement between authors regarding the level of protein which should be given to a breeding boar. In the experiment descibed in chapter II a protein rich diet is compared to a normal commercial sow diet to investigate whether extra protein (amino acids) has an effect on the reproductive performance of the boar.

Figure 1: Mean daily sperm output ($x10^9$) at various months at an A.I. Centre (number of boars is approx. 350).



In Dutch A.I.Centres a 20% reduction in the number ofproduced sperm cells is seen at the end of the winter period (see Figure 1). Such a decrease has also been described by other authors (Peter et al., 1981; Kennedy and Wilkins, 1984). Swiersta (1970) found no differences in testicular development, sperm production or semen quality between boars kept in outside pens (ambient temperature: $-18^{o}C$) or inside pens (ambient temperature: $+17^{o}C$) during the winter. It should be noted, however, that the boars in the outside pens were fed ad libitum while boars in the inside pens were fed restricted.
Verstegen et al.(1971), Holmes and MacLean (1974), Hovell et al. (1977), Geuyen et al. (1984) and Verhagen et al. (1986) showed

that ambient temperature can have a large influence on the energy metabolism of non lactating breeding sows. At low ambient temperatures a large portion of the sow diet is used for thermoregulatory processes. The literature review in chapter I describes that in rams and bulls, low feeding levels (at or below maintenance) reduce the number of produced sperm cells (maintenance is defined as the dietary energy level at which the energy balance of an animal is zero). Boars on A.I.Centres are fed normally at low feeding levels to prevent overweight which is believed to cause leg weakness and libido problems (Westendorf and Richter, 1977). Moreover, in practice no corrections on the feeding levels are made for low ambient temperature during the winter period unless it is concluded that the condition of the boar becomes unsatisfactory poor.

Energetic undernutrition induced by low ambient temperature might explain the reduced semen production in the winter period. Two trials were carried out to investigate the effect of ambient temperature on the energy metabolism of a boar. These trials are described in chapters III and IV.

Boars need feed for maintenance, growth and reproductive processes. There is no literature available on the energy requirements for reproduction and whether this energy requirement is influenced by the semen collection scheme which is applied. Two trials on the influence of the semen collection scheme on the energy metabolism of breeding boars are described in chapter V.

In chapter VI a medium feeding level, an ad libitum feeding level and a very low feeding level are applied to study whether the differences in feeding level have consequences for the reproductive performance in boars.

The experiments as described in this thesis are performed to contribute to the development of a feeding strategy for breeding boars. Because the development of a good feeding strategy is a life time's work, we concentrated on typical problems as found in literature (feeding high protein levels or no information on the energy costs of reproduction) and on A.I.Centres (reduction in semen production at the end of the winter).

In the general discussion a feeding strategy for breeding boars based on the aforementioned experiments and literature data on sows is developed and discussed.

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CHAPTER I

THE INFLUENCE OF ENERGY AND PROTEIN INTAKE ON THE REPRODUCTIVE PERFORMANCE OF THE BREEDING BOAR. A REVIEW

B. Kemp and L.A. den Hartog.

Animal Reproduction Science: in press

ABSTRACT

Reproductive performance of a boar can be described by three characteristics: libido, number of produced sperm cells per time unit and fertilizing capacity of the sperm cells. The influence of energy and protein intake on reproduction in boars has not been studied very thoroughly. The scarce literature indicates that libido is normally not affected by protein or energy intake, although it has been shown that an extremely poor condition as a result of prolonged undernutrition of a boar results in a reduced libido. From literature on rams and bulls it is concluded that energy intake at or below the defined maintenance requirement reduced the number of sperm cells produced. For boars, only experiments with very few animals or feeding levels well above maintenance are available and they showed no effect on semen production. Data in the literature on the influence of protein intake on the number of produced sperm cells are contradictory. Some authors state that 280 g of crude protein, 11.6 g lysine and 7.2 g methionine plus cystine is enough when feeding 30 MJ metabolizable energy, while other authors state that this should be 743 g of crude protein, 54 g lysine and 37 g methionine plus cystine. It is argued that ejaculation frequency, age and weight of the boar greatly influence on protein requirements. The effect of energy and protein intake on semen quality seems to be very small.

INTRODUCTION

Optimal reproductive performance of a boar is of great importance for the pig industry, since a relative small number of boars is fertilizing a large number of sows. This review is focussed on the influence of intake of energy and protein on reproductive capacity of breeding boars. Experiments on the influence of protein or energy intake during rearing of boars are not included in this review.

Process of sperm formation

Spermatogenesis is the entire process of transformation of the stem cell or A-type spermatogonium, to a spermatozoon. The

process begins in the tubular wall, which is lined by spermatogonia (the so-called stem cells). Such a cell undergoes a series of mitotic divisions which results in one undifferentiated stem cell and a number of primary spermatocytes. After the mitoses, haploid spermatids are formed in meiotic devisions. The third and final step in spermatogenesis involves the transformation of spermatids into spermatozoa. (including formation of a tail and development of mitochondria; Stabenfelt and Edqvist, 1984). Spermatozoa migrate from the lumen of the seminiferous tubuli to the epididymis. In the epididymis a gradual maturation of the sperm cells takes place. Amann (1988) reported in his review that boar sperm cells closer to the cauda epididymis showed a higher percentage of motility and resulted in higher pregnancy rates after insemination compared to sperm cells closer to the caput epididymis.

Two types of cells are responsible for hormone production within the testes: the Leydig cells (or interstitial cells) and the Sertoli cells. The Leydig cells produce testosterone which is important for the maintenance of the spermatogenesis, and especially for the process of meiosis. Testosterone is also important for development and maintenance of libido, secretory activity of the male assessory organs and general body features associated with the male phenotype such as increased muscle mass. The Sertoli cells (nursing cells) produce androgen-binding protein (ABP) which is secreted into the lumen of the tubules where it binds with testosterone and other androgens. The functions of this protein is unknown although it may serve to stabilize the concentration of androgens in the seminiferous tubules. The Sertoli cells are also believed to be the source of inhibin, a protein molecule which is supposed to have a suppresive effect on FSH (follicle-stimulating hormone). The exact control of inhibin secretion and the means by which it may control FSH secretion remain to be investigated.

The endocrine control of spermatogenesis is complicated. The main organ involved is the pituitary gland. However, other hormonal factors such as testosterone are also essential. The pituitary produces two hormones which influence semen production, the luteionizing hormone (LH) and FSH. LH stimulates the production of testosterone. It has been shown that testosterone alone is enough to maintain sperm production in rats, however only 70% of

the normal number of sperm cells will be produced (Courot,1988). Not all stages of spermatogenesis are equally dependent on hormones, some stages being more sensitive than others to a given hormone. Species differences are also seen at the different stages. This hormone dependency at different stages of spermatogenesis has not been clarified for the boar. Therefore it is difficult to translate the hormone profiles found in feeding trials with boars into clear quantitative production components. Whether or not changes in certain hormone profiles will result in improved reproductive performance is questionable. This review is therefore restricted to a discussion of effects of protein and energy nutrition on libido, the number of sperm cells produced and the fertilizing capacity of the semen.

In trials on the effects of nutrition on reproduction in boars, a large preliminary period is needed. According to Singh (1962), it will take 25 days before a sperm cell which is formed from an A-type spermatogonium (stem cell) appears in the epididymis. Swiersta (1968b) considered 34.4 days as a reasonable approximation of the duration of spermatogenesis in boars. The sperm cells stay in the epididymis for about 10 (Swierstra, 1968b) to 14 (Singh, 1962) days after leaving the testes. Therefore it can be concluded that feeding experiments with boars should contain a preliminary period of at least 6 weeks.

LIBIDO

Measuring techniques.

Libido is usually estimated by the ratio between number of refused mountings to number of successful mountings. A successful mounting means the production of an ejaculate on a sow or a dummy. Sometimes the time taken for a boar to mount a dummy or a sow and to produce an ejaculate is recorded. Berger et al. (1981) scored libido of boars, exposed for 5 min to oestrus-induced ovariectomized gilts. They distinguished 9 different classes: 0, no sexual interest; 1, some sexual interest; 2, great deal of interest; 3, one or more false mounts; 4, one correct mount; 5,repeated correct mounts; 6, penis extension; 7, intromission; 8, ejaculation.

Energy

Stevemer et al. (1961) studied six, 22-months-old Yorkshire boars. For a period of 15.5 months two boars were fed ad libitum (74.5 MJ digestible energy (DE)/day), two boars according to the N.R.C. recommendations (Beeson et al.,1959,40.2 MJ DE/day) and twoboars 75 % of the N.R.C. recommendations during thefirstsix months and 50% for the rest of the experiment. The boars on the low feeding level lost large amounts of body fat (backfat thickness decreased during the experimental period from 36 mm to a level too thin to measure). In the 15th month of the experiment the boars on the low feeding level refused to serve the artificial vagine during a period of two weeks. In the ad-libitum-fed boars as well as medium-fed boars no libido problems were detected. The ad-libitum-fed boars had a backfat thickness of 76 mm at the end of the experiment. These data suggest that no effect of energy intake on libido can be expected if boars are not in an extremely poor condition.

Protein

Ju et al. (1985) studied 12 boars fed a basal diet or a basal diet supplemented with 0.32% lysine, 0.25% methionine or 0.32% lysine plus 0.25% methionine. Semen was collected 3 times a week for 12 weeks. No significant differences in libido were found between boars on different diets.

In other experiments described in literature in which semen production characteristics were recorded, libido was not scored. It may be inferred that effects on libido were probably small because no mention was made of problems with collecting ejaculates.

The scarce literature indicates that libido is hardly affected by protein or energy intake. Only an extremely poor condition as a result of prolonged undernutrition may result in reduced libido.

NUMBER OF SPERM CELLS PRODUCED

Measuring techniques

The number of sperm cells can be estimated using several techniques.

1/ The number of sperm cells per ejaculate is counted. This

method is commonly used (Stevemer et al., 1961; Yen and Yu, 1985).

2/ The testicular histology is studied quantitatively. (Kennelly and Foote, 1964; Swierstra, 1966, 1968a). For this method animals are killed and the testes, or sections of the testes, are homogenized and from the number of cells in different stages of development the number of sperm cells produced is estimated.

3/ The number of sperm cells in the epididymis is counted and the reproductive organs, such as testes and seminal vesicles, are weighed. (Braden et al., 1974).

4/ The number of spermatozoa voided through a rete testes catheter is counted (Voglmayr et al., 1967; Lino and Braden, 1972; Alkass et al., 1982). This method has been described only in rams.

5/ The number of sperm cells in the urine in animals which are sexually resting is counted. (Lino and Braden, 1972; Alkass et al., 1982). This method has been described only in rams.

From a comparison of methods 4 and 5 by putting a catheter in one of the two rete testes and leaving the other rete testis intact Voglmayr et al. (1967) concluded that counting the number of sperm cells voiding in the urine was a very accurate method of estimating the number of sperm cells produced (R^2= 0.999). They also concluded that the number of sperm cells measured by using the catheter was about equal to the number of sperm cells voided in the urine from the other testis in sexually resting animals.

The number of sperm cells per ejaculate varies widely depending on stimulation of the boar, the person collecting the semen and the collection frequency. A great advantage of the first method, however, is that one measures the number of collected sperm cells, and that is the parameter of interest. A disadvantage of the methods 2 to 4 is that they involve surgical intervention. It is questionable whether this leads to a good estimation of the number of sperm cells produced. The fifth method gave very promising results in rams (Alkass et al., 1982). In this method the variation in semen production due to mating frequency and semen collector is absent (Alkass et al., 1982). In rams the output of sperm cells in the urine seemed to fit closely to the true production in the testes since there appears to be no resorption in the epididymis. Whether or not resorption takes place in the epididymis of boars is still uncertain. Stabenfelt and Edqvist

(1984) concluded from their literature review on male animals that only few sperm cells were resorbed in the epididymis.

Energy

In the experiment of Stevemer et al. (1961) described above, no significant difference in the number of sperm cells per ejaculate was found between boars with the different feed intake levels. However, these boars were in an extremely good condition at the start of the experiment (backfat thickness about 40mm). The difference in sperm production per ejaculate between ad-libitum and low-level-fed boars was 34% in favour of the former. Due to the small number of boars and the large variation between and within animals, this difference was not significant. Measuring the number of sperm cells per ejaculate as a reproductive parameter requires a large number of boars in experiments of this kind. Yen and Yu (1985) did a 1-year lasting experiment with 96 1-year old breeding boars fed at two levels (28.0 MJ and 33.5 MJ DE/day). They reported no effect of energy intake level on the number of sperm cells per ejaculate (collected at a 4-days interval). More detailed information on one-third of the data from Yen and Yu (1985) is given by Yen et al. (1982). The 1-year-old boars in the experiment of Yen et al. (1982) weighed on average 133 kg at the beginning and 185 kg at the end of the experiment. Assuming a maintenance requirement of 447 kJ metabolizable energy (ME)/kg^{75}/d (Kemp et al., 1989) the boars at the low feeding level of Yen et al. (1982) were fed 1.2 to 1.5 times the energy requirement for maintenance.

No effects of energy intake were found on the number of sperm cells produced by boars. In rams and bulls, however, clear effects of energy intake on semen production were found. From literature on rams (Alkass et al., 1982) and bulls (Keraby et al., 1983; Coulter and Kozub, 1984) it can be concluded that male animals fed at or below maintenance will have a reduced reproductive capacity compared to animals fed well above maintenance. This might explain why Yen et al. (1982) found no differences in reproductive performance between the boars fed 1.2 and 1.5 times maintenance.

TABLE 1

Summary of the experiments describ ing the effect of energy and protein intake on reproductive performance in boars

Type of animal	Breed	No. of animals		Type of exp.*	Age or weight	Range of energy	
		Total	Per treatment			Absolute	× Maintenance
Boar	Yorkshire	6	2	F	22-37.5 months	26.3-72.2 MJ DE/ day	0.8.1.8
Ram	Merino	62 10	15-16 3-4	EP	2 years 5 years	44-98 MJ DE/d	
Boar	German Land-race/German edelschwein	28	7	P/AAS	8-18 months	30 MJ ME/ day	-
Boar	-	90	43-47	P	-	1.00 SFU/kg	-
Ram	-	16	8	F	20-40 weeks	-	0.74-1.25, 1.5
Bull	Friesian	35	11-12	F	?	-	1.0 x g ad lib., intermed.
Bull	Hereford Aberdeen Angus	120	60	E	6-24 months	502-630 KJ/$kg^{0.75}$	1.2-1.5
Boar	Landrace Duroc	96	12	EP	1-2 years	28.0-33.5 MJ DE/ day	1.2-1.5
Boar	Landrace	12	3	AAS	6-12 months	34.3 MJ DE/ day	-
Boar	Dutch Land race/Yorkshire	72	24	P	?	31.4 MJ ME/day	

*Type of experiment: E = energy experiment; F = feed intake experiment; EP = energy and protein investigated separately; P = protein experiment; AAS = amino acid supplementation experiment.

SFU = Scandinavian feed unit

Protein content (range)	Lysine content (range)	Methionine +cysteine content (range)	Author's conclusions	Reference
320–863 g/d	-	-	No influence of feed intake on libido, sperm production and sperm quality	Stevemer et al. (1961)
240–1005 g/d	-	-	There were large effects of diet on semen production, the effect of energy intake being much greater than that of protein	Braden et al. (1974)
-	-	-		
506.6–743.7 g/d	42–57 g/d	21–38 g/d	Positive effects on semen production of extra protein, and addition of lysine and methionine in boars at a mating frequency of 3–4 times a week, no effects at 1–2 times a week. No effects on semen quality	Poppe et al. (1974)
158–184 g/kg	7.1–8.7 g/kg	5.2–5.7 g/kg	No effects on sémen quantity and quality	Meding and Nielsen (1977)
-	-	-	The low feeding level reduces sperm production. No influence on semen quality	Alkasa et al. (1982)
-	-	-	Low semen production at maintenance level of feeding	Keraby et al. (1983)
-	-	-	Hereford bulls fed high energy diets show decreased sperm production and quality. No effect in AA bulls.	Coulter and Kozub (1984)
200–394 g/d	6.2–18.2 g/d	5.8–9.6 g/d	Sperm quality and quantity is unaffected by energy intake. A minimum intake of protein to maximize semen production = 280 g/d, 11.8 g lysine and 7.2 g methionine	Yen and Yu (1985)
289 g/d	0.45–0.77	basal + 0.25	No significant effects on libido, semen quantity and semen quality	Ju et al. (1985)
405–455 g/d	18.5–22 g.d	15.3–19.5 g/d	No effect of protein intake on semen production. High methionine and lysine intake has negative effect on semen quality	Van der Kerk and Willems (1985)

Protein

Various experiments have been carried out on the effect of protein, and more specifically the amino acids lysine and methionine plus cystine, on the number of sperm cells produced. Detailed information on the level and composition of the diets in these experiments is not often given. Nevertheless it is possible to give a summarize of experiments on the relation protein feeding and fertility in boars.

Boars given various levels of protein were compared with animals on an unknown basal diet (Kolenko, 1977; Zabut'ko, 1977; Yurin, 1981; Ovchinnikov, 1984). Protein intake seemed to influence the number of sperm cells produced. At low protein levels the number of sperm cells ejaculated decreased. A certain amount of protein in the diet seems to be necessary to ensure maximal production of sperm cells. However, because no detailed information was found on the experiments and significance of the data, it is difficult to draw conclusions from these experiments.

The fact that low protein levels reduced the number of produced sperm cells is confirmed by experiments from Yen and Yu (1985) who measured the number of sperm cells produced by 96 1-year old boars fed on four protein levels. The number of sperm cells produced reached a maximum at an intake of 280 g of crude protein, 11.6 g lysine and 7.2 g methionine plus cystine per day (at an energy intake of 28.0 or 33.5 MJ DE/day). No further increase in number of sperm cells was found at higher protein levels.

The boars in these experiments were between 1 and 2 years old and weighed about 133 to 185 kg. This is a relatively low liveweight because modern breeding boars can weigh 250 kg or more at this age. Hence, growth and protein requirement for growth will have been lower in the animals of Yen and Yu (1985) compared to modern breeding boars.

Investigations on the influence of specific amino acids on sperm production always describe the effects of the two essential amino acids lysine and methionine. Positive effects of supplementation on the number of sperm cells were found by Moskutelo (1970, lysine supplementation), Tomme and Loskutnikov (1972, methionine supplementation) and Zaripova and Shakirov (1978, lysine plus methionine supplementation). Ju et al. (1985) found no effect of dietary supplementation of lysine and methionine either together

or separately.

In 1974 Poppe et al. did a well documented experiment with 28 A.I. boars (20 boars were 8 - 14 months old and 8 boars were 12 - 18 months old). One group of boars received a low-protein diet (507 g crude protein (CP)/animal/day) and 3 other groups a protein rich diet (744 g CP/animal /day). The three high protein diets were supplemented with synthetic lysine, methionine or not supplemented, respectively. All boars were kept on a low mating frequency of 1 - 2 times a week for 6 - 8 weeks and then on a high mating frequency of 3 - 4 times a week for 6 to 8 weeks. Number of sperm cells produced and sperm quality were determined (see Table 1).

At low mating frequency, the differences in sperm production between groups were not significant. At high mating frequency, the sperm production in the groups of boars given synthetic amino acids was significantly higher than in the other groups. Extra lysine increased the number of sperm cells produced by 7% and the extra methionine increased the number by 28%. Poppe et al. (1974) also calculated that in the high-mating-frequency period the young boars kept at the low protein levels showed a linear decrease in time in the number of sperm cells produced while sperm production in boars at high protein levels remained stable. They concluded that sperm production could be improved by feeding extra protein or extra lysine and methionine when boars were used intensively.

Van der Kerk and Willems (1985) reported an experiment with 72 A.I. boars fed one of three diets, a basal diet, a diet containing extra methionine and diet containing extra lysine and methionine (see Table 1). In contrast to the results of Poppe et al. (1974) they found no effect of protein and amino acid supplementation on the number of sperm cells produced. Meding and Nielsen (1977) also found no effect of feeding a diet containing 184 g of crude protein compared to a diet containing 158 g of crude protein on the number of sperm cells produced. However the mating frequency in both experiments was rather low: twice a week in the experiment of Van der Kerk and Willems (1985) and 6.4 times a month in the experiment of Meding and Nielsen (1977). Poppe et al. (1974) stated that the positive effect of protein and amino acid supplementation on sperm production is only found at high mating frequencies.

One can conclude that the effects of protein and amino acid supplementation on sperm production of boars as reported in literature are contradicting. Yen and Yu (1985) concluded that a daily intake of crude protein, lysine and methionine plus cystine of 280, 11.6 and 7.2 g/day, respectively, is enough to ensure a good rate of reproduction (ME-intake=26.3 to 31.4 MJ/day). Because these boars are rather slow growing, protein needs for modern breeding boars might be higher. In the studies of Van der Kerk and Willems (1985) and Meding and Nielsen (1977) no effects of higher protein levels were found. Poppe et al. (1974), however, concluded that in boars fed 744 g of crude protein per day sperm production did not decrease while in boars fed 507 g/day (ME-intake about 30 MJ/day) it did. In fact, an increase of lysine and methionine intake in the boars fed 744 g protein/day improved the sperm production still further. Mating frequency might be an important parameter in explaining these differences.

THE FERTILIZING CAPACITY OF SPERM CELLS

Measuring techniques

The only true way to measure the fertilizing capacity of sperm cells is to inseminate sows with the semen. The pregnancy rate and litter characteristics (litter size and weight of piglets) can then be determined. In literature, however, in vitro techniques are mostly described to estimate the fertilizing capacity of semen before insemination, as follows.

1/ Percentage of moving or living sperm cells.

2/ Vitality of the moving sperm cells. Vigorous straight-forward movement indicates good vitality whereas weak, slow and spasmodic movement indicates poor vitality.

3/ Counting the number of abnormal sperm cells. Abnormal sperm cells have deficiencies like bent tails, loose heads or protoplasmic droplets (as defined by Bretschneider, 1948).

4/ Number of sperm cells with morfological deficiencies of the acrosome (as defined by Pursel et al., 1972).

These methods, however, whether they are used singly or in combination, do not offer a satisfactory basis for measuring the fertilizing capacity of an ejaculate. In bovine species , which have been thoroughly studied in this respect, the findings

revealed serious shortcomings in all the currently used laboratory tests. None of them predict with certainty the fertilizing capacity of a semen sample. At best, the laboratory tests indicate certain limits outside which a semen sample may be expected to have a smaller fertilizing capacity. However, the minimum quality of an ejaculate with regard to in vitro quality parameters is still a matter of discussion (Mann and Lutwak-Mann, 1981).

Energy

Stevemeret al. (1961) reported no effect of feed intake on the percentage of moving sperm cells. Yen and Yu (1985) found no effects of energy intake on the percentage of abnormal sperm. Data on rams (Alkass et al., 1982) also show no effect of energy intake on semen quality. Only data on bulls from Coulter and Kozub (1984) show that both high (above 1.5 x maintenance) and low energy intake (maintenance) lead to reduced semen quality.

Protein

The effect of protein intake on sperm quality is not clear. Experiments which describe the influence of high or low levels of protein compared to a basal protein intake (Kolenko, 1977; Zabut'ko, 1977; Yurin, 1981; Ovchinnikov, 1984) on the percentage of moving sperm cells show no effect of the amount of protein in the diet. Yen and Yu (1985) found no significant effect of increasing the dietary protein level from 10 to 16% on the percentage of deformed sperm cells in the ejaculate.
Some experiments on the effect of lysine and/or methionine supplementation in the diet on semen quality show positive results. A reduced percentage of abnormal sperm was found by Zaripova and Shakirov (1978) when extra lysine or lysine plus methionine was given. Higher pregnancy rates were reported by Stancioiu and Predica (1980) when lysine was added to the diet and by Tomme and Loskutnikov (1972) with supplementing methionine. No positive effects of lysine and/or methionine supplementation on semen characteristics were found by Ju et al. (1985). Detailed information on the diet and feeding level is not given for the experiments on the effect of amino acids on semen quality as mentioned

above.
As shown in Table 1 no effects of treatments on percentage of moving sperm cells, pregnancy rates and number and weight of piglets born were found by Poppe et al. (1974). Meding and Nielsen (1977) also found no effect of amino acid intake on pregnancy rates and number of piglets. Van der Kerk and Willems (1985) determined morphology of sperm cells (Bretschneider, 1948) and percentage of moving sperm cells and found no effect of the supplementing lysine and/or methionine. They did, however, find a slightly lower non-return percentage (90.5 vs 88.3) and more damaged acrosome heads in boars fed extra methionine. They explained this by a possible imbalance in amino acids fed because of the relatively high supplementation of methionine.
The effect of energy and protein intake on semen quality seems to be very small.

EFFECTS OF FEEDING LEVEL OR DIETARY ENERGY ON HORMONES

Setchellet al. (1965) fed six rams ad libitum and six rams at a very low feeding level which depleted their fat reserves during a period of 3 months. At the end of this period they measured the blood flow to and from the testes, the oxygen and glucose uptake per unit weight of testes and the testosterone output from the testes. They found that testes of underfed rams had a lower oxygen and glucose uptake than those of the ad-libitum-fed rams. The testosterone output of the underfed rams was 0.4 mg/day per ram compared to 3.5 mg/day per ram in the well-fed rams. Spermatogenic activity (measured by diameter of the seminiferous tubuli), sperm content of the epididymis and other parameters were lower in underfed rams. Alkass et al. (1982) found a highly significant difference in LH content in the pituitary gland in rams fed 1.25 - 1.5 times maintenance compared to those fed 0.75 times maintenance.

One can conclude from the literature that the reproductive performance in males is influenced by the amount of energy and protein given. The amount of energy and protein needed to ensure good reproductive performance of boars is unknown; however, from experiments in rams and bulls it is likely that the energy intake must be well above maintenance. Literature on protein intake and

reproductive performance in boars is not unanimous in its conclusions. Systematic research on the effect of energy and protein in breeding boars is still lacking.

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CHAPTER II

THE EFFECT OF A HIGH PROTEIN INTAKE ON SPERM PRODUCTION IN BOARS AT TWO SEMEN COLLECTION FREQUENCIES.

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ABSTRACT

A protein rich diet was fed to half of 97 Yorkshire boars maintained at two semen collection frequencies in two experiments measuring sperm production and semen quality.
The boars were fed a control diet (12.56 MJ metabolizable energy (ME) per kg, 14.5% crude protein, 0.68% lysine and 0.44% methionine plus cystine) or an isocaloric diet with increased protein content (12.56 MJ ME per kg, 22.2% of crude protein, 1.20% lysine and 0.81% of methionine plus cystine). The sperm collection occurred either three to four or six times in two weeks (low or high collection frequency). None of the parameters were influenced by amino acid supply. The semen collection frequency influenced the number of ejaculated sperm cells ($P < 0.0001$). The number of ejaculated sperm cells per day was increased if the semen collection frequency increased. Sperm quality was not influenced by semen collection frequency.
The control diet contained enough protein to ensure good sperm production of a boar used for Artificial Insemination.

INTRODUCTION

Sperm production can be defined as the number of good quality sperm cells which are ejaculated within a certain time. Parameters which are commonly used to assess quality are the percentage of living sperm cells and the subjectively scored vitality of the sperm cells. The level of dietary protein may influence the reproductive performance of the boar (review Westendorf and Richter, 1977). However, the reports on the effect of protein in the diet on sperm production in the literature are contradictory. Literature sometimes shows an increased sperm production when boars are fed extra protein (Kolenko, 1977), or, more specifically, extra lysine and methionine (Moskutelo, 1970; Poppe et al., 1974). On the other hand, Meding and Nielsen (1977) and Van der Kerk and Willems (1985) found no effect of extra dietary protein on sperm production in boars. Semen collection frequency might be an important characteristic in explaining these differences. Poppe et al. (1974) found a significant improvement of the sperm production caused by high protein levels at high semen collection frequencies (3-4 times a week) and not at low frequencies (1 or 2

Table 1:Formulation and chemical analyses of the diets.

Diet	Control diet (%)	Protein rich diet (%)
Ingredients		
Animal fat	1.20	-
Meat meal tankage	-	1.00
Peas	10.00	7.50
Alfalfameal	2.70	2.80
Maizeglutenfeed	4.20	-
Hominy feed	15.45	7.40
Cane molasses	5.00	-
Soybeans (toasted)	3.00	2.00
Soybeanmeal (solv. extracted)	9.10	35.80
Tapioca	16.35	25.29
Wheat middlings	20.00	-
Wheat	-	15.00
Vitamin mineral mixture*	0.20	0.20
Synthetic methionine	-	0.16
Dicalcium phosphate	0.95	1.20
Chalk	1.00	0.80
Mineral	0.50	0.50
NaCl	0.35	0.35
Analyses (as fed)		
Dry matter	86.03	85.69
Ash	7.87	7.24
Crude protein	14.47	22.22
Crude fat	3.28	1.68
Crude fibre	5.42	5.37
Indispensable amino acids		
Arginine	0.96	1.52
Histidine	0.35	0.54
Iso leucine	0.57	0.94
Leucine	1.01	1.58
Lysine	0.68	1.17
Methionine	0.22	0.48
Phenylalanine	0.65	1.06
Threonine	0.57	0.85
Valine	0.70	1.09
Dispensable amino acids		
Alanine	0.68	0.96
Aspartic acid	1.42	2.32
Cystine	0.22	0.33
Glutamic acid	2.62	4.08
Glycine	0.63	0.95
proline	0.88	1.18
Serine	0.76	1.14
Tyrosine	0.47	0.72

* Contributed the following mineral and vitamin sources per kg diet: 1.64 g Ca, 0.2 g P, 10 mg Cu, 24 mg Mn, 40 mg Zn, 80 mg Fe, 0.25 mg Co, 0.4 mg I, 0.1 mg Se, 12000 I.E. Vit. A, 2400 I.E. Vit. D3, 4 mg Vit. B2, 18 mg Niacine, 7 mg d-panthothenic-acid, 250 mg Choline, 0.015 mg Vit. B12, 22 mg Vit. E, 0.1 mg Biotine, 0.2 g dl Methionine.

timesa week). The semen collection frequencies in the experiments of Van der Kerk and Willems (1985) and Meding and Nielsen (1977) were relatively low (2 times a week and about 6-7 times per month, respectively).
In the present study, the objective was to test whether the sperm production of boars on different semen collection frequencies could be improved by feeding a boar a protein-rich diet as compared to a normal commercial sow diet. Changes in body weight and backfat thickness were also investigated.

MATERIAL AND METHODS

The study was performed at two Artificial Insemination Centres (defined as Experiment 1 and 2). In Table 2, number of boars, starting weight, age at the start and the number of produced sperm cells per ejaculate in the month previous to the preliminary period are shown for both experiments.

Table 2: Number of boars, live weight (kg), age (days) at the start of the experiments and the number of sperm cells per ejaculate ($x10^9$) in the month preceding the experiments (sd).

Experimental parameters	Experiment			
	1		2	
Number of boars	36		61	
Start weight (kg)	215	(5)	266	(5)
Age at start (days)	407	(17)	621	(35)
Sperm cells / ejaculate preceding trial ($x10^9$)	66.0	(2.3)	86.4	(3.3)

The boars in Experiment 1 (36 boars) were housed individually in pens with a partially slatted floor. The boars in Experiment 2 were individually housed in cubes with slatted floors. Including the preliminary period, the experiments lasted from January to May, 1986. The preliminary period was 42 and 49 days and the main

period 59 and 52 days for Experiments 1 and 2, respectively. The preliminary period of at least six weeks was to take into account the production of a sperm cell from an A-type spermatogonium, including the time to pass the epididymus, about 39 to 44.5 days (Singh, 1962; Swierstra, 1968).
The minimum/maximum barn temperatures in the preliminary period were 13.3°C (sd = 1.7) and 16.8°C (sd = 1.0) for Experiment 1 and 13.8°C (sd = 1.6) and 17.7°C (sd = 0.9) for Experiment 2. The minimum/maximum temperatures in the main periods were 15.0°C (sd = 1.3) and 18.8°C (sd=1.3) for Experiment 1 and 16.6°C (sd = 1.4) and 20.0°C (sd = 1.1) for Experiment 2, respectively.
The experiments were carried out as a 2x2 factorial design with two types of diet and two semen collection frequencies.

Diets

In both experiments, half of the number of boars were fed the protein-rich diet and the remaining boars received the control diet. The composition of the diets is given in Table 1. The boars were fed the experimental diets from the start of the preliminary period. They received as an average 45 g and 43 g of diet per (kg liveweight)$^{0.75}$ in Experiments 1 and 2, respectively.

Semen collection frequency

Within each diet, the boars were divided into two groups and kept on a fixed semen collection scheme. The semen collection frequency in one group was 3 times a week (high semen collection frequency). For the other group, semen collection frequency was twice a week in Experiment 1 and 3 times over two weeks in Experiment 2 (low semen collection frequency). These fixed semen collection schemes were implemented at the beginning of the main period. During the preliminary period, all boars were kept at the same collection frequency. In this period the collection interval was 3.5 days (sd = 1.6) and 4.0 days (sd = 2.0) for Experiments 1 and 2, respectively. The boars were assigned to treatments on the basis of age and number of sperm cells per ejaculate in the month previous to the preliminary period.

MEASUREMENTS

Refused mountings

The boars had to mount a dummy to produce an ejaculate. If the boars did not mount the dummy and/or did not produce an ejaculate this was considered a refused mounting. For each boar the percentage of refused mountings was calculated.

Number of sperm cells

Ejaculates were collected by hand glove technique and the gelatinous fraction was removed from the ejaculate using a gauze. The volume of each ejaculate was measured. The concentration of sperm cells was measured colorimetrically (Niwa et al., 1981). Using the volume of the ejaculate and the concentration, the number of sperm cells per ejaculate was calculated. The number of sperm cells per day was calculated by dividing the number of sperm cells per ejaculate by the semen collection interval preceding that ejaculate. The mean number of sperm cells per ejaculate was also calculated for each boar.

Quality of the ejaculate

The quality of the ejaculate was determined by microscopic examination. Quality was assessed using two parameters, the percentage of moving cells and the vitality of the movement of the ejaculate. Each quality parameter received a score varying from zero (very bad) to ten (extremely good). The vitality of the movement was defined to be a weak, slow and spasmodic movement of the sperm. For each boar, the mean sperm quality per ejaculate was calculated.

Bodyweight and backfat thickness.

From each boar, length, heart girth and backfat thickness (ultrasonically) were measured similarly to Verstegen et al. (1979). This was done three times: at the beginning of the preliminary and the main period and at the end of the main period. Live weight was measured at the start and end of the main period. Live

weight at the beginning of the preliminary period was estimated by its relation with heart girth, age, length, and backfat thickness of the boar as calculated from data in the main period. (R^2, Experiment 1 = 0.93; R^2, Experiment 2 = 0.98). With these data, growth and backfat development of the boars could be estimated during the preliminary and main period.

STATISTICAL ANALYSES OF THE RESULTS

All analyses were performed seperately for each experiment. The percentage of refused mountings was transformed to a normally distributed rank number using the BLOM version of SAS-RANK (SAS, 1985). For each boar, this rank number, as well as the average number of sperm cells per ejaculate, the average quality of the ejaculates, body weigth growth and development of backfat thickness, have been subjected to analyses of variance (using SAS-GLM; SAS, 1985) according to Model 1. Average values were weighed with the reciprocals of their variances.

$$Y_{ijkl} = u + D_i + MF_j + HG_k + e_{ijkl} \qquad \text{(Model 1)}$$

Y_{ijkl} - the dependent variable
u - the overall mean
D_i - the effect of the i-th diet (i = 1,2)
MF_j - the effect of the j-th collection frequency (j = 1,2)
HG_k - the effect of the k-th heart girth class (k = 1,...,4)
e_{ijkl} - error

Treating heart girth as a variable with four discrete classes, rather than as a contineous one, provided a better fit of the model.
The interval between two semen collections might have a direct effect on the number of sperms produced per ejaculate and per day. Within each semen collection frequency class in Model 1, different semen collection intervals occur. To analyze the influence of collection interval on the number of sperm cells produced in the ejaculate and per day, these parameters have been analyzed using Model 2.

$$Y_{ijkl} = u + B_i + MI_j + P_k + e_{ijkl} \qquad \text{(Model 2)}$$

Y_{ijkl} - the dependent variable
u - overall mean
B_i - the effect of the i-th boars (i = 1,...,36 for Expt. 1, i = 1,...61 for Expt. 2)
MI_j - the effect of the j-th length of semen collection interval, if collection interval is between collection and the previous sperm collection (j = 1,...,4)
P_k - the effect of the k-th two week period (k = 1,...,5 for Expt. 1 and 1,...,4 for Expt. 2)
e_{ijkl} - error

None of the interaction effects was found to be significant in either model. All tests of significance were performed against error terms. Post-hoc analyses of length of semen collection interval effects were performed using Scheffe's-test (using SAS-GLM; SAS, 1985).

RESULTS

Culling

Two boars were culled in Experiment 2, one boar for leg weakness and one boar because of a poor breeding index. There was no indication that culling rate was influenced by treatments.

Sperm production

Refused mountings

Twenty-five percent of the boars in Experiment 1 and 13% of the boars in Experiment 2 refused to mount the dummy one or more times in the main period. On the average, those boars which refused to mount, did so 2.1 and 1.4 times in the main period for Experiments 1 and 2, respectively. The percentage of refused mountings among boars at the low semen collection frequencies was 4.7% compared to 0.3% among those at the higher frequencies. This difference was not significant ($P > 0.10$) and was not influenced by diet ($P > 0.10$); (R^2, Expt. 1 = 0.14; R^2, Expt. 2 = 0.18).

Table 3: Least square mean estimates (LSM) of the mean number of sperm cells per ejaculate per treatment group ($x10^9$).

	Experiment 1	Experiment 2
Type of diet		
Control	38.6	37.4
Protein-rich	38.4	36.2
Semen collection frequency		
Low	46.5^a	45.6^a
High	30.4^b	28.0^b

^{a,b}Data with different superscripts in the same column differ ($P<0.05$).

R^2 Expt. 1: 0.49; R^2 Expt. 2: 0.54.

Number of sperm cells

In the main period, 761 and 973 ejaculates were collected in Experiments 1 and 2, respectively. On the average, the number of sperms produced in Experiment 1 was 39.8×10^9 per ejaculate and 13.3×10^9 per day. The average number of sperms produced in Experiment 2 was 36.7×10^9 per ejaculate and 10.55×10^9 per day. Analyses of the mean number of sperm cells per ejaculate per boar (Model 1) showed no effect of heart girth ($P > 0.05$). In Table 3, the least-squares mean estimates of the mean number of sperm cells per ejaculate are given per treatment group. In both experiments, differences between the boars on the protein-rich diet and the boars on the control diet were not significant ($P > 0.10$). The differences associated with semen collection frequency were highly significant ($P < 0.0001$). The number of sperm cells per ejaculate from boars on the high frequency was 35-39% lower for Experiments 1 and 2, respectively, compared to the low semen collection frequency.

To obtain further information on the influence of semen collection interval on the number of sperm cells in an ejaculate and per day, Model 2 was used. The semen collection interval significantly affected the number of sperm cells produced per ejaculate

and per day ($P < 0.0001$). In Table 4 the least square means for different semen collection intervals (days) are given. A semen collection interval of 4 days compared to 2 days increased the number of sperm cells produced per ejaculate by 31-41% but reduced the number of sperm cells produced per day by 29-32%. Ejaculates collected with shorter collection intervals contained a lower number of sperm cells, but, if calculated per day, resulted in more sperm cells.

Table 4: Least squares means of the number of sperm cells per ejaculate and the number of sperm cells per day at different semen collection intervals*.

Semen collection interval (days)	Number of sperm cells per ejaculate ($x10^9$)				Number of sperm cells per day ($x10^9$)	
	n	Expt. 1	n	Expt. 2	Expt. 1	Expt. 2
2	307	34.1^{a}	385	31.8^{a}	16.2^{a}	15.1^{a}
3	265	39.8^{bd}	314	36.8^{b}	13.3^{b}	12.3^{b}
4	168	44.8^{c}	33	44.7^{c}	11.0^{bd}	10.7^{abc}
≥ 5	21	51.3^{cd}	241	48.6^{c}	10.5^{cd}	9.2^{c}

Data with different superscripts in the same column differ ($P<0.05$).

* Expt.1 $R^2=0.52$, RSD=12.1; Expt.2 $R^2=0.54$, RSD=13.2.

The quality of the ejaculates

The mean boar score for percentage of movement was the same as the mean boar score for quality of movement, 6.9 and 7.3 in Experiments 1 and 2, respectively. Type of diet and semen collection frequency did not influence either quality parameter significantly (collection frequency, $P > 0.10$; type of diet, $P > 0.10$).

Growth and backfat thickness development

Growth of the boars in the preliminary period was, on the average, 143 g/day for animals in Experiment 1, while in Experiment

2, animals lost 125 g/day. Backfat thickness decreased in the preliminary period with 0.5 mm as a mean in Experiment 1 and 1.8 mm in Experiment 2.

In the main period, animals gained 421 g/day and 497 g/day in Experiments 1 and 2, respectively. Backfat thickness increased in this period by 0.9 and 2.3 mm for the two experiments, respectively. In Table 5, growth and backfat development are given for the different treatment groups in the main period. Growth and backfat development are not influenced significantly by type of diet or by semen collection frequency ($P > 0.10$).

Table 5: Growth (g/day) and backfat thickness development (mm) for treatment groups in the main period.

	LOW SEMEN COLLECTION FREQUENCY				HIGH SEMEN COLLECTION FREQUENCY			
	Control diet		Protein rich diet		Control diet		Protein rich diet	
	mean	se*	mean	se	mean	se	mean	se
Growth								
Experiment 1	385	46.7	469	17.0	433	14.7	396	19.8
Experiment 2	525	18.9	475	34.6	456	11.9	530	24.8
Backfat thickness development								
Experiment 1	0.3	0.25	1.0	0.12	1.1	0.12	1.2	0.13
Experiment 2	2.1	0.22	1.7	0.25	1.2	0.15	3.0	0.48

*se = standard error.

(R^2 growth, Expt.1: 0.60; Expt. 2: 0.47; R^2 backfat thickness development, Expt. 1: 0.70, Expt. 2: 0.30).

DISCUSSION

From the results in this experiment, it is clear that feeding a high protein diet did not influence sperm production and development in A.I. boars. Semen collection frequency had a clear influence on the number of sperm cells produced. Higher semen collection frequencies increased sperm production per day but decreased sperm production per ejaculate. Sperm quality seemed to be independent of treatments.

The results of the present study at low as well as high collection frequency agree with those obtained by Meding and Nielsen (1977) and Van der Kerk and Willems (1985). However, Poppe et al.

(1974) found a higher sperm production with a protein-rich diet at high semen collection frequencies. In the experiments of Poppe et al. (1974), the boars on the lowest protein level received 506.6 grams of protein per day, 30-32 grams of lysine and 21-22 grams of methionine plus cystine. In the present study, boars on the low protein level were fed 361.8 to 506.5 grams of protein, 17.0-23.8 grams of lysine and 11.0-15.4 grams of methionine plus cystine per day. In the experiments of Poppe et al. (1974), the growth rates of the young boars at high semen collection frequency given extra lysine and methionine was positively influenced. The higher sperm production might be partly explained by a higher growth rate. Anastasyevic et al. (1981) found a significant positive correlation between weight of the testes parenchyma and daily gain (r = 0.59). Hemsworth et al. (1983) found a positive correlation between testes weigth and amount of sperm cells produced (r = 0.74-0.80). The positive effect of extra protein on the number of sperm cells produced indicates that the low protein diet used by Poppe et al. (1974) was not sufficient for maximum growth while the low protein diet in our experiment was sufficient. However, the low protein level in the experiments of Poppe et al. (1974) was high compared to our experiments.

Differences in efficiency of protein retention might be explained by differences between experiments. Poppe et al. (1974) used German Landrace and German Edelschwein, while, in our experiments, Yorkshire boars were used. Boars in the experiment of Poppe et al. (1974) were 13 months old when kept at high semen collection frequency. Boars in the present study were 15.2 months old in Experiment 1 and 21.6 months old in Experiment 2.

From these experiments, it can be concluded that feeding a boar a diet containing 12.56 MJ metabolizable energy, 14.47% crude protein, 0.68% lysine and 0.44% methionine plus cystine per kg diet provides sufficient protein to ensure a good libido and maintain the numbers and quality of sperm produced by the A.I.boars. The semen collection frequency of boars is an important factor influencing sperm production. High semen collection frequencies increase the number of sperm cells which are ejaculated per unit of time. The optimal semen collection frequency for A.I. boars depends on the costs of collecting ejaculates and should result from an economic evaluation.

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CHAPTER III

THE EFFECT OF ENVIRONMENTAL TEMPERATURE ON METABOLIC RATE, AND PARTITIONING OF ENERGY INTAKE IN BREEDING BOARS.

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ABSTRACT

An experiment was performed to study the effect of ambient temperature on metabolic rate and partitioning of energy intake in breeding boars. In each of two trials, 4 Yorkshire boars (10-13 months old, 224 kg liveweight) were housed in balance cages in an open circuit calorimeter. Each boar was fed 480 kJ of metabolizable energy (ME) per $kg^{0.75}$/day. Semen was collected twice weekly. In both trials temperature was decreased successively from 24°C to 20, 16, 12 and 10°C (3.5 days per temperature treatment). After 7 days at 10°C, temperature was increased in reversed order to 12, 16, 20 and 24°C (each 3.5 days).
Measurements of metabolic rate were carried out every 3.5 days and collection of excreta occurred weekly.
The estimated lower critical temperature, extra thermoregulatory heat production and thermoneutral maintenance heat production were 20°C, 16 $kJ/kg^{0.75}/d/°C$, and 382 $kJ/kg^{0.75}/d$, respectively. The results from both trials were in close agreement.
Digestibility of energy, protein and dry matter and metabolizability of energy intake were not influenced by ambient temperature. Above the critical temperature, energy balance, protein and fat retention were 70 $kJ/kg\ W^{0.75}/d$, 103 g/an/d and 41 g/an/d, respectively. Below the lower critical temperature, protein and fat gain decreased about 10 and 20 g/an/d/°C. At 10°C the boars lost 156 g fat per day, while above 20°C they gained 41 g fat per day on the same feeding level.

INTRODUCTION

A decrease in the production of sperm cells was seen during the winter period at Dutch Artificial Insemination Centres (Kemp et al., 1987a). In that respect environmental and feeding conditions are important factors to consider when examining reproductive performance.
Breeding boars are usually kept at low feeding levels, only slightly above the assumed amount for thermoneutral maintenance (420 kJ $ME/kg^{0.75}$) to prevent them from getting too fat. Overweight is believed to cause leg weakness and libido problems (Westendorf and Richter, 1977). In addition, boars are often housed on a slatted or half slatted floor system. Therefore it is

clear that housing and feeding regimes are poor for boars in terms of aiding thermoregulatory processes during the winter period.

In pregnant sows low ambient temperatures largely influence the energy metabolism of the animal (Kemp and Verstegen, 1987). It can be expected that a too cold environment increases metabolic rate and thus increases maintenance requirement. In winter, as a consequence of low ambient temperatures combined with poor thermoregulatory conditions, the maintenance requirement may be increased to a level above the given feeding level. In this respect the application of a low feeding level to boars may reduce reproductive performance. In a review, Kemp and den Hartog (1989) concluded that male animals fed below maintenance show a decreased semen production. This suggests that there is a need to study the effect of feeding level and ambient conditions on the metabolic needs of boars. Therefore the present experiment was designed to study the influence of ambient temperature on the metabolic rate and protein- and fat-retention in breeding boars.

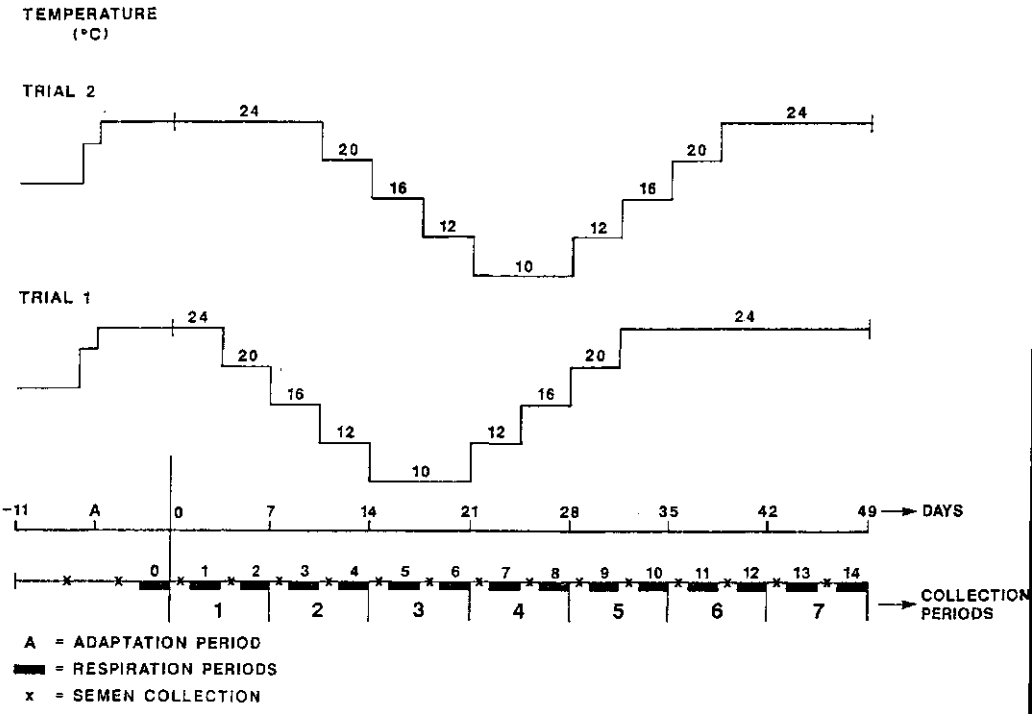
MATERIAL AND METHODS

Eight Yorkshire boars, 10-13 months of age and weighing 224 kg were used in the experiment. In each of two trials 4 boars were housedin an open circuit calorimeter (Verstegen et al., 1987). The boars were housed individually in balance cages with slatted floors. Boars were exposed to artificial fluorescent lighting for 12 hours per day. All boars were fed a commercial sow diet, containing 12.32 MJ ME and 149 g crude protein per kg, at a constant level of 480 kJ metabolizable energy (ME) per $kg^{0.75}$ per day. Boars were fed twice daily at 8.15 and 16.15 h., and water was available ad libitum from 8.00 h to 17.00 h. Semen was collected twice weekly using the glove hand technique.

Experimental design

According to Kemp and Verstegen (1987) individually housed pregnant sows fed at 1.0 to 1.35 times maintenance have a lower critical temperature (LCT) of 18 to 21°C. It was expected that breeding boars have a similar thermal demand at the aforementioned feeding level. Therefore twenty four degrees Celsius was

Figure 1: Experimental design.



expected to be thermoneutral. In this experiment ambient temperatures in the range of 10 - 24°C were employed to study their influences on the energy metabolism.

Boars were tethered in the calorimeter and after allowing an adaption period of 11 days at temperatures increasing gradually from 20 to 24°C, the boars in both trials were exposed to seven successive 7-day collection periods (see Figure 1). In trial 1 in the main period temperature decreased from 24°C to 20, 16, 12 and 10°C (3.5 days per temperature treatment). After 7 days at 10°C, temperature was increased successively to 12, 16, 20 and 24°C. Temperature was kept at 24°C for 2.5 collection period. In trial 2 the same temperature treatment was imposed except that in the main period temperature was kept for 1.5 collection period at

24°C before temperature decreased stepwise and after the increase, temperature was kept at 24°C for 1.5 collection period. The changes in temperature were adopted since under practical conditions boars are not allowed a long period of adaptation either. The longer periods at 24°C were used to determine more accurately the thermoneutral heat production and to observe any signs of adaptation to temperature and calorimeter.
In both trials the relative humidity was maintained at about 65% throughout the experiment.

MEASUREMENTS

Boars were weighed once a week before the start of each collection period.
Heat production was calculated from measurements of gaseous exchange of carbon dioxide and oxygen every 18 min. throughout 48 h. Two 48 h periods were imposed in each collection period, after an adaption period of 24-36 h at each temperature (see Figure 1).

Collection, sampling and chemical analyses.

Excreta were collected daily during each collection period. Urine was collected in a plastic tank to which 100 ml hydrochloric acid (19%) was added daily. Faeces were collected in a plastic tank containing 5 ml formaline (37%). Semen was collected twice weekly between the 48h heat production measurement periods (see Figure 1). At the end of each collection period all samples were bulked, weighed and sampled for determination of their energy and nitrogen content. In addition samples of the diet were also analysed for dry matter, nitrogen and energy.
Energy content of feed, faeces, urine and semen was determined by bomb calorimetry (faeces, urine and semen after freeze drying). Nitrogen content was determined by the Kjeldahl method. Protein content was estimated by multiplying the nitrogen content with 6.25.

Analyses on heat production and balance procedures.

Data on the relation between heat production and ambient temperature are analysed with the model of van der Peet et al. (1987).

This model describes the relation in the thermoneutral zone as well as below the thermoneutral zone. In this model heat production is described as a function of intake of metabolizable energy, metabolic weight and ambient temperature as:

$$H = (1-a) * ME + a * H_m * W^P + \ln (1+e^{(ETH*(LCT-T)*W^P)})$$

H = total heat production. (kJ/an/d)
a = partial efficiency of energy retention from ME above maintenance.
ME = metabolizable energy intake. (kJ/an/d)
H_m = maintenance heat production. ($kJ/W^P/d$)
W^P = metabolic weight. (kg^P)
ETH= extra thermoregulatory heat production ($kJ/kg^P/^oC/d$)
LCT= lower critical temperature (^oC)
T = temperature (^oC)

Estimates of maintenance heat production, extra thermoregulatory heat production, p in metabolic weight and the critical temperature were calculated from the 18 minutes heat production data using SAS-NLIN (SAS,1985). For correct estimation of the partial efficiency of energy retention a variety of feeding levels should be applied in the experiment. The energetic efficiency of energy retention was not estimated since in this experiment a constant feeding level was applied. Estimates on efficiency would not be reliable, therefore the efficiency was assumed to be 0.72 as found in pregnant sows according to Close et al. (1985).
Digestibility of energy and protein were calculated from the difference between gross intake and output in faeces.
ME intake was calculated as the difference between gross energy intake (GE) and energy output in faeces and urine. ME was determined for each individual boar in a collection period.
Energy balance (EB) was calculated by subtracting heat production and energy in semen from the ME intake.
Protein gain was determined from nitrogen intake in feed minus nitrogen excreted in faeces, urine and semen and corrected for NH_3 in the air and in the water collected from the heat exchanger.
Energy retained as protein was calculated from protein gain multiplied by 23.9 kJ/g (the energy value of protein). The gain

in fat was derived from the EB by subtracting energy gained in protein from the total energy gain and dividing by 39.7 kJ/g (the energy value of fat).

STATISTICAL ANALYSES

Metabolizability of energy, as well as digestibility of energy, protein and dry matter and protein retention as determined per boar during each collection period have been subjected to analyses of variance (using SAS-GLM; SAS, 1985) according to the following model:

$$Y_{ijkl} = u + R_i + B(R)_{j(i)} + T_k + e_{ijkl},$$

Y_{ijkl} = the dependent variable.
u = the overall mean
R_i = the trial effect (i=1-2)
$B(R)_{j(i)}$ = the boar effect nested within trial (j(i)=1-8).
T_k = the temperature effect (k=1-4).
e_{ijkl} = the error

Treating temperatures as a variable with four discrete classes (the four different mean temperature steps in the collection periods), rather than as a continuous one, provided a better fit of the model. None of the interaction effects was found to be significant. All tests of significance were performed against error terms except for trial effects. The trial effect was tested against the mean squares of the boar effect. Post hoc analyses of temperature effects were performed using Tukey's test (using SAS-GLM; SAS, 1985).

RESULTS AND DISCUSSION

Heat production

Heat production data as calculated per 24 h for each respiration period are given in Table 1. At respiration period number 2 data on the second 24 h period were not measured.
Heat production was increased at lower ambient temperatures. A

sharp increase is seen below 20°C. Heat production of boars which are kept for longer periods at the same temperature is not always constant.

Table 1: Heat production data as calculated for 24 h periods (kJ/ $kg^{0.75}$/d) at various respiration periods.

		TRIAL 1		TRIAL 2	
Respiration	24 h-Period	Temperature (°C)	Heat Prod.	Temperature (%)	Heat Prod.
0	1	23.5	513	24.0	505
	2	23.4	485	24.1	477
1	1	23.5	465	24.1	449
	2	23.6	429	24.0	432
2	1	19.5	403	24.0	390
	2	-	-	-	-
3	1	15.5	461	24.0	395
	2	15.4	474	23.9	391
4	1	11.6	533	20.0	415
	2	11.6	539	20.0	421
5	1	9.5	586	15.9	470
	2	9.5	582	15.9	484
6	1	9.3	577	11.6	556
	2	9.3	579	11.7	563
7	1	11.8	534	10.8	576
	2	11.8	528	10.7	579
8	1	15.7	480	10.6	576
	2	15.6	468	10.7	588
9	1	20.2	418	11.8	557
	2	20.2	414	11.7	560
10	1	23.8	400	16.2	474
	2	23.7	408	16.2	467
11	1	23.8	405	19.8	429
	2	23.7	409	19.9	433
12	1	23.8	390	23.2	408
	2	23.6	387	23.3	411
13	1	23.6	384	23.2	416
	2	23.6	374	23.2	411
14	1	23.9	380	23.2	401
	2	23.7	373	23.2	402

Adaptation

When boars are kept for longer periods at about 24°C a decrease in heat production is found. In Table 2 the regression coefficients are given for the regression from number of days in the experiment on heat production measured in periods at about 24°C. At the start of the experiment this decrease was much sharper (14.1 kJ/kg$^{0.75}$/d in trial 1 and 15.0 kJ/kg$^{0.75}$/d in trial 2) than at the end of the experiment (2.3 kJ/kg$^{0.75}$/d in trial 1 and 1.0 kJ/kg$^{0.75}$/d in trial 2). In trial 2 heat production showed no decrease any more from respiration 2 onwards. These changes in heat production cannot be explained by temperature and could be a result of adaptation. At the start of the experiment this change may be an adaptation to calorimeters and temperature and at the end of the experiment just an adaptation to temperature.

One might conclude that change in heat production due to adaptation to calorimeters is much greater than that due to adaptation to temperature. However, the thermal history of the boars might be of importance. This experiment was conducted after the winter period started, therefore the boars may have been physiologically adapted to low barn temperatures. The data of this experiment might suggest that heat production change due to adaptation to high ambient temperatures is much greater after long periods in the cold compared to short periods in the cold (during the experiment). In the short periods, boars could not adapt to the cold environment and were therefore still adapted to high temperatures.

Table 2: Regression (b) and correlation (r) coefficients of 24 h heat production data on day of experiment for the respiration periods at 24 °C (Hprod. = a + b*time).

Trial	respiration number	a	b	r
		(kJ/kg W$^{0.75}$/day)		
1	0-1	649	-14.1	-0.95
	10-14	414	- 2.3	-0.90
2	0-3	651	-15.0	-0.98
	12-14	414	- 1.0	-0.55

Table 3: Estimates for heat production at thermoneutral maintenance (H_m in kJ/kg$^{0.75}$/d) in kJ/kg$^{0.75}$/°C/d, extra thermoregulatory heat production (ETH) in kJ/kg metabolic weight/ °C/d and lower critical temperature (LCT) in °C.

	TRIAL 1		TRIAL 2	
	p=variable	p=0.75	p=variable	p=0.75
p	0.70	--	0.70	--
Hm	489	381	509	383
ETH	20.8	15.8	21.6	16.3
LCT	20.1	19.6	20.1	20.4
From the model:				
residual sd	7.24	7.24	7.53	7.53
R-square	0.94	0.94	0.93	0.93

Ambient temperature and heat production.

To estimate the influence of ambient temperature on heat production, data of periods of comparable duration should be used. Therefore only heat production data of respiration period 2 to 12 in trial 1 and respiration period 4 to 13 in trial 2 were used. In Table 3 estimates are given for heat production at maintenance, extra thermoregulatory heat production and critical temperature for both trials as calculated with the model of van der Peet et al. (1987). Estimates are made both with p in metabolic weight at 0.75 or as an extra variable (p). Estimates in both trials show a good agreement. Thermoneutral maintenance heat production is about 382 kJ/kg$^{0.75}$/ d, extra thermoregulatory heat production is about 16 kJ/kg$^{0.75}$/ °C/ d and the lower critical temperature was estimated at about 20°C. From Table 3 it is clear that using p as a variable or at 0.75 did not significantly improve the model (residual standard deviation and R-square were similar). A boar weighing 200 kg has a thermoneutral maintenance heat production of 20.32 MJ/d and an ETH of 0.851 MJ/°C/d when calculated

Table 4: Least square means for digestibility coefficients on protein (DP), energy (DE) and dry matter (DM) and metabolizability of energy intake (ME/GE) as calculated at different temperatures.

	Temperature (°C)				R-square	RSD	Sign. (p<)
	10	14	22	24			
DP (%)	76.4	77.0	78.5	78.0	0.21	2.4	--
DE (%)	80.5	81.4	82.1	81.2	0.30	1.5	--
DM (%)	78.7	79.5	80.1	79.1	0.28	1.6	--
ME/GE(x100)	75.1^{a}	76.5^{ac}	77.9^{bc}	76.7^{ac}	0.33	2.0	0.014

Data with different superscripts in the same row differ (P<0.05).

with the model using p = 0.75 and a thermoneutral maintenance heat production of 20.36 MJ/d and an ETH of 0.865 MJ/°C/d when calculated with the model using p as a variable. Estimated values of ETH, heat production at maintenance and LCT are very similar between the models using p as constant and p as a variable.
Kemp and Verstegen (1987) reviewed experiments on the influence of climatic factors on metabolic rate of sows. Most experiments on this topic are carried out with pregnant sows. Since there is no information available on the influence of ambient temperature on the energy metabolism of breeding boars, the pregnant sow is probably the best comparable animal, because they are usually individually housed at relatively low feeding levels like boars. Kemp and Verstegen (1987) concluded that in literature maintenance heat production ranged from 385 to 476 kJ/$kg^{0.75}$/d, the lower critical temperature from about 18 to 21°C and the extra thermoregulatory heat requirement from 12.7 to 17.6 kJ/°C/d/$kg^{0.75}$. The data found in this experiment on boars fit in these sow data fairly well.

Digestibility and metabolizability of energy intake.

The least square means for the digestibility coefficients (expressed as %) of energy, protein and dry matter and the meta-

bolizability of the energy intake at different temperatures are given in Table 4. Where a collection period enclosed two temperature treatments the mean temperature was taken. Digestibility coefficients showed no significant difference at different temperatures. The metabolizability of energy showed a slight but significant decrease at lower ambient temperatures. In the model used all other effects were not significant for digestibility as well as metabolizability.

Hovell et al. (1977) found a significant decrease in digestibility of energy, protein and dry matter in sows kept at 5°C compared to sows at 20°C. Kemp et al. (1987b) found that metabolizability of the gross energy intake was reduced in sows kept at 12-14°C compared to sows kept at 20°C.

Table 5: Partitioning of ME-intake.

Collection period	Temperature	Weight of animals	ME-intake	H	EB	Protein retention	Fat
	(°C)	(kg)	(kJ/kg $W^{0.75}$/d)			(g/an/d)	
TRIAL 1							
1	21.5	221.6	492	425	66	122	28
2	13.5	221.6	482	502	-22	52	-63
3	9.4	219.7	479	581	-103	1	-149
4	13.7	219.0	483	503	-20	31	-47
5	22.0	221.6	491	410	80	87	63
6	23.7	223.9	435	398	41	74	15
7	23.7	236.3	484	378	105	111	93
TRIAL 2							
1	24.0	222.8	489	415	72	99	45
2	22.0	224.7	437	406	26	88	-15
3	13.8	224.1	488	518	-32	95	-104
4	10.7	221.1	476	580	-106	15	-162
5	14.0	220.2	491	515	-25	24	-50
6	21.6	224.6	505	420	83	123	47
7	23.2	230.1	490	408	81	117	50

Partitioning of ME intake.

In Table 5 the partitioning of ME-intake has been given for both trials. As for heat production, results from both trials show good agreement.
Energy balances were decreased at lower temperatures. Above the lower critical temperature EB was about 73 kJ/kg $W^{0.75}$/d in trial 1 and 66 kJ/kg $W^{0.75}$/d in trial 2. At about 14.0 and 10 °C the EB was negative. Body reserves were then used to supplement the diet in order to meet the increased thermal demand.
Using the model as described in the statistical analyses temperature had a significant effect on protein retention. At 24 and 20°C there was no significant difference in protein retention, below 20°C, however, the differences in protein retention were significant (see Table 5). As shown in Table 6, the protein gain of 103 g/an/d at temperatures above the lower critical temperature was depressed about 10 g/an/d/°C when temperatures dropped below LCT. Similarly fat retention of 41 g/an/d was depressed by 20 g/an/d/°C. Fat retention is clearly more depressed than protein retention at lower ambient temperatures.

Table 6: Mean protein- and fat-retention above the LCT (20°C) and below the LCT.

Temperature (°C)	Protein retention (g/an/d)	Fat retention (g/an/d)
>20	103 (6)[a]	41 (13)
13.8 (0.2)	51 (13)[b]	-66 (16)
10.1 (0.9)	8 (10)[c]	-156 (9)

Between brackets the standard deviation between trials is given. Different superscripts in a column means significant difference ($P < 0.5$), R-square model=0.52, RSD=43)

Boars at the same feeding level lost about 155 g of fat per day at about 10°C while above 20°C they were able to gain about 40 g per day.
Kemp and Verstegen (1987) confirm in their literature review on pregnant sows that protein retention is less influenced by low ambient temperature than fat retention.
This experiment clearly demonstrates the importance of the thermal environment for efficient use of feed by boars. From Kemp and den Hartog (1989) it is clear that boars should be fed above maintenance to ensure a good reproductive performance. Therefore it is necessary to provide a thermoneutral environment or correct the feeding level.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Miss F.J. Lammers and Miss M.P. Dorst for their work at the experiment and Mr W. van der Hel, K. van der Linden and H.A. Brandsma for the technical assistance. The Artificial Insemination Centres "Gelderland" and "Brabant" are acknowledged for collecting semen and delivering of boars. We thank the referees for making usefull comments.

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CHAPTER IV

SOME ASPECTS OF DAILY PATTERN IN THERMAL DEMAND OF BREEDING BOARS.

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Journal of Thermal Biology: in press.

ABSTRACT

An experiment was performed to study the relationship between time of day and heat production, the lower critical temperature (LCT) and the extra thermoregulatory heat production (ETH) in breeding boars.

In each of two trials, 4 Yorkshire boars (10 - 13 months old, 224 kg liveweight) were housed in balance cages in an open circuit calorimeter. Each boar was fed 480 kJ metabolizable energy (ME) per kg metabolic weight $(W)^{0.75}$/day. Semen was collected twice weekly. In both trials temperature was decreased successively from 24°C to 20, 16, 12 and 10°C (3.5 days per temperature treatment). After 7 days at 10°C, temperature was increased in reversed order to 12, 16, 20 and 24°C. (Each treatment lasted 3.5 days.)

At each temperature treatment, measurements of metabolic rate were recorded at 18 min. intervals over a duration of 48 h. To calculate the circadian variation in thermal demand, the 24 h days were divided into twelve 2 h periods.

Heat production showed a bifasal pattern with high peaks in heat production during the two feeding periods. Heat production was clearly lower at night when compared to the day.

The LCT of boars was also lower at night (17.5°C) compared to the day (20.8°C), while the ETH, however, was higher at night (22 kJ/ $kg^{0.75}$/24 h/ °C) than during the day (14 kJ/ $kg^{0.75}$/24 h/ °C). At an ambient temperature of 10°C, the benefits in extra thermal demand of a lower LCT at night are no longer present.

INTRODUCTION

The thermal environment has a large effect on the energy metabolism of pigs. Especially in boars and non-lactating sows which are usually fed only slightly above maintenance, variation in thermal environment is of greater importance than in animals at a higher feeding level.

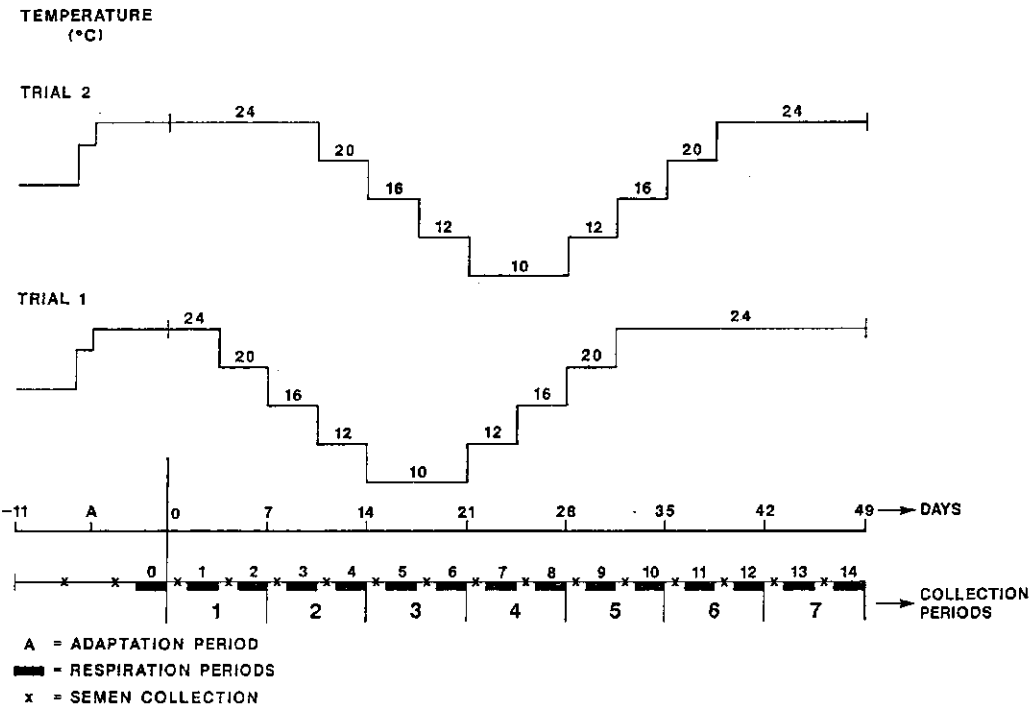
Kemp and Verstegen (1987) concluded in their literature review that individually housed sows fed at feeding levels of 1.1 to 1.4 times thermoneutral maintenance had a lower critical temperature (LCT) of approximately 18 to 21°C and an extra thermoregulatory heat production (ETH) of 12.7 to 17.6 kJ/°C/d/$kg^{0.75}$. In an

experiment with breeding boars Kemp et al. (1989) showed similar results. Breeding boars had a LCT of 20°C and an ETH of 16 kJ/°C/d/kg$^{0.75}$ at a feeding level of 1.25 times maintenance. They concluded that in order to have boars in a thermoneutral environment they should be kept at a temperature of at least 20°C. Verstegen et al. (1986) and van der Hel (1986) showed in experiments with growing pigs that the ETH and the LCT could vary considerably during a 24 h period. Furthermore, Verstegen et al. (1986) concluded that the thermal requirement of group housed growing pigs was lower during the night than compared to the day. Kemp et al. (1989) reported data on heat production, protein- and fat-retention of breeding boars exposed to various ambient temperatures. LCT and ETH were calculated from these data as a mean per day. It can be expected from literature (Aschoff et al., 1974; Curtis and Morris, 1982) that variation in the thermal demand will occur. In the present investigation variation in the thermal demand of breeding boars during the day has been studied. In this study data originating from the experiments reported in chapter III were used.

MATERIAL AND METHODS

Eight Yorkshire A.I.boars, 10-13 months of age and weighing on average 224 kg were used in the experiment. In each of two trials 4 boars were housed in an open circuit calorimeter (Verstegen et al., 1987). The boars were housed individually in balance cages with slatted floors. Boars were exposed to artificial fluorescent lighting from 06.00 h to 18.00 h. All boars were fed a commercial diet containing 12.32 MJ ME and 149 g crude protein per kg at a level of 480 kJ metabolizable energy (ME) per kg$^{0.75}$ per day. Boars were fed twice daily at 8.15 and 16.15 h and water was available ad libitum from 8.00 to 17.00 h. Semen was collected twice weekly using the glove hand technique. Details on the experimental design and the energy balance data are reported elsewere (Kemp et al., 1989).

Figure 1: Experimental design.



Experimental design

The ambient temperatures in this experiment were in the range of 10-24°C. Energy metabolism at various temperatures was measured as described by Kemp et al. (1989). In both trials temperatures were decreased in stepwise fashion (4°C per step) from 24 to 20, 16, 12 and 10°C. At each temperature between 20 and 10°C temperature was maintained during 3.5 days. At 10°C temperature was kept constant for 7 days. The two trials differed in one respect. In trial 1 acclimation time at the first 24°C exposure was 9 days and in trial 2 the acclimation time at the start was 16 days. Data on acclimation are reported in Kemp et al. (1989). A determination of metabolizable energy intake (ME) was made over each 7 days collection period. Apart from the start and the end of the

experiment this collection period consisted of two successive temperature treatments. The sequence of temperature treatments and collection periods is given in Figure 1. Also sequence and duration of respiration measurements and semen collections are given in Figure 1.
In both trials the relative humidity was maintained at about 65%.

MEASUREMENTS

Heat production was calculated from measurements of gaseous exchange of carbon dioxide and oxygen every 18 min. thoughout 48 h. Two 48 h periods were inserted in each 7 day period. Respiration measurements were started after an adaptation period of 24 to 36 h at each temperature (see Figure 1).

Analyses on the circadian pattern of heat production.

The circadian pattern of heat production was estimated by dividing a 24 hour day into twelve 2 h periods. The periods of 2 h were chosen arbitrarely. The mean heat production per 2 h period (expressed as number of kJ/ $kg^{0.75}$ per 24 h) per temperature treatment was calculated from the 18 min. data using SAS-MEANS (SAS, 1985).
Data on the relation between heat production and ambient temperature can be analyzed with the model of van der Peet et al. (1987). This model describes the relation within the thermoneutral zone as well as below the thermoneutral zone. In this model heat production is described as a function of intake of metabolizable energy, metabolic weight and ambient temperature and can be determined using the following equation:

$$H = (1-a) * ME + a * H_m * W^{0.75} + \ln (1+e^{(ETH*(LCT-T)*W^{0.75})}) \quad (1)$$

H = total heat production (kJ/an/d).
a = partial efficiency of energy retention from ME above maintenance.
ME = metabolizable energy intake (kJ/an/d).
H_m = maintenance heat production ($kJ/^{0.75}/d$).
$W^{0.75}$ = metabolic weight ($kg^{0.75}$).

ETH = extra thermoregulatory heat production ($kg/kg^{0.75}/^{o}C/d$).
LCT = lower critical temperature (^{o}C).
T = ambient temperature (^{o}C).

To describe the relationship between heat production and ambient temperature at various 2 h periods, an adjusted Model 1 was used.

$$H_i = H24_i + \ln (1+e^{(ETH_i*(LCT_i-T)*W^{0.75}})) \quad (2)$$

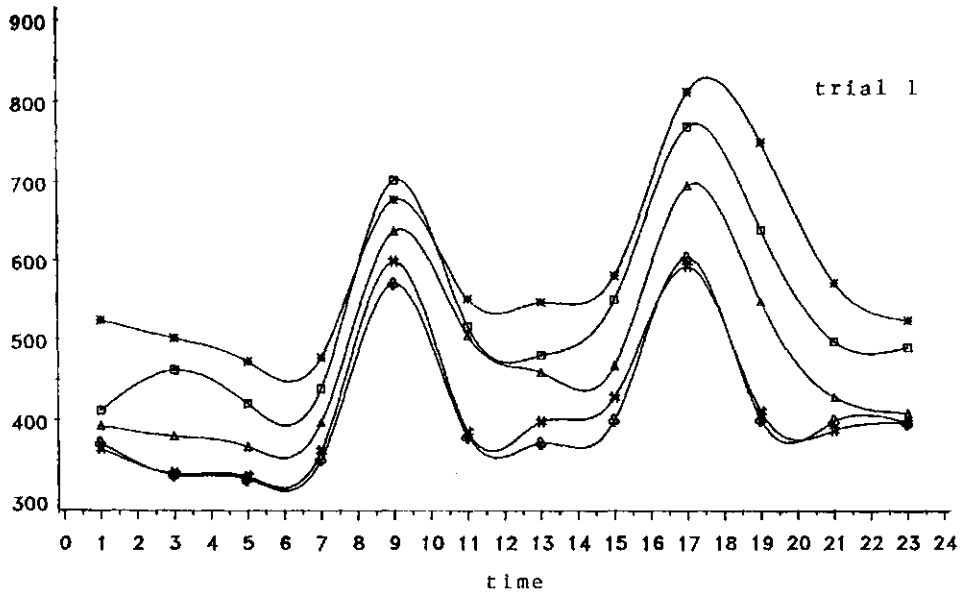
H_i = total heat production (kJ/an/d) in the i-th period.
$H24_i$ = heat production at $24^{o}C$ as found in the i-th period.
$W^{0.75}$ = metabolic weight (kg).
ETH_i = extra thermoregulatory heat production ($kJ/kg^{0.75}/^{o}C/d$) in the i-th period.
LCT_i = lower critical temperature (^{o}C) in the i-th period.
T = ambient temperature (^{o}C)

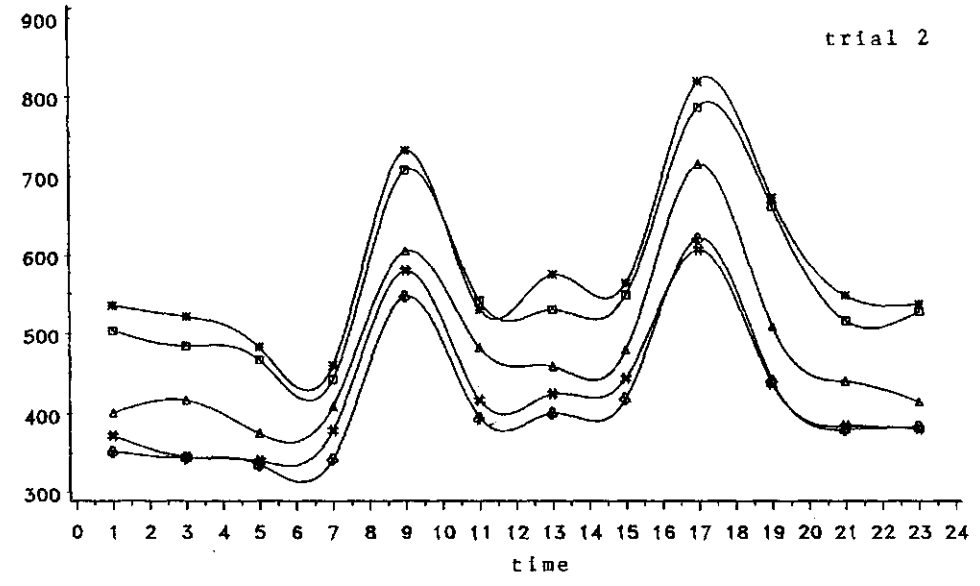
In the adjusted model, the term $[(1-a)*ME + a * H_m * W^{0.75}]$ is replaced by $H24_i$. This was required since partial efficiencies of energy retention and maintenance heat production can not be estimated on the basis of just 2 h periods. $H24_i$ is the heat production in a certain (i-th) 2 h period as measured at $24^{o}C$. $24^{o}C$ was thought to be thermoneutral in each of the twelve 2 h periods.
Using Model 2, the LCT_i and the ETH_i per 2 h period could be estimated with SAS-NLIN (SAS, 1985) using the 18 min. heat production data at different temperatures in the i-th 2 h periods. Furthermore, LCT was calculated using Model 2, assuming ETH would remain constant for each 2 h period of the day (same value). The constant value for ETH was the mean ETH calculated over 24 h periods as calculated by Kemp et al. (1989).

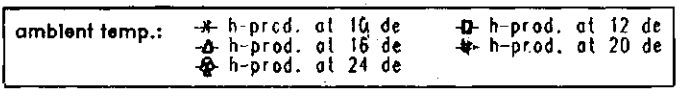
RESULTS AND DISCUSSION

Verhagen et al. (1988) found in a study using young pigs, that heat production may depend on the duration of exposure to a specific temperature. Therefore, it was decided to use heat production data from periods of comparable duration. Therefore only heat production data were used of respiration period 2 to 12

Figure 2: Heat production (kJ/ $kg^{0.75}$/ d) of the boars at different 2h periods during 24 h.







in trial 1 and respiration period 4 to 13 in trial 2 (see Figure 1).

The circadian pattern of heat production.

In Figure 2 the mean heat production during the day for successive 2 h periods is shown at different temperature levels. From this figure it is clear that heat production shows a bifasal pattern with visible peaks during feeding time and an increased heat production during the day compared to the night.

In Table 1 the range in heat production is shown at different temperature levels. The highest levels of heat production, as shown in Table 1, were found mostly between 16.00 and 18.00 h, the time in which the boars were fed for the second time. The lowest heat productions were found between 4.00 and 8.00 at night.
In both trials heat production as well as the standard deviation calculated from the 18 min periods within a certain temperature is increased at lower ambient temperature.
Verstegen et al. (1986) showed in growing pigs, weighing 30 to 46 kg and fed twice daily, a similar bifasal pattern in heat production. They found that the high heat production during feeding could be explained for a large part due to increased activity. Charlet-Levy (1975) also found that heat production around feeding was related to activity.

Table 1: 18 min. heat production ($kJ/kg^{0,75}/d$), means, standard deviation and range at different temperatures.

TRIAL 1				TRIAL 2			
temp. (°C)	mean	sd	range	temp. (°C)	mean	sd	range
23.7	406	111	294-970	23.2	412	112	296-992
20.0	424	116	284-895	20.0	425	120	295-1045
15.5	471	128	335-1003	16.1	474	129	309-1120
11.7	533	136	338-960	11.7	559	140	275-1135
9.4	581	130	332-972	10.7	580	138	363-1248

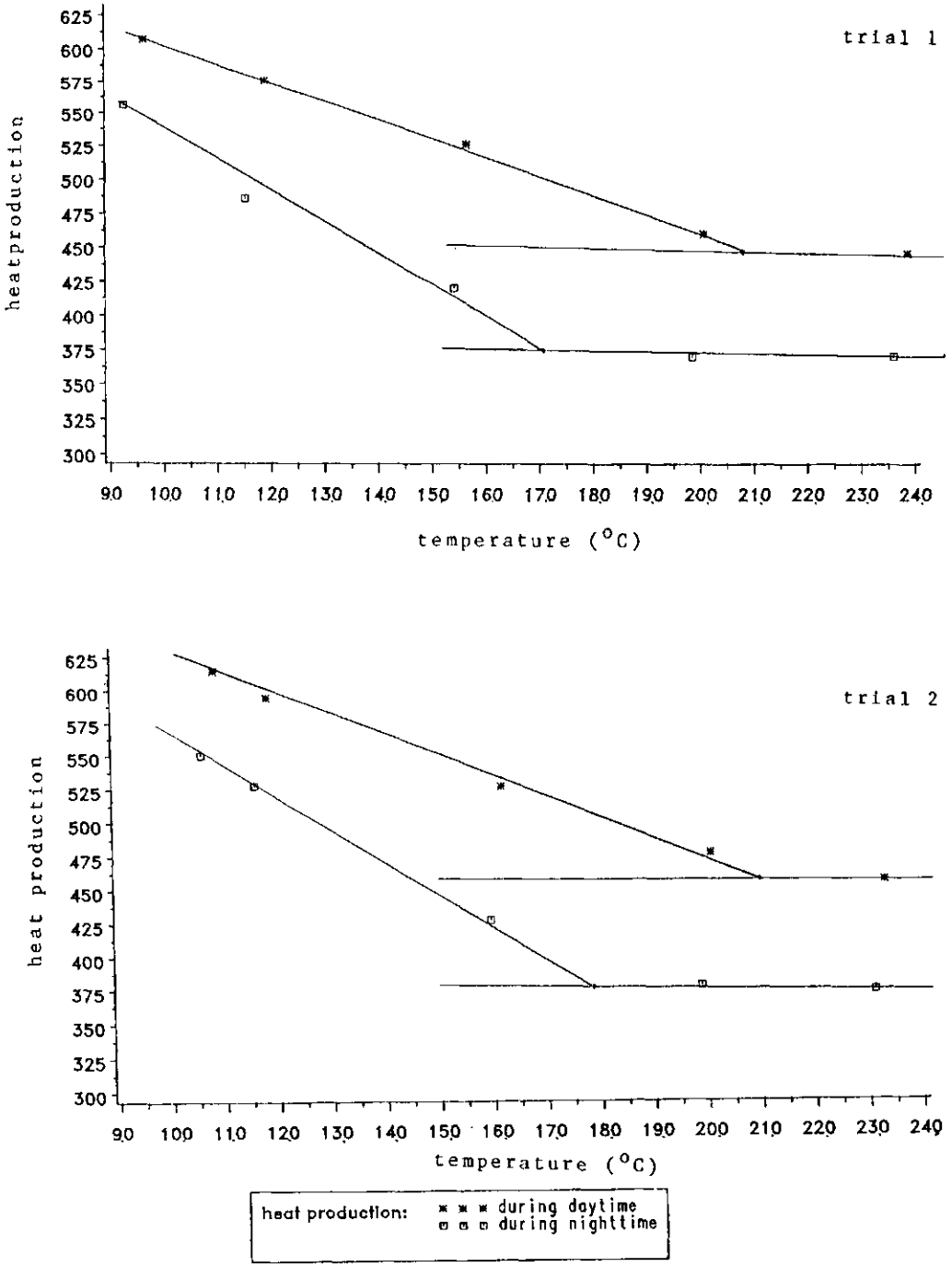
Estimates on LCT and ETH

In Table 2 data are given on LCT and ETH as estimated at each 2 h period. From this table it is quite clear that there is a distinct variation in ETH and LCT within a day. Estimates from the LCT vary from 15.5 to 22.9°C during a day. Estimates from ETH vary from 9 to 31 kJ/ $kg^{0.75}$/ °C/ day.
LCT is clearly higher during day time while ETH is clearly lower during the day time. From 18.00 h until 6.00 the mean LCT is 17.1 and 17.9°C for trial 1 and 2, respectively. Mean ETH during that period is 22 and 23 kJ/$kg^{0.75}$/ °C/ day. From 6.00 to 18.00 h the mean LCT is 20.8°C for both trials. Mean ETH during that period is 14 and 15 kJ/$kg^{0.75}$/ °C/ day. The difference between day and night in LCT is 3.3°C (sd between trials = 0.6), this difference in ETH is 8 kJ/$kg^{0.75}$/°C/ day. Difference in ETH and LCT between day and night are both significantly different from zero when the students t-test was used ($P < 0.05$).

Table 2: H24 (MJ/an/d), ETH (kJ/$kg^{0.75}$/°C/d), LCT (°C) and the residual standard deviation and R-square of the adjusted model for each 2 h period.

	TRIAL 1					TRIAL 2				
hour	H24	ETH	LCT	RSD	Rsquare	H24	ETH	LCT	RSD	Rsquare
0+1	21.5	22	15.5	2.52	0.99	20.8	24	17.6	1.87	0.99
2+3	19.2	20	17.6	1.38	1.00	20.3	19	18.7	1.61	1.00
4+5	18.9	17	17.3	1.88	0.99	19.8	20	17.3	1.41	1.00
6+7	20.3	12	18.6	3.21	0.98	20.2	9	22.5	3.45	0.98
8+9	33.0	9	22.9	8.22	0.95	32.2	15	20.9	11.23	0.92
10+11	22.0	14	22.0	3.79	0.98	23.3	13	21.6	3.95	0.98
12+13	21.5	13	21.5	4.28	0.97	23.6	17	19.4	4.13	0.98
14+15	23.1	16	20.4	4.28	0.98	24.7	13	20.6	4.62	0.97
16+17	34.8	21	19.6	8.45	0.96	36.6	21	19.6	10.04	0.94
18+19	23.1	31	20.1	7.06	0.95	26.0	30	18.5	6.77	0.96
20+21	23.0	23	16.1	2.30	0.99	22.4	19	18.6	2.41	0.99
22+23	22.9	20	15.5	2.15	0.99	22.6	23	16.9	2.03	0.99

Figure 3: Heat production of boars (kJ/ $kg^{0.75}$/d) at different temperatures during day and night.



In Figure 3a and b the mean heat production during daytime (6.00 to 18.00 h) and the mean during night time (18.00 to 6.00 h) is plotted against ambient temperature. These figures are composed on basis of the calculated mean 12 h heat production at day and at night at various temperatures (represented by an asteriks or a square) and the mean LCT, ETH and $H24_1$ of the six 2h periods at day and the six at night as calculated from Table 2 (given by the lines drawn). These two figures summarize the difference in heat production between day and night.

In both trials it is clear that individually housed boars have a lower LCT at night compared to the day. So the temperature below which boars will have to increase heat production due to the lower ambient temperature is lower during the night. Therefore the ambient temperature at night may be lowered to about 18°C instead of the 21°C which should be applied during day time. These data support the conclusions of Curtis and Morris (1982) that animals require a lower temperature at night than during day time.

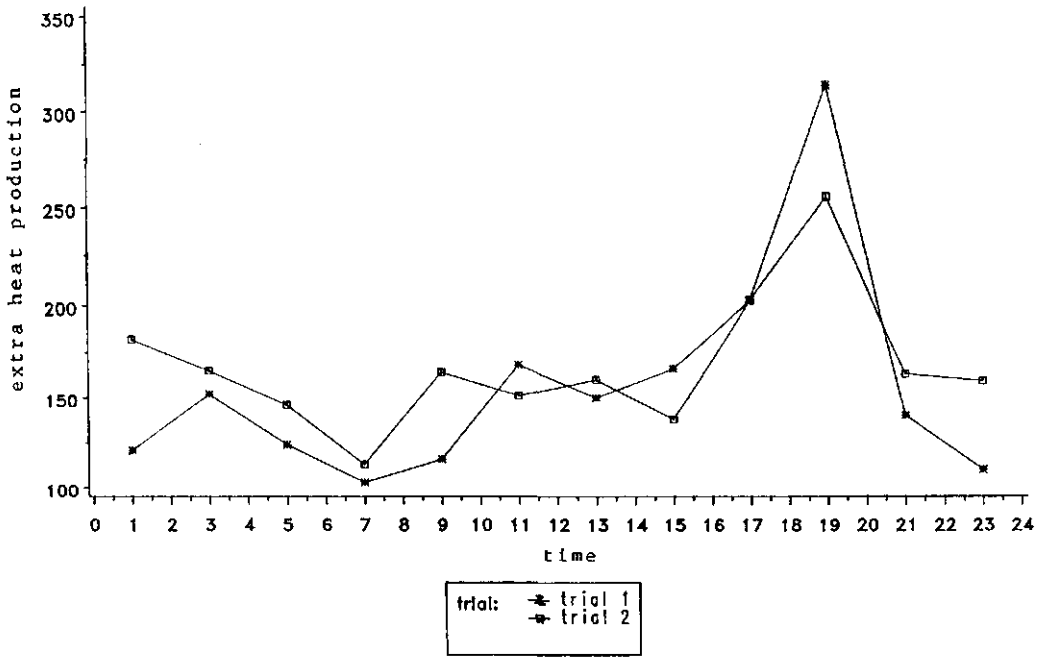
When the boars are housed below the LCT, the amount of extra heat produced at night for a given temperarture difference with the LCT is higher than during the day.

Lower critical temperature during the night time may be associated with the mainly laying position of the animal. It has been found (Verstegen and Curtis, 1988) that sows had a lower radiant surface when they were lying compared with standing. Associated with a lower metabolic rate this means a higher insulation value. When pigs are below thermoneutral, however, extra heat will be produced mainly by shivering thermogeneses (Bartunkova et al., 1971). Heat is produced from the muscle tonus and it can be expected that insulation decreases.

In Figure 4 the extra amount of heat produced for thermoregulatory processes ((nr. of degrees below LCT) X ETH) is calculated for boars which are kept at 10°C at different 2 h periods. It was calculated what extra heat is produced at 10°C using LCT and ETH as illustrated in Figure 4. Both trials give similar results. At night there clearly is an advantage of the lower extra thermal demand at 10°C. The lowest value is reached in the period 6 and 7. Around period 18 and 19 this extra heat production is highest. These extremes can be explained by the great difference in ETH in the 2 h periods (6.00-7.00: 12 and 9 for trial 1 and 2, respecti-

vely; 18.00-19.00 h: 31 and 30 for trial 1 and 2 respectively.). Verstegen et al. (1986) also found an increased total heatrequirement particularly in the evening period.

Figure 4: Extra heat production at 10°C (kJ/ $kg^{0.75}$/d) at different 2h periods over 24 h.



The means of thermal demand at 10°C during day and night are not much different. In trial 1 the amount of extra heat produced during the night (18.00 h to 6.00 h) is 160 kJ/$kg^{0.75}$/ 24 h compared to an extra heat production during day time of 151 kJ/$kg^{0.75}$/ 24h. In trial 2 the calculated amount of extra heat produced at 10°C during the night is 178 kJ/$kg^{0.75}$/ 24 h compared to 155 kJ/$kg^{0.75}$/24 h during the day. In this experiment the advantage of the lower LCT is fully compensated by the increased ETH.

From this experiment we conclude that thermal demand from individually housed breeding boars varies considerably within a day. A

lower ambient temperature can be allowed for these individually housed animals at night. The penalty of being below the LCT, however, is greater in terms of an increased ETH.

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CHAPTER V

SEMEN COLLECTION FREQUENCY AND THE ENERGY METABOLISM OF A.I. BOARS.

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Animal Reproduction Science: submitted for publication

ABSTRACT

Six trials with 4 Yorkshire A.I. (artificial insemination) boars each (200 kg live weight and 1 year old) were done to measure the effect of semen collection frequency on energy metabolism. During six weeks boars were adapted to a semen collection scheme of one or three times a week and after 2 weeks of measurements the semen collection scheme was reversed and another 2-3 weeks of measurements were carried out.

Extra heat production on a semen collection day compared to non semen collection days is as a mean 18 $kJ/kg^{0.75}/d$ (sd=7). Boars adapted to higher mating frequencies have a significant (10 $kJ/kg^{0.75}/d$) lower heat production at non semen collection days (HNCD) and a non-significant (16 $kJ/kg^{0.75}/d$) lower heat production at semen collection days (HCD), resulting in a non significant (6 $kJ/kg^{0.75}/d$) lower mean heat production during a week (HM). No significant differences in weekly calculated EB, gain in protein and gain in fat were found. Boars which are adapted to high semen collection frequency more than compensate their extra energy requirement due to the higher mating frequency when compared to boars adapted to a low semen collection frequency.

Adaptational reactions on heat production due to change of semen collection frequency were not significant. However, boars adapted to a low semen collection scheme set on a high scheme showed an increased extra heat production due to mating (EHM) during one week.

INTRODUCTION

A.I. boars require energy for: maintenance, growth (fat- and protein-deposition) and the reproductive processes. The reproductive processes in a breeding boar comprise the production of the components which constitute an ejaculate and the requirements for mating a sow or a dummy.

No literature was found on the energy costs of these reproductive processes. However, Waldmann (1984) and Perez et al. (1988) showed that a boars metabolism is heavily stressed while mating a sow or a dummy sow.

The following experiment was conducted to get information about the energy costs of the reproductive processes when A.I. boars

are kept on different semen collection frequencies. The experiment was conducted in such a way that the following data whould be derived of boars kept at a semen collection scheme of 1 or 3 times a week.:

- heat production on non mating days,
- heat production on mating days,
- energy retention,
- protein- and fat-retention.

Furthermore it was studied whether these parameters were influenced by the fact that boars were adapted to a mating frequency of 1 or 3 times a week or that they were not adapted.

MATERIAL AND METHODS

Three experiments were performed. Each experiment consisted of two trials which were conducted in two calorimeters at the same time. In each of the 6 trials 4 Yorkshire boars were housed in one open circuit calorimeter (Verstegen et al., 1987).The boars were kept individually in balance cages with a slatted floor. Boars were exposed to artificial fluorescent lighting for 12 hours per day. Data on which boars are selected are given in Table 1. All boars were fed a commercial sow diet, containing 13.5 MJ metabolizable energy (ME) and 160 g crude protein per kg in exp.1 and 13.5 MJ ME and 155 g crude protein per kg in exp. 2 and 3. The diets were given at a level of about 490 kJ metabolizable energy (ME) per $kg^{0.75}$ per day. (Details are given in Table 1). Boars were fed twice daily at 7.15-8.00 h and 16.00 h. Water was added to the feed in a weight ratio from 3 to 1. In all trials ambient temperature was maintained at about 20°C and relative humidity at 65% throughout the experiment.

Experimental design

In Dutch A.I. Centres the semen collection frequency variesbetween 1 and 3 times per week (Kemp, 1986).Therefore these two collection frequencies were adopted in the experimental design. In Figure 1 the experimental design is given. Boars at a semen collection scheme of 3 times a week mated at monday, wednesday and friday. Boars on a collection scheme of once a week mated on wednesday. Semen was collected from boars mounting a dummy sow,

Table 1: Weight (kg) and ultrasonically measured backfat thickness (mm) at the start of the adaptation period and feeding level (kJ metabolizable energy (ME)/$kg^{0.75}$/d) and feeding time in the morning at the main period.

	TRIAL					
	1	2	3	4	5	6
Weight (kg) (sd)	203 (8)	209 (21)	192 (11)	193 (10)	200 (8)	198 (10)
Backfat thickness (mm) (sd)	13.6 (1.7)	13.7 (2.4)	15.3 (1.3)	14.8 (2.1)	14.8 (2.1)	13.4 (1.7)
Feeding level (kJ ME/$kg^{0.75}$/d)	526	526	478	478	475	475
Feeding time (a.m.)	8.00	8.00	7.15	7.15	7.15	7.15

Figure 1: Experimental design.

		NUMBER OF SEMEN COLLECTIONS PER WEEK							
		A.I. Centre	Adaptation period	Main period 1			period 2		
Weeknr.				1	2	3	4	5	
Exp.	Trial								
1	1	3	3	3	3	1	1	1	(HL)
1	2	1	1	1	1	3	3	3	(LH)
2	3	1	1	1	1	3	3		(LH)
2	4	1	1	1	1	1	1		(LL)
3	5	3	3	3	3	1	1		(HL)
3	6	3	3	3	3	3	3		(HH)

using the glove hand technique.
Before the start of each trial, boars were kept at an A.I. Centre on a semen collection frequency of 1 or 3 times a week for a period of 5 weeks. In this period all boars were individually housed in crates, and fed the commercial sow diet at a level of 3 kg per day. Water was given ad libitum. In this period boars were kept at a constant semen collection frequency as shown in Figure 1. After this period boars were assigned to the calorimeters. From 10.30 h to 11.30 h in trial 1, 3 and 5 and from 12.30 h to 13.30 h in trial 2,4 and 6 always the same technician was in the calorimeter for semen collection. After an adaptation period of 1 week the main period of 4 to 5 weeks was started, in which measurements were done. The first 2 weeks of the main period boars were kept at the same semen collection frequency as in the previous adaptation period and at the A.I. Centre. After these two weeks semen collection frequency was changed as shown in Figure 1 and measurements were carried on for another two or three weeks. From this experimental design it was expected that the first 2 weeks of the main period whould reveal information about boars adapted to a mating frequency of 1 or 3 times weekly while the second two to three weeks would give information on adaptation to a changed frequency of 1 to 3 or 3 to 1 times a week.

MEASUREMENTS

Heat production was calculated from measurements of gaseous exchange of carbon dioxide and oxygen every 12-18 min. period throughout 48 h. Two 48 h periods were imposed in each week. One period (tuesday 9.00 h to thursday 9.00 h) included a semen collection period while the other period (saturday 9.00 h to monday 9.00 h) did not include a semen collection period.

Collection, sampling and chemical analyses

Excreta were collected daily in a vessel containing 1.5 l of 96% sulfuric acid. Semen was collected at all times when boars were mating. In each ejaculate the number of sperm cells was counted using a colorimeter. At thursday all samples were bulked, weighed and sampled for determination of their energy and nitrogen con-

tent. In addition samples of the diet were analysed for nitrogen and dry matter. Energy content of feed, excreta and semen was determined by bomb calorimetry (excreta and semen after freeze drying). Nitrogen content was determined by the Kjeldahl method. Protein content was estimated by multiplying the nitrogen content with 6.25.

Analyses on heat production and balance procedures.

Per week during four 24 h periods heat production was measured. Three 24 h periods were non-semen collection days and one 24 h period was a semen collection day.
Per week per trial the mean heat production at non semen collection days (HNCD) and at semen collection days was calculated (HCD). The extra heat production due to mating (EHM) was calculated by subtracting HNCD from HCD.
The mean heat production per week (Hi, as expressed per day) was calculated as follows:

$$Hn=[(HNCD*n1) + (HCD*n2)]/7$$

n1 = number of non semen collection days in a week.
n2 = number of semen collection days in a week.

Diurnal pattern in heat production at semen collection days compared to non semen collection days was shown by calculating the heat production per hour within a day as calculated from the 12-18 min. heat production data.
ME-intake was calculated as the difference between gross energy intake (GE) and energy output in excreta. ME was determined weekly. Energy balance (EB) was calculated by subtracting the mean weekly heat production and energy in semen from the ME-intake. Protein gain was determined from nitrogen intake in feed minus nitrogen excreted in faeces, urine and semen and corrected for NH_3 in the air and in the water collected from the heat exchanger. Energy retained as protein was calculated from protein gain multiplied by 23.9 kJ/g (energy value of protein). The gain in fat (in g) was derived from the EB by subtracting energy gained in protein from the total energy gain and dividing by 39.7 kJ/g (the energy value of fat).

STATISTICAL ANALYSES

Adapted boars

To get values for the situation of adaptation the first two weeks of the trials were analysed. HNCD, HCD, EHM, EB, gain in protein, gain in fat and number of produced sperm cells per ejaculate as calculated per trial per week have been subjected to analyses of variance (using SAS-GLM; SAS, 1985) according to the following model:

$$Y_{ijk} = u + EXP_i + MF_j + e_{ijk}$$

Y_{ijk}	- the dependent variable
u	- the overall mean
EXP_i	- the effect of the i-th experiment (i=1-3)
MF_j	- the effect of the j-th mating frequency (j=1-2)
e_{ijk}	- error

No interaction effects were found to be significant ($P > 0.05$).

Non-Adapted boars

For analyzing adaptational reactions of boars data of trials 1, 2, 3 and 5 can be used. HNCD, HCD, EHM, EB, gain in protein, gain in fat and number of produced sperm cells per ejaculate as calculated per trial per week have been subjected to analyses of variance (using SAS-GLM; SAS, 1985) according to the following model:

$$Y_{ijkl} = u + EXP_i + HL/LH_j + WK_k + WK*HL/LH_{jk} + e_{ijkl}$$

Y_{ijkl}	- the dependent variable
u	- the overall mean
EXP_i	- the effect of the i-th experiment (i=1-3)
HL/LH_j	- the effect of the j-th treatment HL or LH (j=1-2)
WK_k	- the effect of the k-th week (k=1-5)
$WK*HL/LH_{jk}$	- the effect of the interaction term
e_{ijkl}	- error

All tests of significance were performed against error terms. Post hoc analyses of the interaction term were performed using the students t-test (using SAS-GLM; SAS, 1985).

RESULTS AND DISCUSSION

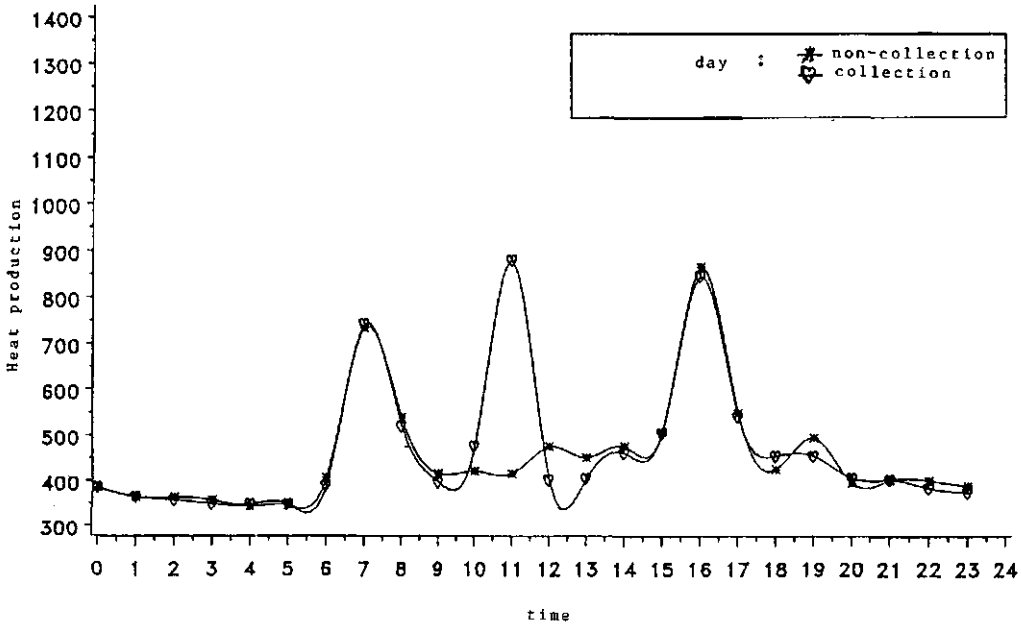
Heat production at semen collection days showed a significant ($P < 0.01$) increase compared to heat production at non semen collection days (EHM= 18 kJ/kg$^{0.75}$/day (sd=7)). At semen collection days the technician who collected semen from the boars was in the calorimeters during 56 min. (sd=9). The four boars were 31 min. (sd=3) on the dummy (7.75 min. per boar). During the other 25 min. boars were guided from and to the dummy and some time was needed before boars mounted on the dummy.
After the experiments one time the heat production of the technician was measured while working with the boars. On the basis of this measurement heat production of the technician was determined to be 828 kJ for the period in the calorimeter. The boars weighed as an average 200 kg. In one calorimeter 4 boars were present and therefore extra heat production due to semen collection seems to be over-estimated by $828/(4*200^{0.75}) = 3.9$ kJ/kg$^{0.75}$/d. The technician entered the calorimeter via an airlock. This means that air in the calorimeter (containing about 0.8% CO_2) was exchanged by outside air (containing about 0.04% CO_2). Due to this exchange of air heat production was under-estimated by about 690 kJ/d (Bikker and Janmaat, unpublished). The resulting over-estimation of heat production due to the presence of the technician is therefore about 0.8 kJ/ kg$^{0.75}$/d. In further calculation this over-estimation was neglected.

Diurnal pattern in heat production

In Figure 2 an example of the diurnal pattern in heat production of a semen collection day compared with a non- semen collection day is shown. The mean heat production every hour of a day at semen collection days and non semen collection days is calculated for the first two weeks of trial 3. Other periods in other trials show similar results.
Heat production at semen collection and non semen collection days is very similar at night and during the feeding times around 7.30

h and 16.00 h. On a semen collection day, however, there is a clear increase in heat production in the semen collection period. This peak in heat production as shown in Figure 2 is the mean of four boars per trial. Data of individual boars can not be calculated since the boars were housed together in a calorimeter. Since events in a calorimeter are measured from the total four boars the heat production curve is also related to the four boars together. Although the area unter the curve will be the same, the shape of the curve when measured with only one boar might be different. A much steaper and narrower curve is expected for one boar indicating that the heat production at the moment of semen collection is really impressively increased.
After the semen collection period heat production is decreased below the level found in boars at non semen collection days. Probably boars are resting after mating.

Figure 2: The diurnal pattern in heat production (kJ/ $kg^{0.75}$/d) at semen collection and non-semen collection days for the first two weeks of trial 3.



It is evident from analysing the diurnal pattern in heat production that the significant EHM is due to the very high heat production during semen collection.
In Table 2 the HNCD, HCD and EHM are given as a mean for the first two weeks (period 1) and the following two to three weeks (period 2) for the six trials.

Table 2: Heat production (kJ/kg$^{0.75}$/day) as a mean per week (HM), at non semen collection days (HNCD), at semen collection days (HCD) and extra heat production at semen collection days (EHM) as calculated for different trials at different semen collection frequencies.

TRIAL	PERIOD 1				PERIOD 2			
	HM	HNCD	HCD	EHM	HM	NHCD	HCD	EHM
1 (HL)	452	443 (5)	463 (8)	20	468	466 (9)	481 (3)	15
2 (LH)	464	461 (8)	484 (15)	23	497	484 (9)	515 (2)	31
3 (LH)	467	464 (11)	484 (7)	20	470	459 (8)	485 (14)	26
4 (LL)	467	464 (17)	484 (14)	20	465	462 (4)	480 (1)	18
5 (HL)	460	456 (4)	466 (14)	10	446	445 (6)	449 (7)	4
6 (HH)	465	459 (7)	474 (15)	15	446	441 (6)	452 (7)	11

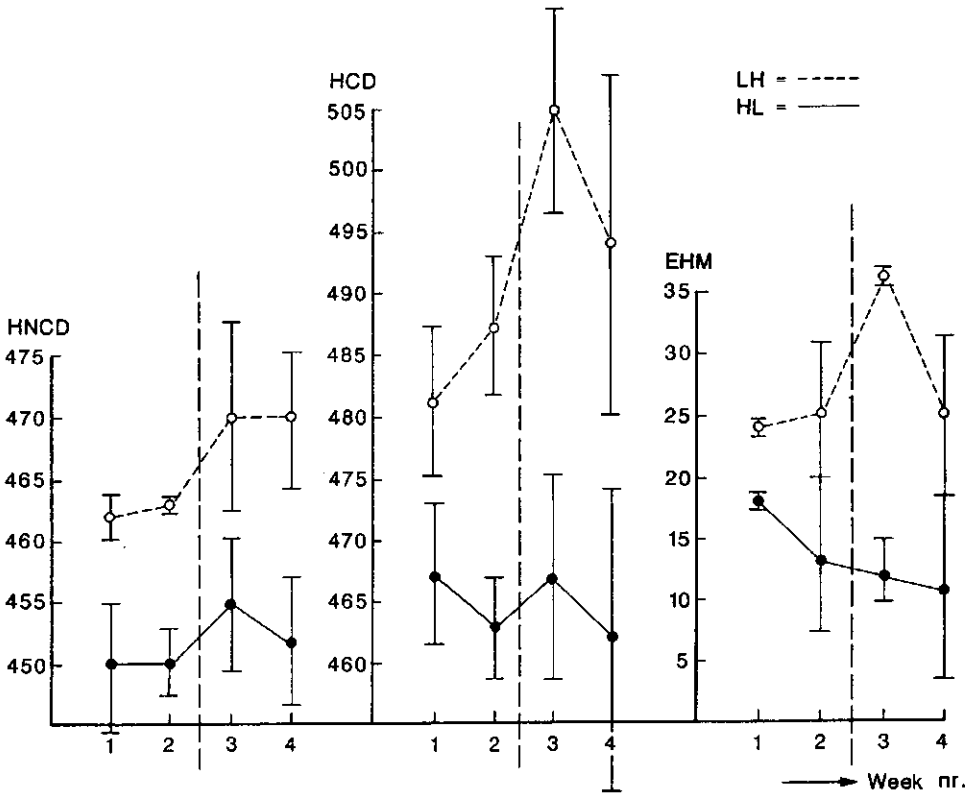
(Between brackets the standard deviation between respiration days is given.)

Heat production of adapted boars

In period 1 the mean HNCD for boars at the low and high semen collection frequency is 463 and 453, respectively. Boars on the high semen collection frequency have a significantly lower (about 10 kJ/kg$^{0.75}$/d, P = 0.043) HNCD compared to the boars on the low semen collection frequency. Also on semen collection days intensively collected boars had a 16 kJ/ kg$^{0.75}$/d (484 vs 468)) lower heat production compared to boars on the low semen collection scheme (although not significant, P = 0.106).
In contrast to what one might expect, boars which are adapted to

a high semen collection scheme seem to produce less heat compared to boars on the low scheme (however differences are small). Heat production as a mean per week (HM) is 459 (sd=7) vs 466 (sd=2) for the high and low semen collection scheme, respectively. Boars on the high semen collection scheme seem to compensate the extra heat due to extra number of semen collection days by a lower mean heat production. Maybe animals at a high semen collection frequency are as an average less active during non-mating and mating days compared to boars on a low semen collection frequency. From the second period of trial 4 and 6 the same conclusions can be drawn.

Figure 3: HNCD, HCD and EHM as a mean per week of trial 1 and 5 (HL) and 2 and 3 (LH) (kJ/ $kg^{0.75}$/ d).



The EHM for boars at the high semen collection scheme is 15 $kJ/kg^{0.75}$ compared to 21 for boars at the low semen collection scheme (not significant, P = 0.226). The same tendency in heat saving at high semen collection frequencies is seen as stated above.

Heat production of non-adapted boars

For non-adapted boars data of trial 1, 2, 3 and 5 can be used. In Figure 3 HNCD, HCD and EHM are shown as a mean for trial 1 and 5 (HL) and for trial 2 and 3 (LH) as calculated for different weeks.
A decrease in semen collection frequency from three times to once a week did not result in an effect on either HNCD, HCD or EHM (P > 0.6). An increase in semen collection frequency from one to three times a week did not result in significantly different HNCD, HCD and EHM either (P > 0.06). From Figure 3 one can see that HCD and EHM were, however, somewhat higher in the LH group in the first week after the change. EHM was 36 $kJ/kg^{0.75}/d$ in the first week after adaptation compared to 24 $kJ/kg^{0.75}/d$ in the two previous weeks. HCD was 505 $kJ/kg^{0.75}/d$ in the first week after adaptation compared to 484 $kJ/kg^{0.75}/d$ in the two previous weeks.

Table 3: Energy balance ($kJ/kg^{0.75}$/day), protein- and fat-gain (g/an/day) for different trials and different semen collection frequencies.

TRIAL	PERIOD 1			PERIOD 2		
	EB	gain in protein	gain in fat	EB	gain in protein	gain in fat
1 (HL)	72 (2)	128 (1)	24 (2)	54 (5)	117 (5)	4 (5)
2 (LH)	53 (3)	124 (4)	2 (7)	26 (6)	124 (6)	-36 (11)
3 (LH)	17 (1)	123 (17)	-52 (9)	10 (2)	123 (8)	-61 (8)
4 (LL)	11 (14)	101 (14)	-46 (9)	2 (11)	86 (4)	-52 (8)
5 (HL)	7 (3)	104 (2)	-54 (5)	37 (2)	108 (2)	-14 (2)
6 (HH)	0 (8)	113 (10)	-69 (16)	32 (10)	105 (1)	-20 (13)

In the fourth week EHM and HCD are comparable with the data derived in the first two weeks of the experiment. Boars adapted at a low semen collection frequency, when set on a high semen collection frequency might show some increased heat production at mating days due to adaptation although reactions are too small to be significant. This adaptational effect is only seen the first week after change.

Energy balance, gain in protein and gain in fat

In Table 3 the energy balance, gain in protein and gain in fat are shown for different trials at the two different periods. Due to the large variation no effects of semen collection frequency or adaptation were found. In all trials gain in protein is high (about 113 g/an/d) and the fat gain is low or even negative (as a mean about -32 g/an/day). There is no doubt that the relative low feeding level is associated with the low EB. It seems that about 1 year old Yorkshire A.I.boars still have a very high growth potential. Since boars should not loose fat because of expected reproductive problems (Kemp et al., 1989) it is obvious that the feeding levels as applied in these experiments (475 to 526 kJ ME/ $kg^{0.75}$/d are too low.

Semen production

In Table 4a the numbers of produced sperm cells ($x10^9$) per week are given for the different trials. In the first two weeks boars adapted to a collection frequency of 3 times a week have as an average a number of produced semen cells per week of 113 $x10^9$ and boars adapted to a semen collection frequency of one time a week produce 93 $x10^9$ sperm cells a week. In these two weeks the difference between boars on a high an a low semen collection scheme was 20 $x10^9$ (not significant, $P = 0.628$).
In Table 4b the mean number of produced sperm cells per week is given for the HL and the LH treatment groups from trial 1,2,3 and 5. The first week after changing the semen collection frequency the HL boars show a significant decrease ($P < 0.05$) and the LH boars show a significant increase in number of produced sperm cells. This results in a difference between the HL and LH group of 75 $x10^9$ sperm cells in the thirth week. In the second week

after change semen production is clearly going to the levels for the adaptation situation (difference between HL and LH is now 25 $x10^9$).

Table 4a: Number of produced sperm cells ($x10^9$) per week for the different trials.

Weeknr.	1	2	3	4	5
trial					
1 (HL)	106	112	61	81	82
2 (LH)	107	99	142	122	120
3 (LH)	81	70	138	87	
4 (LL)	114	85	82	96	
5 (HL)	115	119	68	78	
6 (HH)	115	111	116	117	

Table 4b: Mean semen production of the boars in trial 1 and 5 (HL) and 2 and 3 (LH) for different weeks.

Weeknr.	1	2	3	4
treatment				
HL	111^{bc}	116^{b}	65^{e}	80^{de}
LH	94^{cd}	85^{d}	140^{a}	105^{bc}

Data with a different superscript in a row or column are significantly different ($P < 0.05$).

The association of adaptation effects in heat production with changes in semen production after adaption can not be properly evaluated from our data. Boars produce ejaculates of about 300-400 ml containing 95% water, 3.4% protein and 1.6% other products like carbohydrates and fat (Hansel and McEntee, 1981). A boar ejaculating 2 times a week will have to produce 100 ml ejaculate per day containing 3.4 g of protein and 1.6 grams of other products. The energy costs of this very low production is neglectib-

le compared to the energy cost of maintenance and growth. According to Singh (1962) and Swiersta (1968) it takes more than six weeks before an A-type spermatogonium is developed and is ejaculated in the semen. This is another reason why the relation between semen production parameters and heat production during a few weeks as in this experiment is unlikely.

The extra energy requirement for boars at a semen collection day is about 18 kJ/ $kg^{0.75}$. This is a very small part of their daily energy requirement. It is also clear that boars adapted to high semen collection frequency reduce their heat production and therefore more than compensate their extra heat requirement due to the higher mating frequency. Adaptational reactions on heat production due to changes in semen collection frequency are small. Therefore one can conclude that, in formulating feeding requirements for boars, no special attention will have to be payed to the extra costs of mating due to different semen collection schemes.

ACKNOWLEDGEMENTS

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CHAPTER VI

THE EFFECT OF FEEDING LEVEL ON SEMEN QUANTITY AND QUALITY OF BREEDING BOARS.

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Animal Reproduction Science: in press

ABSTRACT

An experiment was imposed to investigate the influence of feeding level on semen quantity and quality in breeding boars in two successive periods of 12 and 8 weeks. 42 Yorkshire boars (13 months old) were fed during 12 weeks ad libitum (H=5.74 kg/d), a medium feeding level (M=3.62 kg/d) or a low feeding level (L=1.92 kg/d). After 8 weeks the number of ejaculated sperm cells for the L boars was lower than for the H and M boars ($P < 0.05$). In the last two weeks, the M and H fed boars ejaculated 46 % and 69% more sperm cells, respectively, compared to the L fed boars. Differences between all three levels were significant ($P < 0.05$). After this twelve week period feeding level was altered for the H boars and the L boars. H boars were now fed on a low feeding level (HL) and L boars were now fed on the medium feeding level (LM). The medium fed boars were kept at the same feeding level (MM).

After 8 weeks in the second period differences in the number of ejaculated sperm cells between the HL and MM boars and the differences between the LM and MM boars were no longer significant ($P > 0.05$).

During the whole experiment no differences in the quality parameters, percentage of moving sperm cells in the ejaculate, vitality of the moving sperm cells and non return percentage at 56 days were found between treatment groups.

INTRODUCTION

In the winter period boars on A.I. Centres show a decrease in the number of ejaculated sperm cells. This might be explained by the lower ambient temperature in this period. From experiments (Kemp et al., 1988a) it was shown that ambient temperature has a large influence on the energy metabolism of breeding boars. Boars which gained 100 g of protein and 40 g of fat per day at thermoneutral conditions (ambient temperature $>20^{o}C$) lost 155 g of fat per day and showed a diminished protein retention at $10^{o}C$. Whether boars having less feed available for growth will show a reduced semen quality and quantity is unknown.

Experiments on rams (Alkass et al., 1982) showed that feeding 0.75 times the energy requirement for maintenance resulted in a reduced sperm output compared to rams fed 1.25 to 1.5 times the

maintenance requirement. It was not tested in this experiment whether even higher feeding levels would give further improvement of the semen production.
The following experiment was carried out to investigate whether the level of feed intake would influence semen quality and quantity in breeding boars.

Table 1: Composition of the diet.

	%
Soybean meal solv. extracted	8.7
Linseed	3.0
Soybeans toasted	7.5
Sunflower meal	7.5
Animal fat	0.5
Meatmeal/tankage	2.1
Chalk	0.4
Salt	0.3
Hominy feed	6.1
Cane molasses	3.7
Rice bran	2.5
Cassava	37.1
Wheat middlings	15.0
Peas	5.0
Premix*A	0.5
	as analyzed
Metabolizable energy content (MJ/kg)	12.96*B
Crude protein (%)	16.6
Ash (%)	8.3
Crude fibre (%)	5.7
Crude fat (%)	4.7
Dry matter (%)	88.2

*A Contributed the following mineral and vitamin sources per kg diet: 1.34 g Ca, 10 mg Cu, 24 mg Mn, 40 mg Zn, 80 mg Fe, 0.25 mg Co, 0.4 mg I, 0.1 mg Se, 7000 I.E. Vit. A, 1400 I.E. Vit. D3, 4 mg Vit. B2, 18 mg Niacine, 7 mg d-panthothenic-acid, 250 mg Choline, 0.015 mg Vit. B12, 12 mg Vit. E, 0.1 mg Biotine, 0.2 g dl Methionine.

*B As calculated (CVB, 1988).

MATERIAL AND METHODS

42 Yorkshire boars were housed in crates with slatted floors. They were kept on a constant daylight regime of 10 hours light and 14 hours dark. The boars were fed a commercial sow diet from which the composition is presented in Table 1. Water was available ad libitum. Semen was collected twice weekly on a dummy.
At the start of the experiment the boars were divided into three groups with equal mean values of parameters as shown in Table 2. In each group an other feeding level was applied.

Feeding levels

Ad libitum (H).
Boars on this level had free access to feed.

Medium (M).
Boars on the medium feeding level were fed a basic level depending on the liveweight of the boars and two extra allowances depending on temperature and mating.
In Table 3 the basic level is shown for the medium fed boars.
The metabolizable energy (ME) intake for maintenance was based on a maintenance requirement of 447 kJ metabolizable energy/ kg live weight$^{0.75}$/d. The ME for weight gain was based on the following assumptions. The energy value of protein and fat are 23.9 and 36.7 kJ/g, respectively. The efficiencies of energy in protein and fat retention from metabolizable energy are 0.54 and 0.74, respectively. The daily protein retention in the boar was between 5.9 and 15.3% of the average daily gain. 15.3 % was used in boars weighing 150 kg. At increasing liveweight protein retention was gradually decreased to 5.9% at 400 kg of liveweight. Fat retention varied between 38 and 194 g/d and was calculated as average daily gain - 4 x protein retention.
The extra allowance for ambient temperature was given when mean barn temperatures were below 20°C. The extra allowance was calculated (in MJ ME/an/day) as follows:

[20 - (mean of minimum and maximum temperature in 24 h)] x 1.3

The extra allowance for mating was 1.3 MJ ME and given on the day

of semen collection. This would account for the extra activity due to mating (according to Kemp et al., 1988b).
The basic feeding level of the boars was corrected weekly on the basis of the liveweight of the boars. The extra allowances were corrected daily depending on ambient temperature and day of semen collection.

Table 2: Age, liveweight and backfat thickness of boars at start of the experiment.

	Feeding level		
	L	M	H
Number of boars	15	13	14
Liveweight (kg)	220 (22)	219 (21)	224 (19)
Age (months)	13 (1)	13 (1)	13 (1)
Backfat thickness (mm)	15.5 (2.5)	15.8 (3.5)	14.3 (2.4)

(Standard deviation in parenthesis.)

Table 3: Basic level for medium fed boars (ME = metabolizable energy).

Live weight (kg)	150	200	250	300	350	400
weight gain (g/d)	500	400	300	200	100	50
ME for maintenance (MJ/d)	19.16	23.77	28.10	32.22	36.17	39.98
ME for weight gain (MJ/d)	13.79	12.32	10.21	7.32	4.05	2.18
ME-total (MJ/d)	32.95	36.09	38.31	39.54	40.22	42.16
kg diet	2.55	2.79	2.96	3.06	3.11	3.26

Low (L).
Boars on the low feeding level were fed 447 kJ ME/ $kg^{0.75}$/d without extra allowances. This would account for their maintenance requirement at thermoneutral environment as shown previously. Feeding level was adjusted weekly on the basis of the liveweight of the boar.

Experimental design

Boars are kept for twelve weeks on one of the three feeding levels as shown above (Period 1). After one week in which the feeding level was changed stepwise, H and L boars are set on the new feeding levels. H boars are now kept on the low feeding level although they do receive the extra allowances for ambient temperature and mating (HL). L boars are now kept at the medium feeding level (LM). The new feeding levels were applied for another 8 weeks (period 2). The medium fed boars kept the same feeding level (MM).

MEASUREMENTS

Culling

Boars refusing to mount the dummy for more than two times per period were not included in the calculations.

Weight gain and backfat thickness

Boars were weighed once weekly. The backfat thickness was measured every two weeks ultrasonically as described by Verstegen et al. (1979).

Semen production

Ejaculates were collected by hand glove technique and the gelatinous fraction was removed from the ejaculate using a gauze. Thereafter the volume of each ejaculate was measured. The concentration of sperm cells was measured colorimetrically (Niwa et al., 1981). Using the volume of the ejaculate and the concentration , the number of sperm cells per ejaculate was calculated.

For each boar the number of produced sperm cells per week was calculated.
The quality of the ejaculate was determined by microscopic examination. Quality was assessed using two parameters, the percentage of moving cells and the vitality of the movement of the sperm cells. The second quality parameter received a score varying from zero (very bad) to ten (extremely good). The vitality of the movement was defined to be good if sperm cells showed a vigorous straight-forward movement. A bad vitality was defined to be a weak, slow and spasmodic movement of the sperm. For each boar the mean of each quality parameter was calculated per week.
The semen of the boars was used for artificial insemination with doses of 3 $x10^9$ sperm cells. The mean non-return percentage on 56 days was calculated per boar per week.

STATISTICAL ANALYSES

The number of produced sperm cells as well as the non-return percentage on 56 days have been subjected to analyses of variance according to the following model.

$$Y_{ijkl} = u + FL_i + B_{j(i)} + W_k + FLxW_{(ik)} + e_{ijkl}$$

Y_{ijkl}	--	dependent variable
u	--	overall mean
FL_i	--	feeding level effect (i=1,2,3)
$B_{j(i)}$	--	the effect of the j-th boar nested within feeding level(period 1:j=1-42, period 2: j=1-37)
W_k	--	the effect of the k-th week (period 1:k=1-12 period 2:k=1-8)
FLxW	--	interaction between week and feeding level
e_{ijkl}	--	error

Analyses of variance have been done for both periods separately. All tests except effects of feeding level were tested against the error term. The feeding level effect was tested against the boar term. Post hoc analyses of the interaction between feeding level and week nr. were performed using T-test (using SAS-GLM; SAS, 1985).
The quality parameters were not distributed normally. Therefore

for each boar the quality scores from all ejaculates from a total period or after 6 weeks in a period were enumerated and after ranking a Kruskal Wallis test was performed (using SAS-NPAR1WAY; SAS, 1985).
The culling rate was analysed using the Chi-square test. Differences in average daily gain and changes in backfat thickness between groups over a period were analysed with a T-test.

RESULTS

Number of boars culled, feed intake, average daily gain and changes in backfat per period are shown in Table 4.
In the first period reason for culling was leg weakness (3 H and 2 L boars) and lack of libido (1 L boar). In the second period reason for culling was leg problems (1 MM boar), lack of libido (1 LM boar) and fever (2 LM boars). Differences in culling rate between groups were not significant ($P > 0.05$).
In the first period, feed intake between boars in the different treatment groups differed significantly. The mean barn temperature was about 13°C, therefore an extra 700 g of feed was given daily to the M boars explaining the relative high feed intake. Average daily gain and changes in backfat thickness per period was also significantly different for the boars in the different treatment groups. L boars lost weight and backfat, showing that these boars were obviously fed below their true maintenance requirement. H boars showed an impressive growth rate and increase in backfat thickness. In the second period HL boars showed no significant average daily gain and no significant change in backfat thickness. In period 2 LM boars showed a higher average daily gain level than MM boars ($P < 0.05$). Increase in backfat thickness development was similar for MM and LM boars.

Table 4: Production traits during the experiment.

Treatment group	HL	MM	LM
Period 1 (wk 1-12)			
Feeding level	Ad libitum	Medium	Low
nr. of boars	14	13	15
nr. of boars culled	3[a]	0[a]	3[a]
feed intake (kg/d)	5.74[a] (0.55)	3.62[b] (0.06)	1.92[c] (0.13)
average daily gain (g/d)	1019[a] (214)	516[b] (114)	-229[c] (114)
change in backfat thickness (mm/period)	11.9[a] (3.3)	2.3[b] (1.4)	-3.3[c] (1.6)
Period 2 (wk 14-21)			
Feeding level	Low	Medium	Medium
nr. of boars	11	13	13
nr. of boars culled	0[a]	1[a]	3[a]
feed intake (kg/d)	3.10[a] (0.13)	3.58[b] (0.04)	3.44[c] (0.08)
average daily gain (g/d)	50[a] (137)	327[b] (81)	604[c] (97)
change in backfat thickness (mm/period)	-1.4[a] (1.3)	1.6[b] (0.9)	1.5[b] (0.8)

Between brackets the standard deviations between boars is given. Different superscripts in a row means significant differences ($P < 0.05$).

Semen production

Number of ejaculated sperm cells

In the first as well as in the second period a significant feeding level x week interaction was found on the number of ejaculated sperm cells ($P < 0.05$).

Table 5: Number of ejaculated sperm cells ($\times 10^9$) per week in the first period.

Week nr.	1-6	7	8	9	10	11	12
Feeding level							
Low	121	118	109	110^a	111^a	99^a	89^a
Medium	125	121	126	121^a	128^{ab}	125^b	130^b
High	126	125	128	168^b	134^b	149^c	151^c

Different superscripts in a column means significant differences ($P < 0.05$). (R square = 0.62, RSD = 24.3, $P < 0.05$).

In Table 5 the least square means of number of ejaculated sperm cells per week for the different treatment groups are given for the first period. For the first 6 weeks the average is given. After 8 weeks the differences in number of ejaculated sperm cells between treatment groups become significant. Compared to the M boars in the last two weeks of the first period the H boars show an 18% higher number of ejaculated sperm cells while L boars show a 26% lower number of ejaculated sperm cells.

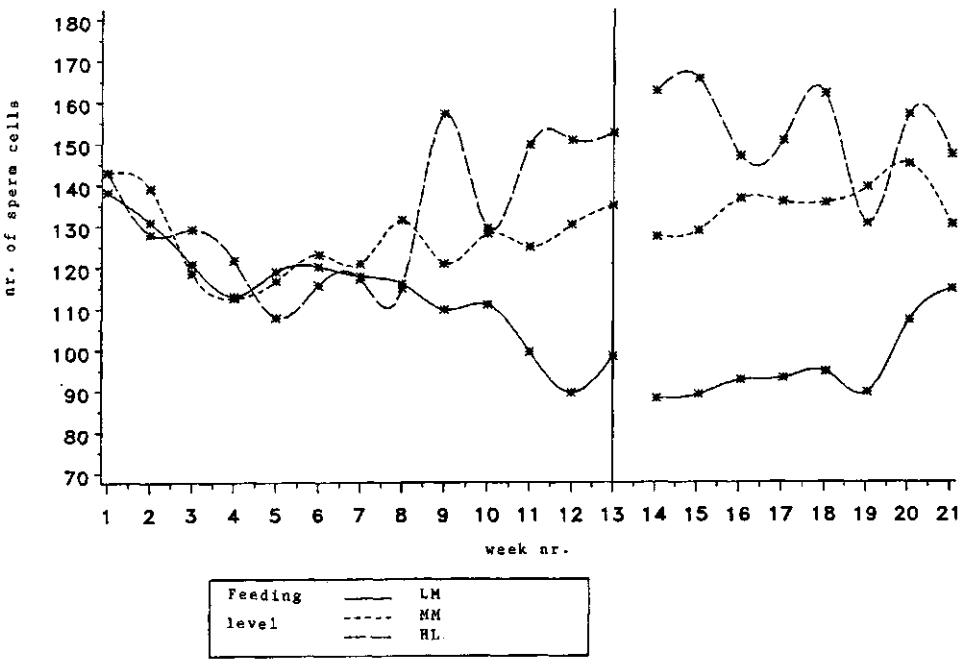
In Table 6 the least square means of the number of ejaculated sperm cells are given for the second period. Although feeding levels are changed, the differences in number of ejaculatedsperm cells remain for several weeks. After 6 weeks at the medium feeding level the LM boars show an increased number of ejaculated sperm cells. In week 21 the difference in number of ejaculated sperm cells between the LM and MM boars is no longer significant. The difference in number of produced sperm cells between the HL and the MM boars is no longer significant from week 16 onwards with exception of week 18.

Table 6: Number of ejaculated sperm cells (x 10^9) per week in the second period.

Weeknr.	14	15	16	17	18	19	20	21
Feeding level								
HL	163^a	166^a	147^a	151^a	162^a	131^a	157^a	147^a
MM	127^b	129^b	137^a	137^a	138^b	140^a	145^a	131^{ac}
LM	87^c	87^c	93^b	94^b	95^c	90^b	108^b	115^c

Different superscripts in a column means significant differences ($P < 0.05$). (R square = 0.74, RSD = 24.4, $P < 0.05$).

Figure 1: Number of ejaculated sperm cells for different treatment groups.



In Figure 1 the number of ejaculated sperm cells per week is shown for different treatments. Obvious is the large variation in number of produced sperm cells between weeks in the HL boars.

Quality parameters of the ejaculate.

The mean values for percentage of moving sperm cells, the vitality of the movement of the sperm cells and the non-return percentage of the ejaculates as calculated per week were not significantly influenced by feeding level in each period.

In period 1 the mean value for percentage of moving sperm cells and for vitality of the moving sperm cells was 70.9 (sd=3.9) and 7.64 (sd=0.27), respectively. Non-return percentage was 95.4 (sd=2.0) in this period.

In period 2 the mean value for percentage of moving sperm cells and for vitility of the moving sperm cells was 71.4 (sd=5.0) and 7.64 (sd=0.38), respectively. Non-return percentage was 94.0 (sd=2.7) in this period.

(sd in this paragraph is the standard deviation between boars).

DISCUSSION

Westendorf and Richter (1977) advise in their literature review on feeding of boars that a low feeding level should be applied since a high feeding level may induce leg weakness and therefore libido problems. Based on an experiment of Stevemer et al. (1961), Westendorf and Richter (1977) state that no negative effects of low feeding levels on semen production might be expected. Stevemer et al. (1961), however,did their experiment with only two boars per treatment group. Finding effects on semen production with such low number of animals is unlikely. It seems that the conclusions of Westendorf and Richter are only partly right. Semen quality parameters (even non-return %) are not depressed by low feeding levels; the number of produced sperm cells, however, is depressed.

The statement of Westendorf and Richter (1977) that leg weakness and libido problems are induced at high feeding levels could not be confirmed by the present experiment. However, it should be noted that the present experiment lasted only 21 weeks.

In the performed experiment no differences in semen production

were expected for at least 6 weeks because the production of a sperm cell from an A-type spermatogonium, including the time to pass the epididymis, takes about 39 to 45 days. (Singh,1961; Swierstra, 1968). After 8 weeks the differences in number of produced sperm cells between treatment groups became significant. In the second period differences in number of ejaculated sperm cells between HL and MM boars and differences between LM and MM boars were not significant anymore after 8 weeks although differences in live weight and backfat thickness were still significant. This suggests that the effect of feeding level is a rather direct one and not due to a differences in stage of development of the rather young boars.

Boars on A.I.Centres are usually kept on feeding levels which are below the medium level as used in this experiment (Kemp 1986). In terms of reaching a maximum sperm output one can state that feeding levels of boars on A.I.Centres are too low. Especially in the winter period with relative low barn temperatures the number of produced sperm cells may be reduced.

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GENERAL DISCUSSION

Reproductive performance of boars is a rather variable characteristic. The heritability of reproductive characters is usually low (h^2 estimates for volume, concentration and number of sperm cells vary between 0.1 and 0.3; Steen and Molenaar, 1983). Therefore environmental factors will be mainly responsible for variation in reproductive performance. One of these factors is nutrition.

In the present study various aspects of the nutrition of breeding boars are investigated to contribute to the development of a feeding strategy.

First it will be discussed how the aspects of the nutrition as investigated in this thesis can be used in a practical feeding strategy. Then a practical feeding strategy is developed on basis of literature and the information from this thesis.

THE PRACTICAL IMPLICATION OF THE EXPERIMENTS

Protein

The literature review (chapter I) reveals specific interest in the protein nutrition of boars. Meding and Nielsen (1977) and Kerk and Willems (1984) found no effect of increasing protein or more specific of increasing lysine and methionine levels above the usual levels in commercial sow diets. It should be noted that in the cited experiments boars were kept on a low semen collection frequency. Poppe et al. (1974) kept boars on a low semen collection frequency of 1 or 2 times a week. After 12 weeks the collection frequency was increased to 3 to 4 times a week. They concluded that high protein levels (and especially high methionine levels) in the diet increased semen production of breeding boars at high mating frequencies. On low mating frequencies (1 to 2 times a week) no effect of extra methionine in the diet was found.

It is quite unlikely that at higher mating frequencies a high protein (methionine plus cystine) intake is needed. Poppe et al. (1974) found at high semen collection frequencies a positive effect of an extra methionine intake of 16 g/day on reproductive characteristics. The experiment as described in chapter II shows,

however, that protein levels above that of a commercial sow diet have no effect on semen production, not even at high semen collection frequencies.
In the discussion of chapter V it is shown that the amount of protein in semen is about 3.4 g/100 ml. About 1% of the protein in semen is methionine (Kerk and Willems,1985). In the experiments of Poppe et al. (1974) the volume of semen produced increased from 36 to 95 ml/day with increasing semen collection frequency. This means that only an extra 0.02 g of methionine was produced per day. It's unlikely that an extra 16 g of methionine is needed in the diet for the increase of 0.02 g of methionine in the semen.
It is concluded that in practice a commercial sow diet (per kg: 12.56 MJ ME, 145 g of crude protein, 6.8 g of lysine and 4.4 g of methionine and cystine) contains sufficient protein to ensure good reproductive performance of breeding boars.

Energy metabolism and ambient temperature

The results of the experiments in chapter III and IV concerning the effect of ambient temperature on energy metabolism, show that the feeding level of breeding boars should be adjusted according to the ambient temperature in the winter period. The lower critical temperature (LCT) was estimated to be 20°C. The extra thermoregulatory heat production (ETH) was estimated at 16 $kJ/kg^{0.75}/°C/day$.
The data in chapter III are calculated from boars fed 1.2 times maintenance. The LCT is dependent on the feeding level (Verhagen et al., 1986). The feeding level will not be constant for breeding boars at different liveweights when using a feeding strategy. As shown in Table 4 the feeding level in our feeding strategy (as discussed later) varies depending on liveweight between 1.0 to 1.9 times maintenance.
Extra heat production due to protein and fat retention can be calculated as: $(1-k_g)*MEp$ (k_g is the efficiency with which metabolizable energy (ME) is deposited in growth, MEp is the metabolizable energy available for growth). If maintenance is 415 $kJ/kg^{0.75}/day$ and k_g is estimated to be 0.72 then the extra heat produced due to 0.1*maintenance extra ME for growth, is 42*0.28= 12 $kJ/kg^{0.75}/day$. This means that the LCT will decrease with

(12/ETH) ^{o}C per 0.1 times maintenance increase of the feeding level. In chapter III the ETH was estimated at 16 kJ/kg$^{0.75}$/^{o}C/d. Verhagen et al. (1986) showed with sows that ETH was also feeding level dependent. From his data it was calculated that increasing the feeding level with 0.1*the maintenance requirement would result in 2 kJ/ kg$^{0.75}$/ ^{o}C/ day lower extra thermoregulatory heat production. In Table 1 the ETH and LCT are calculated for different liveweight values using these assumptions.

Table 1: ETH, LCT, and extra feed allowance at 10^{o}C at different live weights as influenced by different feeding levels above maintenance.

Liveweight (kg)	150	200	250	300	350	400
Feeding level (x maintenance)*	1.9	1.6	1.4	**1.2**	1.1	1.0
ETH (kJ/kg$^{0.75}$/^{o}C/day)	30	24	20	**16**	14	12
LCT (^{o}C)	17.2	18.0	18.8	**20**	20.9	22.0
Extra feed per ^{o}C below LCT (g/d)	102	102	100	92	90	85
Extra feed allowance at 10^{o}C (g/d)	737	813	880	920	983	1025

(*maintenance is 415 kJ/kg$^{0.75}$/d.)

Most of the boars at A.I. Centres have a live weight between 200 and 300 kg. From Table 1 it is clear that the practical advice of feeding 100 g of the commercial sow diet mentioned above at each ^{o}C below 20^{o}C will more than cover the extra feed requirements due to low ambient temperatures.

It was also shown (chapter IV) that both LCT and ETH were not constant over a 24 h period but had a daily pattern. The LCT of boars was lower during the night (17.5^{o}C) compared to the day (20.8^{o}C). Usually during winter time, the night is the most difficult period in trying to keep the barn temperature at a sufficient level. Practical consequence of the data derived from chapter IV is that a minimum barn temperature at night can drop

to as low as 18°C before extra thermoregulatory heat is produced. Since, however, the ETH requirement per degree Celcius is higher at night compared to the day, this advantage is gradually lost at temperatures below 18°C.
In a more practical advice we suggest a LCT of 20°C and the feed requirement to be increased 100 g/day per degree Celcius below the 20°C to account for the extra thermoregulatory requirement.

Energy cost for reproduction

In chapter V the influence of a semen collection scheme on the energy metabolism of a breeding boar is investigated. The schemes as chosen in this experiment represent the range in which semen is collected on a practical A.I. Centre. Within this range the consequences of adopting a high or a low scheme on the energy metabolism seems to be small. Also adaptational reactions in energy metabolism due to changing for a high to a low or a low to a high semen collection scheme are small.
From chapter V it has become clear that the energy requirements for reproduction amount to about 18 kJ per kg metabolic weight on a mating day. This means that a 200 kg breeding boar will need about 958 kJ metabolizable energy (ME) extra on a mating day. Compared to the 35180 kJ ME the boar needs for maintenance and growth (see next paragraph) at thermoneutrality, the energy costs for mating are negligible (less than 3% on a mating day). Calculated as a mean per week no differences in heat production could be found between boars on a high and low semen collection scheme. Therefore in this factorial approach energy cost for reproduction is not incorporated.

THE FEEDING REQUIREMENTS FOR BREEDING BOARS

Chapter VI shows that boars should be fed a certain basic level ensuring good reproductive characteristics like libido, number of produced sperm cells and fertilizing capacity of the sperm cells. The question is what this feeding level should be. In the following paragraph an attempt is made to estimate this requirement by means of a factorial approach.
When good reproductive performance is required, energy is needed not only for reproductive processes but also for maintenance and

for growth.
Weight gain of boars is necessary because boars are still young at arrival on A.I. Centres (7-9 months old, 150 kg live weight) and need to develop to mature weight. An adult Yorkshire boar can easily weigh over 400 kg.
As stated above no extra feed allowance is calculated for reproduction. Feeding requirements of boars are estimated on the basis of data concerning maintenance and growth as derived from data in this thesis combined with literature data.

Maintenance

Table 2: Estimates of the energy requirement for maintenance in sows according to different authors.

Stage	Maintenance requirement (kJ ME/ $kg^{0.75}$/ d)	Author
pregnant	418	Verstegen et al. (1971)
pregnant	415	Holmes and Maclean (1974)
non-pregnant	476	Hovell et al. (1977a)
pregnant	530	Hovell et al. (1977b)
pregnant	452	Lodge et al. (1979)
non-pregnant	452	,, ,,
non-pregnant	411	Muller and Kirchgessner (1979)
pregnant	502	Wilde (1980)
non-pregnant	513	,, ,,
pregnant	427	Burluca et al. (1982)
pregnant	422	Close et al. (1985)
non-pregnant	420	,, ,,

Estimating from literature
Maintenance can be defined as the heat production of an animal when the energy balance is zero. The maintenance requirement of an animal can be described as being proportional to the metabolic weight (Brody, 1945).

$$\text{Maintenance} = a^* (\text{liveweight})^{0.75}$$

In an optimal environment the value "a" is fairly constant even

over species. Due to unfavourable environmental conditions like low ambient temperature and draught this value can vary considerably (Es, 1972). Data on the maintenance requirement of breeding boars are not given in literature. Estimates on basis of sows are, however, available. In Table 2 estimates of the maintenance requirement for sows are given as calculated by several authors. From the data in Table 2 one can conclude that the estimates on the energy requirement for maintenance show good agreement. The mean estimate is 453 kJ metabolizable energy (ME) (sd=42).

Estimation on basis of this thesis

Although maintenance requirements for energy are directly related to $W^{0.75}$, animals are usually not kept at zero energy balance. Maintenance requirements can then be derived from total heat production after an appropriate correction for heat losses due to protein and fat retention.

Data on ME-intake, total heat production, protein and fat gain were collected in the experiments reported in chapter III, IV and V. The results are summarized in Table 3.

In the trials from chapter III and IV only heat production, protein and fat gain data are given as calculated at 20°C. From the experiments in chapter V, all trials could be used because an effect of semen collection frequency on metabolizability of energy and protein and fat retention was not found. The energy in body protein is estimated to be 23.9 kJ/g, energy in body fat is estimated to be 39.7 kJ/g and the efficiencies with which energy in protein and in fat are deposited from metabolizable energy are 0.54 and 0.74, respectively (ARC, 1981). The heat production due to maintenance can be estimated (using SAS-NLIN; SAS, 1985) from the formula:

$$\text{ME-intake} = \text{maintenance} * W^{0.75} + (1/0.54)*23.9*\text{gain in protein} + (1/0.74)*39.7*\text{gain in fat}$$

Using the data from these trials, maintenance heat production (MEm) was estimated at 415 kJ/kg$^{0.75}$/day (se=9.6).

This MEm is not significantly different ($p>0.05$) from the sow data derived from Table 2. In this factorial approach of the energy requirement of breeding boars 415 kJ/kg$^{0.75}$ is used.

Table 3: ME-intake (kJ/kg $W^{0.75}$/d), protein and fat retention (g/an /d) and live weight of the boars (kg) as calculated from the various trials reported in this thesis.

Chapter	trial	ME -intake	gain in protein	gain in fat	liveweight
3,4	1	491	105	46	222
	2	471	106	16	225
5	1	524	123	14	213
	2	523	124	-17	219
	3	482	123	-57	193
	4	473	94	-49	193
	5	478	106	-34	208
	6	472	109	-45	207

Growth

Development of a boar

If an animal can express growth without being negatively influenced by environmental factors, in all species the relation between liveweight and age will be an S-shaped curve as shown in Figure 1 (Taylor, 1980). Moore (1985) calculated a mathematical equation which describes this S-shaped curve very well:

$$W=A(1+e^{-pn*(elog(t-3.5)/A0.27)})^{-1/0.27}$$

W = live weight (kg)
A = adult weight (kg)
pn= n-th order polynomial.
t = age of the animal from conception (d).

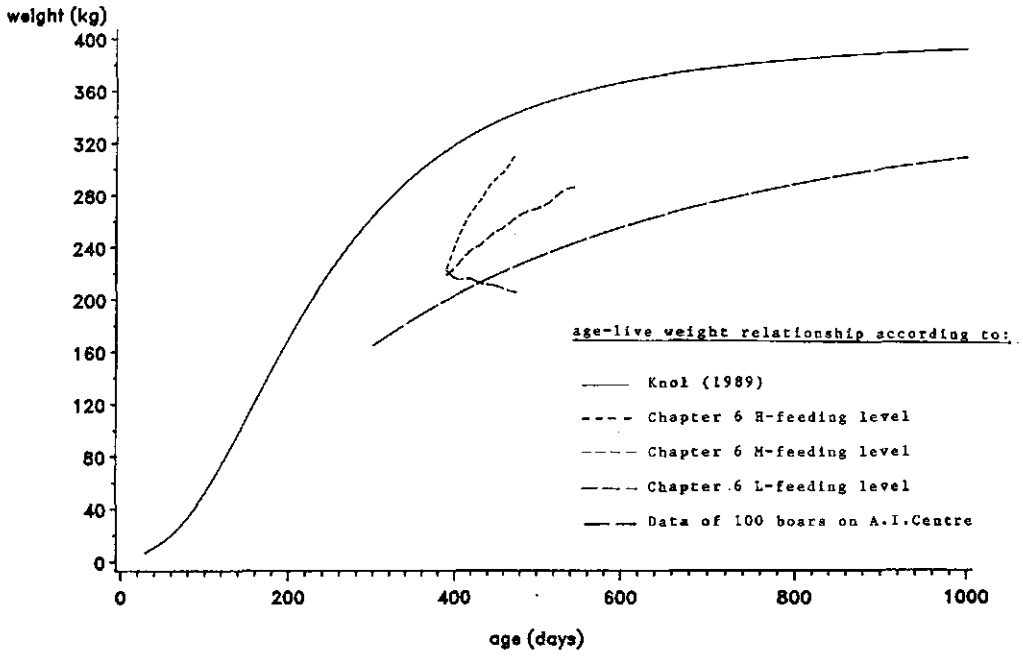
For "pn" Moore (1985) concluded that a third order polynomial based on data collected by Brody (1945) and Hammond (1954) described the relation between weight and age for boars very well. These old data used by Moore (1985) to fit this polynomial resulted in low growth rates for boars. Knol (1989, personal communication) recalculated this third order polynomial on data of modern genetically improved Yorkshire boars as one can find on

A.I. Centres and found the following equation:

$$p(n) = (1.5154/10000) + 3.7892*X - 1.3992*X^2 + 0.0974*X^3.$$

In Figure 1 the age-liveweight relation is given as based on this function for a boar having an adult liveweight of 400 kg.
This so called "undisturbed" development of an animal is a maximum development and due to all kinds of environmental influences (implied or coincidental) this development will not be seen in practice.

Figure 1: The relation between age and live weight based on several data sets.



Of the factors which influence this development, nutrition is one of the most important. Within the age-liveweight relation the weight gain in a boar can be manipulated by the dietary energy and protein level applied. In Figure 1 also the relationship between age and liveweight is shown as calculated from data on

100 boars at an A.I. Centre. This makes clear that boars in practice are kept on feeding levels which allow a restricted development. In general this seems a good strategy because restricted growth saves feed for maintenance and growth. It also keeps the weight of the boar relatively low, which is an advantage in natural mating on relatively small gilts. Also culling due to leg weakness will probably be lower. However, too low feeding levels will have a negative impact on the semen production of A.I. boars as shown in chapter VI. In Figure 1 also the relationship of age-live weight of three treatment groups in the first 12 weeks of the experiment as described in chapter VI is shown. All three treatments groups give significant differences in semen production. Cameron (1988) concluded in a literature review that semen production is age related. During the first 12 months of reproductive life semen production increases. This increase is likely to be related with the boars development.

Quantifying the statements made above is very difficult. Ad libitum feeding for longer periods will result in too heavy boars and will increase the risk of leg problems. Therefore ad libitum feeding can not be recommended as a practical feeding strategy for long periods.

Data in chapter VI show that ad libitum fed boars had a higher semen production compared to the medium fed boars. This was, however, a short term experiment. The slope of the age-weight relation line of the ad libitum fed boars (see Figure 1) compared to that of boars fed unrestrictedly from birth onwards shows that there is a compensatory effect of the boars fed ad libitum due to previous low feeding levels. Perhaps long term experiments on feeding would show that the increased semen production from ad libitum fed boars is due to the compensatory development of the boars. Only long term experiments starting from birth can give an answer as to what the ideal development of a boar in relation to reproduction should be. Such experiments are not done yet.

Too low feeding levels will most certainly result in a reduced semen production. It remains unknown to what level one can restrict the daily feed intake of boars without a negative reaction on reproductive characteristics.

Based on our limited data we therefore recommend the desired growth as realised with the medium feeding level from the boars of chapter VI. These boars showed good reproductive performances

during a period of 20 weeks with no libido or leg problems.
In Table 4 the growth rate at different liveweights is shown as expected from a medium feeding level.

Energy costs for growth

The energy costs for growth can be estimated from the expected protein and fat retention and the efficiency by which protein and fat is retained from metabolizable energy. No data are found in literature on the protein and fat retention and efficiency of deposition in reproducing boars. Therefore again data on sows will be used. ARC (1981) estimated the energy deposition in maternal weight gain in pregnant sows on 23.6 kJ/g. Close et al. (1985) calculated an efficiency of energy retention in maternal gain from metabolizable energy of 0.72. Therefore one can estimate the metabolizable energy requirement per gram maternal growth at 23.6/0.72 = 32.8 kJ. This estimate will also be used for energy costs of growth in boars. From the different desired growth rates as given in Table 4, energy retention for growth can be calculated.
All together the factorial estimate for basic energy requirements is given in Table 4.

Table 4: Basic level for boars according to the factorial approach (ME= metabolizable energy).

Liveweight (kg)	150	200	250	300	350	400
weight gain (g/d)	500	400	300	200	100	50
ME for maintenance (MJ/d)	17.79	22.07	26.09	29.91	33.58	37.12
ME for weight gain (MJ/d)	16.40	13.11	9.83	6.55	3.28	1.64
ME-total (MJ/d)	34.19	35.18	35.92	36.46	36.86	38.76
kg of diet (12.56 MJ)	2.7	2.8	2.9	2.9	2.9	3.1

Practical implications

On basis of this thesis one should recommend a feeding level for breeding boars of 2.7 to 3.1 kg per day using a commercial sow

diet containing 12.56 MJ ME, 145 g of crude protein, 6.8 gr of lysine and 4.4 g of methionine and cystine per kg.
An extra allowance of 100 g of diet for every degree below an ambient temperature of 20°C should be fed below 20°C. Especially this extra allowance is not often fed to boars in practice. It is very likely that at least part of the reduction in semen production in the winter period is caused by this lack of energy.

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GENERAL ABSTRACT

Artificial Insemination (A.I.) is a rapid growing industrial activity. In 1987 about 45 % of the Dutch breeding sows were fertilized by means of Artificial Insemination. One of the factors influencing the efficiency of an A.I. Centre is reproductive output of the breeding boars. A good reproductive output from a boar means a good libido, a high number of produced sperm cells and a good fertilizing capacity of these sperm cells. Within boars these characteristics vary due to all kinds of environmental conditions.

One of the factors which will influence the reproductive characters is nutrition. There are few data in literature regarding the nutritive needs of boars to optimize reproductive characters. In this thesis some aspects of the energy and protein requirements of breeding boars are investigated.

In chapter I a literature review is given concerning the influence of energy and protein intake on the reproductive characters, libido, number of produced sperm cells and fertilizing capacity of the sperm cells of breeding boars. Scarce literature data on breeding boars shows a contradiction in the required level of protein in the diet to optimize reproduction. Some authors state that protein levels far above the usual level in commercial sow diets will have a positive effect on the number of produced sperm cells when high mating frequencies are applied. Other authors state that a normal commercial sow diet contains enough protein; in their experiments, however, boars were kept on a low semen collection frequency.

Furthermore it is shown from literature on rams and bulls that reproductive characters can be influenced by the level of energy intake. Feeding male animals at or below a defined maintenance requirement would result in a decreased number of produced sperm cells. In experiments with boars these effects on semen production could not be confirmed. This results in the fact that many authors recomment a low feeding level for breeding boars.

The contradiction in literature regarding the effect of high protein levels in the diet on reproductive parameters in boars was the reason to conduct an experiment on the effect of a high protein intake on sperm production in boars on a high and low semen collection frequency. This experiment is described in chap-

ter II. Results show that at low as well as at high semen collection frequencies no effect of protein levels above that of a commercial sow diet (12.56 MJ metabolizable energy, 14.5 % crude protein, 0.68% lysine and 0.44 % methionine plus cystine) can be expected on semen production characteristics.

In Dutch A.I. Centres a 20% decrease of the number of produced sperm cells is seen at the end of the winter period. Energetic undernutrition induced by low ambient temperatures might explain reduced semen production in this season. For this reason, the variation in energy requirements due to the variation in environmental temperature is studied. Literature on non-lactating sows shows a large effect of low ambient temperatures on the energy metabolism. At low ambient temperatures a large portion of the daily energy intake is used for thermoregulatory processes.

In chapter III the effect of ambient temperature on the energy metabolism of breeding boars is investigated. Breeding boars in this experiment had a lower critical temperature (LCT) of 20°C, and extra thermoregulatory heat requirement (ETH) of 16 kJ/ $kg^{0.75}/°C$ per day. Boars above the LCT showed a protein and fat gain of 103 and 41 g/day, respectively, while the same boars at the same feeding level but housed at 10°C had a protein gain of 8 g/d while they lost 156 g/d of body fat. From this experiment it was concluded that low ambient temperatures have a large influence on the energy metabolism of boars. In a feeding strategy allowances for low ambient temperatures should be included.

In chapter IV it is shown that the thermal demand of a breeding boar shows a clear daily pattern. The LCT was lower at night (about 18°C) compared to the day (about 21°C). The ETH however was higher at night (22 $kJ/kg^{0.75}/24h/°C$) than during the day (14 $kJ/kg^{0.75}/24h/°C$). At low ambient temperature this compensates the advantage of a lower LCT.

Boars need feed for maintenance, growth and reproductive processes. From chapter III and IV it was clear that, due to environmental temperature, the amount of energy required for maintenance could vary considerably. There was no literature available on the energy requirements for reproduction and whether or not this would be influenced by the semen collection scheme applied.

In chapter V the influence of the semen collection scheme on the energy metabolism of A.I. boars was investigated. Measurements on

the energy metabolism were done with boars adapted to a constant semen collection frequency of 1 or 3 times a week. Also measurements were done after changing the collection scheme of adapted boars from 1 to 3 times a week or 3 to 1 time a week. Effects of semen collection scheme on the energy metabolism of breeding boars are small. On semen collection days boars produce about 18 $kJ/kg^{0.75}$/day extra heat compared to non-semen collection days. Total heat production per week was equal or even lower in boars at high semen collection frequencies. Boars on high semen collection schemes more than compensate their extra energy requirement due to the higher mating frequency when compared to boars on low semen collection schemes. Probably boars on a high scheme rest more between mating. Effects of different semen collection schemes and adaptational reactions are too small to incorporate them into in a feeding strategy for boars.

The literature review in chapter I showed that feeding rams or bulls at or below maintenance resulted in a lower semen production. In literature on boars these effects were not found. Experiments on boars were done with few boars per treatment group or feeding levels well above maintenance. Therefore it was not clear whether differences in feeding strategy could result in differences in semen quality and quantity.

In chapter VI the effect of feeding level on semen quality and quantity of breeding boars is investigated. Boars were fed ad libitum (H=5.74 kg/d), a medium (M=3.62 kg/d) or a low feeding level (L=1.92 kg/d) for twelve weeks. The adoption of these feeding levels resulted in a significantly different number of produced sperm cells. In the last two weeks of the experiment the M and H fed boars ejaculated 46 and 69% more sperm cells, respectively, compared to the L fed boars. After the 12 weeks H boars were fed on a L feeding level (HL boars) and L boars were fed on a M feeding level (LM boars). M fed boars were kept on the same feeding level (MM boars). After 8 weeks the differences between the HL and MM boars and LM and MM boars were not significant anymore. Quality parameters of the ejaculate were not influenced by the adopted feeding levels.

There seems to be a clear effect of feeding strategy on semen quantity of breeding boars. Therefore it is important to try and find an optimal feeding strategy for boars.

In the general discussion a feeding strategy for boars on basis

of maintenance requirements, requirements for growth and requirements for reproduction is described on basis of sow data from literature and data from this thesis. This results in a basic feeding allowance for boars on A.I. Centres of 2.7-3.1 kg (depending on liveweight) of the above mentioned commercial sow diet. An extra allowance of 100 g of the diet per ^{o}C below 20^{o}C per day should be given to account for extra thermoregulatory heat production in the cold. This extra allowance is not often given to breeding boars at Dutch A.I. Centres. This may explain the decrease in semen production at the end of the winter.

SAMENVATTING

Kunstmatige Inseminatie (K.I.) bij varkens is een snel groeiende economische aktiviteit. In 1987 werd ongeveer 45% van de Nederlandse zeugenstapel bevrucht door middel van kunstmatige inseminatie. Eén van de factoren die een grote invloed hebben op de efficientie van een K.I. vereniging is de reproduktie output van de beren. Een goede reproduktie output van een beer wordt gekenmerkt door een goed libido, veel geproduceerde spermacellen per tijdseenheid en een goed bevruchtend vermogen van de spermacellen. Deze reproduktie karakteristieken van een beer kunnen enorm varieren t.g.v. allerlei omgevingsinvloeden.
Eén van deze beinvloedende factoren is voeding. Er zijn erg weinig literatuurgegevens over de relatie nutritieve behoefte van dekberen en optimalisatie van reproduktie kenmerken. In dit proefschrift worden enige aspecten van de invloed van energie- en eiwit-voeding op de reproduktieve kenmerken nader onderzocht.
Een literatuuroverzicht van de invloed van eiwit- en energieopname op de reproduktie kenmerken (libido, aantal per tijdseenheid geproduceerde spermacellen en bevruchtend vermogen van de spermacellen) is gegeven in hoofdstuk I. De weinige literatuurgegevens duiden op een contradictie tussen auteurs over het vereiste eiwitniveau in het dieet ter optimalisatie van de reproduktie eigenschappen van K.I. beren. Sommige auteurs beweren dat het eiwitniveau van een berendieet ver boven het niveau moet liggen dat gebruikelijk is in zeugenvoeders. Dit zou bij hoge dekfrequenties (3x per week of meer) positieve effecten hebben op het aantal per tijdseenheid geproduceerde spermacellen. Andere auteurs beweren dat een normaal zeugenvoeder voldoende eiwit bevat; de beren in hun onderzoekingen stonden echter op een laag dekschema.
Ook komt uit het literatuuroverzicht naar voren dat bij beren de reproduktie parameters niet door energieopname beinvloed zouden worden. Dit heeft tot gevolg dat in handboeken vaak een lage energiegift aan dekberen geadviseerd wordt. Literatuur laat zien dat bij rammen en stieren de reproduktie parameters door energieopname zijn te beinvloeden. Het voeren van mannelijke dieren op of beneden een gedefinieerd onderhoudsniveau zou vooral negatieve effecten hebben op het aantal per tijdeenheid geproduceerde spermacellen. Een ruimere energievoorziening zou gewenst zijn.

De contradictie in de literatuur over het effect van hoge eiwit niveaus op het reproduktievermogen van dekberen was aanleiding om een experiment uit te voeren m.b.t de invloed van een hoog eiwitniveau in het voeder op het reproduktievermogen van beren gehouden op een hoog of een laag dekschema. Dit experiment wordt beschreven in hoofdstuk II. De resultaten van dit onderzoek tonen aan dat er zowel bij beren op een hoog dekschema als bij beren op een laag dekschema geen positieve effecten op het reproduktievermogen te verwachten zijn van een hoog eiwitdieet i.v.t. een normaal commercieel dieet (per kg: 12.56 MJ metaboliseerbare energie, 14.5% ruw eiwit, 0.68% lysine en 0.44% methionine plus cysteine.

Bij Nederlandse K.I. verenigingen wordt aan het einde van de winter een daling van ongeveer 20% in het aantal geproduceerde spermacellen geconstateerd. Energetische ondervoeding veroorzaakt door lage omgevingstemperaturen zou deze daling in de spermaproduktie kunnen verklaren. Daarom werd de variatie in energiebehoefte bestudeerd zoals veroorzaakt door variatie in omgevingstemperatuur. Literatuurgegevens met niet-lacterende zeugen laten een groot effect zien van lage omgevingstemperaturen op het energiemetabolisme. Bij lage temperaturen wordt een groot gedeelte van de dagelijkse energieopname gebruikt voor thermoregulatoire processen.

In hoofdstuk III is het effect van omgevingstemperatuur op het energiemetabolisme van dekberen bestudeerd. Dekberen in dit experiment hadden een onderste kritieke temperatuur (OKT) van 20°C en een extra thermoregulatoire warmteproduktie (ETW) van 16 kJ/ $kg^{0.75}$/°C/d. Als de beren bij temperaturen rond of boven de OKT werden gehouden, waren hun eiwit- en vet-aanzet respectievelijk 103 en 41 g/d. Dezelfde beren op hetzelfde voerniveau maar gehuisvest bij 10°C hadden een eiwitaanzet van 8 g/d en een vetverlies van 156 g/d. Op basis van dit experiment werd geconcludeerd dat lage omgevingstemperaturen een grote invloed hebben op het energiemetabolisme van dekberen. Wanneer een voederstrategie ontworpen wordt, dient men hierin een correctie voor lage omgevingstemperaturen op te nemen.

Hoofdstuk IV laat zien dat de thermoregulatoire energiebehoefte een duidelijk dagelijks patroon vertoond. De OKT is 's nachts (18°C) lager dan overdag (21°C). De ETW is echter 's nachts (22 kJ/$kg^{0.75}$/°C/d) hoger dan overdag (14 kJ/$kg^{0.75}$/°C/d). Bij lagere

temperaturen wordt dus het voordeel van de lagere OKT 's nachts gecompenseerd door de hogere ETW.
Beren hebben voer nodig voor onderhoud, groei en reproduktieve processen. De hoofdstukken III en IV maken duidelijk dat, t.g.v. lage omgevingstemperaturen, de hoeveelheid voer benodigd voor onderhoud behoorlijk kan varieren. Er is geen literatuur beschikbaar over de energiekosten van reproduktieve processen en of deze kosten beinvloed worden door het gehanteerde dekschema. Hoofdstuk V behandelt de invloed van het hanteren van een bepaald dekschema op het energiemetabolisme van K.I. beren. Er werden metingen gedaan bij beren die geadapteerd waren aan een dekschema van 1 of 3 maal per week. Ook werden er metingen gedaan na het veranderen van het dekschema van geadapteerde beren van 1 naar 3 en van 3 naar 1 keer per week. De effecten van het hanteren van een bepaald dekschema op het energiemetabolisme van dekberen zijn erg klein. Op dekdagen produceren beren ongeveer 18 kJ/kg$^{0.75}$/d extra warmte i.v.t. niet-dekdagen. De totale wekelijkse warmteproduktie van beren op een hoog dekschema is echter gelijk of zelf iets lager i.v.t. beren op een laag dekschema. Deze beren op een hoog dekschema compenseren meer dan de extra energie behoefte t.g.v. het hogere dekschema i.v.t beren op een laag dekschema. Blijkbaar rusten beren op een hoog dekschema meer tussen de dekkingen in. De effecten van het hanteren van een bepaald dekschema en ook de adaptionele reacties van het dier op verandering van dekschema zijn te klein om in een voerstrategie voor dekberen te verwerken.
Uit het literatuuronderzoek in hoofdstuk I bleek dat het voeren van rammen en stieren op of beneden onderhoudsniveau tot gevolg had dat de spermaproduktie daalde. Bij beren werden deze effecten niet gevonden. Omdat de onderzoekingen uitgevoerd bij beren nogal wat beperkingen hadden was het onduidelijk of verschillen in voederstrategie zouden resulteren in verschillen in spermakwaliteit en -kwantiteit bij dekberen.
In hoofdstuk VI zijn de effecten van voeropname op spermakwaliteit en -kwantiteit van dekberen onderzocht. De beren werden gedurende 12 weken ad libitum gevoerd (H, 5.74 kg/d), of op een medium niveau (M, 3.62 kg/d) of op een laag niveau (L, 1.92 kg/d). Twaalf weken op deze voederstrategieën had tot gevolg dat er significante verschillen ontstonden in het aantal geproduceerde spermacellen per tijdseenheid. In de laatste twee weken van het experiment ejaculeerde de M en de H gevoerde beren respectie-

velijk 46 en 69% meer spermacellen per week i.v.t de L gevoerde beren. Na twaalf weken werden de H gevoerde beren overgeschakeld op een laag voerniveau (HL) en de L gevoerde beren op het medium niveau (LM). De M gevoerde beren bleven op het zelfde niveau staan (MM). Na 8 weken waren de verschillen tussen de HL en de MM beren en tussen de LM en MM beren niet significant meer. Kwaliteitsparameters van de ejaculaten waren niet significant verschillend bij de diverse voederstrategieën.
Er is blijkbaar een duidelijk effect van voerniveau op spermakwantiteit van dekberen. Daarom is het belangrijk om te proberen een optimale voederstrategie voor dekberen te ontwikkelen.
In de algemene discussie wordt een voederstrategie voor dekberen beschreven op basis van behoeftecijfers voor onderhoud, groei en reproduktieve processen zoals verkregen uit zeugenliteratuuur en dit proefschrift. Deze basis-voederstrategie komt neer op een voergift voor beren op K.I. verenigingen van 2.7-3.1 kg/d (afhankelijk van het lichaamsgewicht) van het commerciele zeugenvoer dat gehalten bevat vergelijkbaar met het basisvoer zoals behandeld in hoofdstuk II. Een extra voertoeslag van 100 g dieet per graad Celcius beneden de 20°C per dag moet aan beren verstrekt worden om extra thermoregulatoire warmteproduktie te compenseren. Juist deze extra voertoeslag wordt in de praktijk maar zelden verstrekt, hetgeen de winterse spermaproduktiedaling goed kan verklaren.

Curriculum vitae

Bastiaan Kemp werd op 21 september 1960 geboren te 's Gravenhage. Hij behaalde in juni 1979 het Atheneum-B diploma aan de Albert Schweitzer Scholengemeenschap te Geleen. In september van datzelfde jaar begon hij met zijn studie Zoötechniek aan de Landbouwhogeschool te Wageningen. Het doctoraal examen omvatte Veevoeding als hoofdvak en Gezondheids- en ziekteleer der landbouwhuisdieren, Pluimveeteelt en Industiële Bedrijfskunde als bijvakken. Na het afstuderen in januari 1986 werd hij aangesteld bij de vakgroep Veevoeding als wetenschappelijk project medewerker in tijdelijke dienst en hij werkte aan het onderzoek dat resulteerde in dit proefschrift. Dit onderzoek was een samenwerkingsproject van de Landbouwuniversiteit en de Bond van verenigigen voor kunstmatige inseminatie van varkens. Per 1 mei 1989 is hij in vaste dienst gekomen van de LU als universitair docent.