Electronic feeders in the genetic improvement of pigs for the efficiency of lean growth

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Declaration

I declare that this thesis is my own composition
and that the research described in it is my own work,
except where otherwise stated.

A. D. Hall   September 1997

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Abstract

Many pig breeding companies now test their young pigs on electronic feeders. This provides them with the means of obtaining accurate estimates of individual feed intake in a group housing system, which is similar to the production environment. Electronic feeders also provide new information on the pattern of how this feed was consumed, such as number of meals in a day or the size of each meal. The aims of this thesis were: to describe these feeding pattern traits in an objective manner; to determine any major environmental or social effects on them; to estimate genetic and phenotypic parameters for them; to predict their potential benefit for increasing the accuracy of selection for lean growth and feed efficiency.

The data used in these analyses were compiled between 1992 and 1995 from individual feeding records of 1832 pigs from 70 sire families of a Large White derived sire line selected for lean tissue growth rate. Pigs were fed *ad libitum*, in single sex pens of 12 pigs (s.d. 0.87), using FIRE (feed intake recording equipment) system from Hunday Electronics Ltd. at the Cotswold Pig Development Company. Pigs were on test between 45 kg (s.d. 2.76) and 95 kg (s.d. 6.78). Daily feed intake (DFI kg), feed intake per visit (FIV kg), number of visits per day (NV), duration of each visit (TV mins.), time in the feeder per day (TD mins.), feeding rate (FR kg/min) and number of non-feeding visits per day (NFV), were measured as means of test and also as means of bi-weekly periods of test (which were the means of weeks 2-3, weeks 4-5, weeks 6-7 and weeks 8-9).

Feeding patterns were affected by the social and physical environment within a pen, particularly time spent in the feeder per visit and per day. DFI and performance test traits were unaffected which suggests that pigs were able to adapt their behaviour to compensate for different social structures within a pen.

Genetic and phenotypic parameters were estimated by restricted maximum likelihood with a multivariate individual animal model. DFI had a heritability of 0.21 ranging from 0.18 to 0.26 over the four bi-weekly test periods. Correlations between part and whole test records of feeding patterns and DFI were high ($r_g = 0.75$ to 0.99). DFI was highly correlated with performance test traits, but had low correlations with feeding pattern traits. The heritabilities of feeding pattern traits were low except for FIV and NV, but correlations between feeding pattern traits were high. FIV, NV and TV were moderately correlated with performance test traits.

FIV, NV and TV were included as selection criteria in indices to improve lean growth and feed efficiency and resulted in an increase of up to 20% in the predicted accuracy of selection for the aggregate genotype. The greatest increases were seen in ADG (17%) and FCR (55%). The inclusion of part test records of feeding patterns resulted in similar predicted correlated responses to those when whole test records of daily feed intake were used. When the selection objective was only for lean growth rate, rather than feed efficiency, the predicted benefit of including feeding pattern traits and DFI was greatly reduced. The inclusion of feeding patterns as selection criteria however, resulted in indices that were less robust to inaccurate parameter estimates.

It was concluded that feeding pattern traits could be used to improve the predicted accuracy of selection, but the most effective and robust index would include only daily gain, backfat depth, daily feed intake and number of visits. They may also be useful in reducing the length of the test period necessary for accurate measures of feed intake so increasing the potential intensity of selection on a given number of feeders.

Chapter 1

General Introduction

1.1 Introduction.

The preferred method of selection in pig nucleus breeding programmes has been to select the animals in individual pens so accurate measures of feed intake were possible. This allows selection on not only growth rate and backfat but also on feed efficiency which can be of great interest to the breeder as much of the cost of pig production can be due to feed (Webb and King 1983). Individual penning however, does not reflect the production environment which is usually based on group housing. Some researchers, notably Merks (1989), have suggested that there may be considerable genotype by environment interaction between these two environments with genetic correlations between them being lower than previous work had suggested. Work by De Haer and Merks (1992) showed that feeding patterns of group housed growing pigs differed in many respects from those which were individually housed. The advent of electronic feeders, such as the FIRE system (feed intake recording equipment, from Hunday Electronics Ltd.), has provided the means for accurate recording of feeding patterns of individuals within groups (Webb *et al.* 1990, De Haer 1992, Labroue *et al.* 1996, Von Felde *et al.* 1996a,b). They may also enable an increased accuracy of selection due to less genotype by environment interaction (G x E) between nucleus and commercial levels (Webb 1989, Merks 1989).

There are other benefits from using group housing systems. Dolf (1986) showed that agonistic behaviour diminished more rapidly in group housed pigs as compared to stall housed individuals. Also electronic feeders can allow considerable control over individual feed allocation and at the same time allow flexible feeding patterns not seen in individually penned animals and so can offer the opportunity for sophisticated herd management if individual predictability and variability is understood (Carlstead 1986). Several workers have shown that social facilitation actually results in an increase in feed intake as the animals compete for food (Hansch 1982, Hansen *et al.* 1982, Hsia and Wood-Gush 1983). Other researchers, however have noted that group housed pigs fed at single spaced electronic feeders may have a reduced feed intake compared to individually housed pigs or group housed pigs fed at a multi-spaced trough (Nielsen *et al.* 1996, De Haer and Merks 1992).

Another important objective of breeders is to increase the rate of lean growth and one way of doing this is to increase the feed intake of the animals. Foster, Kilpatrick and Heany (1983) showed that protein deposition may be influenced by feeding patterns, especially feed intake and meal size. It has also been shown by De Haer (1992) that feed intake pattern influences the efficiency of production, digestion and utilisation of nutrients for fat and lean deposition so its accurate measurement may prove to be an advance in pig breeding.

It has been demonstrated by several authors that there are general trends of feeding patterns during the test period. Bigelow and Houpt (1988) showed that meal frequency declined with age from approximately ten meals per day at 30-40 kg to eight at 60-70 kg. It is also apparent that the stage of growth has an effect on the daily feed intake (Von Felde *et al.* 1996a,b, Roehe *et al.* 1994) with older animals eating less often, but taking larger meals. Pigs older than six weeks have been shown to have a strong diurnal pattern of feeding behaviour usually with one at the beginning of a the light period, which usually coincides with the advent of activity on the unit in particular the refilling of the hoppers, and one at the end of the light period (Bigelow and Houpt 1988, De Haer and Merks 1992). This early feeding behaviour may well be due to the refilling of the hoppers, rather than the start of the light period, especially for pigs on restricted feed. Young and Lawrence (1994) and Hyun *et al.* (1997) only observed one peak of feeding behaviour, in *ad libitum* fed growing pigs, early in the day with dominant animals almost always feeding first. Hunter *et al* (1988) found similar results and positive correlations between dominance, parity and feeding order were established in sows fed on a restricted diet. This, however was not supported by Eddison and Roberts (1995) or Bressers *et al.* (1993) who found no association between feeding order and dominance.

There have been several reports suggesting that the majority of pigs take a large part if not all of their daily intake at one meal, usually the first (Bengtsson, Svendsen and Andersson 1984, Eddison and Roberts 1995). This seems to be particularly the case with a restricted feeding regime usually associated with older animals. There are however, always some pigs which eat many small meals each day. Eddison and Roberts (1995) tried to determine if the feeding patterns of individual sows were stable and found that generally they were not for about 87% of a population of sows fed a restricted diet. This phenomenon was not peculiar to social rank with both dominant and subordinate animals exhibiting a non-stable feeding pattern. It has been suggested that dominant animals enter the feeder many times in order to defend it from subordinate pigs and this can result in many non-feeding visits whereas subordinates enter many times because they are displaced from the feeder more frequently by dominant animals (Hunter *et al* 1988).

An important aspect of feeding patterns is their effect on production traits especially feed efficiency. This can be measured as food conversion ratio, as has been done in breeding programmes for many years, usually indirectly as a correlated trait to selection on growth rate and reduced backfat. An alternative measure of feed efficiency was proposed by Foster (1983) and was later adopted by several other researchers (Cameron and Curran 1994, De Haer 1992, Luiting 1990, Roehe *et al.* 1994, Von Felde *et al.* 1996b, Mrode and Kennedy 1993) as residual feed intake, which was defined as the recorded feed intake minus the predicted feed intake required for maintenance and the actual level of production based on metabolic body weights, daily gain and lean percentage. A high residual feed intake indicates an inefficient pig. Residual feed intake has also been shown to be positively correlated with daily feed intake and feed conversion ratio (Cameron and Curran 1994) and generally has a higher heritability than feed conversion ratio with literature averages of 0.31 and 0.24 respectively, but residual feed intake provides no new information for the breeder.

1.2 Genetic and phenotypic parameters of feeding pattern traits

There are several commonly used feeding pattern traits which describe the timing and level of feeding activity in the population. The most obvious of these is daily feed intake, given as an average either over the entire test period or on a weekly basis. Average daily feed intake is affected by many of the other traits, such as feed intake per visit, number of visits and time per visit. Means and standard deviations of feeding pattern traits of Large White pigs from electronic feeders, estimated by several researchers, are presented in Table 1.1. It is noted that studies using ACEMO feeders, which have an entirely enclosed race, tend to result in fewer, longer visits with more feed consumed in each visit than either FIRE or IVOG feeders, both of which have a partially open race. There also appears to be more feed intake per day in ACEMO feeders, but little difference in other traits. The pattern of few long visits is probably a result of a pig being uninterrupted whilst in the feeder, whereas in the FIRE system evictions are common.

Table 1.1 *Means (and s.d.) of feeding pattern traits in studies on group housed Large White pigs, fed ad libitum, using electronic feeders*

Trait	Von Felde *et al.* 1996a(1)	De Haer *et al.* 1992(2)	Nielsen *et al.* 1996(3)	Hyun *et al.* 1997(3)	Guéblez *et al.* 1996(1)
Daily Feed Intake (kg)	2.4 (0.5)	2.0 (0.3)	1.4 (0.5)	1.7 (0.03)	2.1 (0.2)
Feed Intake per Visit (kg)	0.47 (0.19)	0.16 (0.05)	0.13 (0.11)	0.15 (0.069)	*
Feed Intake per Meal (kg)	*	0.23 (0.06)	*	*	0.31 (0.13)
Number of Visits per day	5.1 (1.9)	14.4 (5.0)	13.4 (7.7)	11.6 (0.49)	18.0 (10.0)
Number of Meals per day	*	9.2 (2.4)	*	*	7.0 (1.9)
Time per Visit (min)	9.6 (3.6)	4.7 (1.5)	4.6 (3.8)	6.6 (0.27)	*
Time per Meal (min)	*	6.9 (1.8)	*	*	8.0 (3.3)
Time per Day (min)	49.0 (11.0)	63.5 (13.0)	53.5 (8.9)	73.4 (2.61)	*
Feeding Rate (kg/min)	0.049 (0.011)	0.032 (0.005)	0.027 (0.007)	0.024 (0.009)	0.045 (0.007)

(1)ACEMO feeders, (2)IVOG feeders, (3)FIRE feeders * data not available

Table 1.2 *Estimates of heritability of feeding pattern traits in studies on group housed Large White pigs, fed ad libitum, using electronic feeders*

Trait	Von Felde *et al.* 1996a(1)	Von Felde *et al.* 1996b(1)	Kalm *et al.* 1996(1)	Labroue *et al.* 1996(1)	Guéblez *et al.* 1996(1)	De Haer *et al.* 1993(2)
Daily Feed Intake	0.26	0.22	0.20	0.42	0.42	0.16
Feed Intake per Visit	0.50	0.51	0.50	0.28	*	0.35
Feed Intake per Meal	*	*	*	0.53	0.51	0.47
Number of Visits	0.47	0.43	0.47	0.23	*	0.38
Number of Meals	*	*	*	0.43	0.43	0.45
Time per Visit	0.39	0.42	0.39	0.23	*	0.27
Time per Meal	*	*	*	0.45	0.49	0.27
Time per Day	0.45	0.43	0.45	0.36	*	0.24
Feeding Rate	0.46	0.44	0.46	0.49	0.49	0.29

(1) ACEMO feeders (2) IVOG feeders * data not available

Table 1.3 *Genetic correlations between feeding pattern traits*

	Daily Feed Intake	Feed Intake per Visit	Number of Visits	Time per Visit	Time per Day
Feed Intake per Visit	0.58_a 0.27_b 0.23_c				
Number of Visits	-0.31_a 0.08_b 0.10_c	-0.89_a -0.86_b -0.91_c			
Time per Visit	0.35_a 0.15_b 0.08_c	0.91_a 0.79_b 0.82_c	-0.85_a -0.78_b -0.82_c		
Time per Day	0.14_a 0.48_b 0.44_c	0.09_a -0.25_b -0.22_c	-0.15_a 0.44_b 0.38_c	0.35_a 0.13_b 0.17_c	
Feeding Rate	0.49_a 0.24_b 0.31_c	0.23_a 0.60_b 0.57_c	-0.02_a -0.42_b -0.42_c	-0.19_a 0.02_b 0.01_c	-0.78_a -0.60_b -0.62_c

a = Labroue *et al.* (1996) b= Kalm *et al.* (1996) c = Von Felde *et al.* (1996b)

There is also some evidence that single space electronic feeders partially restrict feed intake compared to multispace trough feeders due to higher competition within the pen for feed (Nielsen *et al.* 1996). De Haer and Merks (1992) determined that, according to the 'Linda Index' (De Jong 1985), in group housing 69% of the daily meals in the group contributed significantly to the total daily feed intake with only 31% of meals being small and short. The rate of feed intake was observed to be higher in group housing than in individual housing (De Haer and Merks 1992) probably due to an increase in competition for food which may also account for the proportionately higher incidence of large, long meals in group housing (69%) than in individual housing (39%).

Researchers have estimated heritability values in the range of 0.16 to 0.42 for daily feed intake in *ad libitum* fed growing pigs (De Haer and de Vries 1993, Labroue *et al.* 1996 respectively). Studies on individually housed growing pigs provided similar estimates (Cameron 1990, Cameron and Curran 1994). Heritability estimates for daily feed intake and feeding patterns are presented in Table 1.2. All studies represented in this table used Large White growing pigs fed *ad libitum*. Higher heritability estimates were reported for ACEMO feeders (Von Felde *et al.* 1996a,b; Kalm *et al.* 1996; Labroue *et al.* 1996; Roehe *et al.* 1994), which had an entirely enclosed race, for all feeding pattern traits than for the IVOG feeders (De Haer and De Vries 1993). The open race of FIRE or IVOG systems allows a pig to be evicted from the feeder by a dominant pen mate so the social interaction within a pen may well play a larger part in determining the feeding patterns of an individual.

Table 1.3 shows the genetic correlations between feeding pattern traits. The pattern of genetic correlations between feed intake per visit, time per visit and number of visits indicated that high feed intake per visit was associated with longer, fewer visits. The high negative correlations between feeding rate and time per day imply that feed intake per day is relatively constant. However correlations between feeding patterns and daily feed intake are low, which suggests that differences in feeding patterns between pigs do not necessarily result in different overall daily feed intake.

Roehe *et al.* (1994) showed that the parameters for daily feed intake and other feeding pattern traits with *ad libitum* fed growing pigs varied with the period on test, measurements in week five of test having the highest heritability (0.45) and the highest genetic correlation with average daily feed intake over the whole test period (0.76). This was supported by Von Felde *et al.* (1996b) and gives an indication that this period may be the most informative for selection.

1.3 Factors Affecting Feeding Pattern Traits.

Peaks of feeding behaviour have been observed by several authors with differing results (Bigelow and Houpt 1988, De Haer and Merks 1992, Young and Lawrence 1994, Hyun *et al.* 1997). However non-feeding visits to the feeders are common for all pigs in the herd. Young and Lawrence found a range of 3 to 69 non-feeding visits per day which accounted for 10.5% of all feeder visits in a population of 60 growing pigs kept in pens of ten individuals. This activity may affect the feeding behaviour of other animals as suggested by Hunter (1988) who stated that this non-feeding activity was due to the dominant animals defending the feeder from subordinates. Eddison and Roberts (1995) however, did show that some animals ate many small meals during the day and that the incidence of this was not significantly correlated with social dominance. It has also been shown by Morrow and Walker (1994a) that a large proportion of feeding visits (0.7 in their study) can be terminated by enforced withdrawals from the feeder if the pig is not closed in. These evictions from the feeder can result in an increase in the number of visits and lead to more food spillage so measures of feed intake will be less accurate.

Eddison and Roberts (1995) described the distribution of daily feed intake throughout the day and determined that feed intake patterns were not stable (*i.e.* were variable both within and between sows) in sows fed on a restricted diet. Although 79% of feeding visits resulted in more than 95% of the individuals' daily feed intake, usually in the first visit, there were still 21% of animals which ate several small meals during the day. Further analysis showed that only 26 out of 101 sows ate most of their total daily feed intake at one visit. The distribution of the first feeding visits where all food is eaten was skewed towards the upper end with a median value of 83.4% of sows eating 95% or more of their daily feed intake at one meal.

Hunter *et al.* (1988) suggested that feeding patterns were related to parity and social dominance whereas Bressers *et al.* (1993) determined that there was a relationship between feeding order and feeding patterns, although this was not necessarily the caused by social dominance. The high proportion of food taken at the first daily meal is probably a result of the restricted feeding regime in which the sows would obviously eat more if they could and when the hoppers are replenished they are hungry so eat as much as possible. Eddison and Roberts (1995) found no clear influence of parity or social dominance on daily feed intake and no relationship between daily feed intake and the number of visits to the feeder in a day. The most likely explanation for this variability is simply that the sows were allowed to express their individual behavioural traits, and did so.

The time of day also had a significant effect on feeding pattern. Hunter *et al.* (1988) found that at least half of a population of restricted fed sows used the feeder between 4.00am and 10.30am with the earlier visits being longer than others. This start to feeding behaviour was earlier than other authors had detected, but the peak of this behaviour was seen at approximately 7 to 9 am, similar to other studies. He also found that feeding order was relatively constant over the feeding periods. Bressers *et al.* (1993) found evidence that those sows which were newly introduced into the herd were lower in the social order and so had different feeding behaviour, but in Hunter's experiment four out of five newly introduced sows were in the top half of the hierarchy.

Many of these experiments however, were carried out on sow populations fed on a restricted feeding regime where individual sows are rationed according to liveweight and stage of gestation. Growing pigs, as used in this study, are usually fed ***ad libitum***, this makes comparisons between these two types of animals of limited value.

Young and Lawrence (1994) showed that initial body weight at the beginning of test, for young growing pigs, was significantly associated with total feed intake on test (r_p = 0.33), as would be expected, and accounted for 9% of the genetic variance. Gain in body weight, over a 38 day test period, was also shown to be positively correlated with total feed intake on test (r_p = 0.77) and accounted for 59% of the genetic variance (Young and Lawrence 1994). If a pig starts test at a higher body weight than average then it may be either older or faster growing and will therefore need to eat more food on test for maintenance and production. Feeding rate was also shown to be positively correlated with initial body weight with a value of 0.39 (Young and Lawrence 1994) accounting for 14% of genetic variance which is too low to be a good predictor.

Hsia and Woodgush (1983) demonstrated the effect of competition for food in different systems. When only one feeding space was present the rate of food intake was highest but meals were shorter. This is not a problem in electronic feeders as the pigs are generally protected from others while they feed, but a higher level of competition than found in individual housing is apparent (Hsia and Woodgush 1983, De Haer 1992, Nielsen *et al.* 1995a, Merks 1988, Hansen *et al.* 1982, Webb 1989). Morrow and Walker (1994a) showed that opening one side of the feeder to the rest of the pigs by using metal bars rather than a panel resulted in an increase in the rate of feeding; more animals were displaced during feeding and the number of visits per day was higher.

Morrow and Walker (1994b) suggested that the type of feed also influenced feeding patterns. This is supported by work from De Haer and Merks (1992) who demonstrated the effects of feed digestibility and utilisation on feeding patterns and especially feed efficiency. Less digestible feed resulted in a higher feed intake and so less feed efficiency. The amount of food dispensed in one push of the hopper by the pig also affects feeding patterns (Morrow and Walker 1994c). If the pig has to work harder to get the same amount of food, for example if the dispensing rate is very low, it will not make the effort to attain more food and will have a lower daily feed intake. Morrow and Walker (1994c) found the ideal dispensing rate per push of the hopper, to maximise the amount of food eaten and minimise the amount of food wastage, to be approximately seven grammes.

1.4 Relationships between performance and feeding pattern traits

Table 1.4 provides a summary of estimates of genetic correlations between feeding pattern traits and performance test traits. Young and Lawrence (1994) stated that total feed intake on test and growth rate in *ad libitum* fed pigs were positively correlated to time in the feeder per day (0.51 and 0.34 respectively). Most researchers found moderate to low correlations of feeding pattern traits with performance test traits (Table 1.4). Daily feed intake, however was highly associated with daily gain and had positive correlations with backfat depth and feed conversion. Similarly feed intake per visit, feeding rate and time per day were positively associated with daily gain and backfat depth.

Table 1.4 *Genetic correlations between feeding patterns and performance test traits*

	Average Daily Gain	Feed Conversion Ratio	Backfat Depth	Lean Percentage
Daily Feed Intake	0.87[a]		0.35[a]	-0.30[a]
	0.57[b]	0.29[b]		
	0.68[c]	0.13[c]	0.45[c]	-0.61[c]
Feed Intake per Visit	0.49[a]		0.18[a]	-0.18[a]
	0.15[b]	0.18[b]		
	0.20[c]	0.01[c]	0.07[c]	-0.16[c]
Number of Visits	-0.19[a]		-0.10[a]	0.15[a]
	0.07[b]	0.03[b]		
	0.04[c]	0.11[c]	0.06[c]	0.11[c]
Time per Visit	0.23[a]		0.13[a]	-0.06[a]
	0.05[b]	0.09[b]		
	0.07[c]	-0.02[c]	-0.05[c]	-0.01[c]
Time per Day	0.02[a]		0.07[a]	0.11[a]
	0.31[b]	0.16[b]		
	0.32[c]	0.12[c]	0.15[c]	-0.11[c]
Feeding Rate	0.48[a]		0.11[a]	-0.24[a]
	0.16[b]	0.20[b]		
	0.27[c]	0.03[c]	0.19[c]	-0.26[c]

a = Labroue *et al.* (1996) b= Kalm *et al.* (1996) c = Von Felde *et al.* (1996b)

Daily feed intake is generally positively correlated with daily gain, although Roehe *et al.* (1994) found that average daily feed intake for the first week of test was negatively correlated (genetic) with growth rate (-0.89). This may be due to differing ages or weights of the pigs coming on to test with younger and lighter pigs growing proportionately faster because they are still in the early stages of the growth curve but the older, heavier pigs will eat more due to their higher maintenance requirements. However by week five of test the correlation between growth rate and daily feed intake was 0.52 and increased to 0.72 by week nine and was found to be 0.63 for average daily feed intake on the whole of test.

De Haer and Merks (1992) found that most feeding pattern traits had long tailed distributions, often positively skewed, indicating that there is much variation and extreme values which could be of great importance to animal breeders if they can be used to benefit production and if they are indeed true values. However they do present a problem for statistical analysis which can be corrected by the use of logarithmic or square root transformations.

The repeatability of feeding pattern measurements both on a day to day and on the whole of test basis are important to any analysis of these traits. Such values in group housing have been calculated by De Haer and Merks (1992) over the entire test period. These estimates range from 0.27 (for feeding rate) to 0.09 (for daily feed intake) with most other traits lying between 0.15 and 0.2. This low repeatability for daily feed intake could be explained by the change in feed intake on test due to the growth curve (Cambell *et al.* 1985, Whittemore 1985). Such a low repeatability leads to doubts as to the value of measuring daily feed intake, but other authors have found moderate heritabilities (see Table 1.2) which suggest that the value of 0.09 for daily feed intake is an underestimate. In the same paper by De Haer and Merks repeatability of 0.14 and 0.29 are found for daily feed intake on a monthly and weekly basis respectively as opposed to the original estimate from the whole of the test period. This would suggest that the low repeatability was due to the expected change in feed intake as the animal grows during the test period.

1.5 Discussion

Large differences in feed intake patterns have been found between housing, management, sex, breed and stage of growth. Perhaps the most influential factor in the difference between feeding patterns is whether the pigs are on an *ad libitum* or a restricted diet, although these groups can, generally, be split into growing pigs or sows respectively.

Feeding pattern traits have moderate to low correlations with production traits but are moderately heritable (see Tables 1.2 and 1.3). It appears to be the case that these heritabilities and correlations are very variable between breeds, sex and stage of growth which makes it difficult to decide on reasonable values to use in an index. Their potential use in animal breeding programmes may be limited by these correlations but certainly the ability to measure daily feed intake in group housing by the use of electronic feeders will hopefully eliminate much of the genotype by environment interaction between individual testing and group production (De Haer and Merks 1992, Merks 1988). If the genetic correlation between selection and production environments falls below 0.8 then the extra accuracy achieved in test environments is negated, selection is better in the production environment (Brascamp *et al.* 1985, Merks 1988). In this way the use of electronic feeders in the selection environment should improve the accuracy of selection for the production environment and so are of potential benefit to the industry.

They also allow recording of many previously unrecorded traits which may be of academic interest and could be of some use to the pig breeding industry. Current concerns over the welfare of individually housed pigs can be overcome by selecting in a group housing system and measures of lifetime productivity in a 'production like' environment for sows are possible.

Several authors used a 'meal criterion' to distinguish between occasions when the pig just lifts its head out of the feeder for a few seconds or minutes before continuing with the meal from those where the pig left the feeder at the end of a meal (De Haer and Merks1992). Generally if another pig fed between the two visits of another pig then they were counted as separate meals as displacement had occurred. This ‘meal criterion’ was calculated by plotting the cumulative frequencies of interval lengths between visits on a logarithmic scale. Assuming that the beginning of a visit is independent of the moment of finishing the previous visit, then the cumulative frequencies of interval length will be exponentially distributed and hence linear on a logarithmic scale. Cumulative frequencies of intervals between dependent visits, which is within a meal, will show a concave curve on a logarithmic scale hence the 'meal criterion' can be estimated by approximating the log survivorship curve of intervals between visits partly with a curved and partly with a linear function (De Haer and Merks 1992). The values of the meal criterion ranged from 2 to 16 minutes with an average of approximately 6 minutes.

Maximum long term economic improvement in pigs may well be on lean tissue growth rate rather than lean tissue food conversion because as we increase feed conversion ratio we reduce feed intake and so reduce overall growth rate. Some commercial breeds are now approaching their optimum fatness level and further reductions in feed intake may limit potential progress in lean growth rate (Webb and Curran 1986). Therefore the new objective should be to increase the rate of lean growth to reduce feed costs and time on test and increase sow lifetime productivity (Whittemore *et al.* 1988). Webb (1989) suggested a performance test based on group housing with electronic feeders and *ad libitum* feed to allow full expression of feed intake and lean growth as well as behavioural traits.

Chapter 2

Feeding patterns in group housed growing pigs using single spaced electronic (FIRE) feeders

Abstract

The main aims of this chapter were; to describe and evaluate feeding pattern traits, such as feed intake per visit or number of visits per day, in an objective manner; to determine their distribution; to estimate how repeatable they were during the test period.

The data used in these analyses were compiled from individual feeding records of 1832 pigs from 70 sire families at the Cotswold Pig Development Company. Pigs were on test in pens of 12 individuals between 45 kg (s.d. 2.76) and 95 kg (s.d. 6.78). Pigs were fed *ad libitum* at single spaced FIRE feeders (Feed Intake Recording Equipment from Hunday Electronics Ltd., Newcastle-Upon-Tyne). Feed consumed and time in the feeder were recorded whenever pigs entered the feeder. The traits calculated were daily feed intake, feed intake per visit, feed intake per meal, number of visits per day, number of meals per day, duration of each visit and meal, time in the feeder per day, feeding rate and number of non-feeding visits per day. All feeding pattern traits were non-normally distributed with the exception of daily feed intake but $\log_e$ and square root transformations reduced this non-normality. Pigs ate approximately 2 kg of feed per day over 10 visits with a mean time per day in the feeder of 58 minutes. All feeding pattern traits had moderate (0.2 to 0.5) repeatabilities over the test period.

It was concluded that feeding pattern traits are not normally distributed but are easily transformed to reduce this non-normality. The estimates of repeatability, being the

upper limits of heritability, suggest that there is some potential to include these traits in a breeding program.

2.1 Introduction.

The pig breeding industry has recently changed from measuring food intake in individual pens to a group housing system with electronic feeders such as the FIRE feeders used in this study. These feeders not only provide measures of feed intake but also data on the patterns of how this food was taken. Several researchers, notably De Haer (1992), Von Felde *et al.* (1996a,b) and Labroue (1996), have described these traits as discussed in the general introduction to this thesis. The main traits of interest were feed intake per visit, the number of visits per day and the duration of these visits.

Pigs older than six weeks have been shown to have a strong diurnal pattern of feeding behaviour, usually with one peak of feeding activity at the beginning of the light period, which usually coincides with the advent of activity on the unit in particular the refilling of the hoppers, and one peak of feeding behaviour at the end of the light period (Bigelow & Houpt 1988, De Haer & Merks 1992). This early feeding behaviour may well be due to the refilling of the hoppers, rather than the start of the light period, especially for pigs on restricted feed. In *ad libitum* fed growing pigs, Young and Lawrence (1994) observed only one peak of feeding behaviour at the start of the light period with dominant animals almost always feeding first. Hunter *et al* (1988) found similar results and a correlation between dominance, parity and feeding order was established in sows fed on a restricted diet. This was not supported by Eddison and Roberts (1995) or Bressers *et al.* (1993) who found no association between feeding order and dominance although the comparison of restricted fed sows with *ad libitum* fed growing pigs is of limited value. There have been several reports suggesting that the majority of pigs take a large part if not all of their daily intake at one meal which is usually the first one (Bengtsson, Svendsen & Andersson 1984, Eddison & Roberts 1995). This, however seems to be particularly the case with a restricted feeding regime, usually associated with older animals. The study by Eddison and Roberts (1995) used sows, on a restricted diet, in electronic feeders. The sows were denied access to the feeder once they had eaten their daily allowance of feed. However there are always some pigs which eat many small meals each day, particularly in *ad libitum* fed animals. It has been suggested that dominant animals enter the feeder many times in order to defend it from subordinate pigs and this can result in many non-feeding visits, whereas subordinates enter many times because they are displaced from the feeder more frequently by dominant animals (Hunter *et al.* 1988).

The objectives of this chapter were to describe and evaluate these feeding pattern traits in an objective manner, to determine their distribution and to estimate how repeatable they were during the test period.

2.2 Materials and Methods.

2.2.1 *Description of feeding patterns*

Data were collected between 1992 and 1995 on 1832 pigs, 1410 boars and 422 gilts, which were the progeny of 70 sires of a Large White sire line selected for lean tissue growth at Cotswold Pig Development Company. The animals were kept on straw, with one feeder per pen and were fed dry pelleted feed consisting of 14.5 MJ digestible energy, 14 g/kg lysine and 240 g/kg crude protein. Pigs were put on test in pens of 12 (s.d. 0.87) individuals of the same sex at 45 kg (s.d. 2.76) and all penmates were removed from test when the majority of individuals in the pen reached 95 kg (s.d. 6.78).

Feed intake records used in these analyses were from weeks 2 to 9 of test. One week was allowed for the pigs to adapt to the electronic feeding system and to develop a social hierarchy (Nielsen, 1995). Pigs were fed *ad libitum* at single spaced FIRE feeders (Feed Intake Recording Equipment from Hunday Electronics Ltd., Newcastle-Upon-Tyne).Each feed station consisted of a feed trough connected to a load cell and equipment to receive radio signals from ear tag transponders fitted to each pig. Pigs had 24 hour access to the feeder, which also had a race down each side to prevent two pigs feeding at the same time. Feed consumed and time in the feeder were recorded whenever pigs entered the feeder. An example of the FIRE output is given table 2.1.

Table 2.1: *Example of FIRE output*

Animal Tag	Pen	Date	Time in Feeder	Time out of Feeder	Feed (kg)
126	12	10/06/93	07:55:31	07:58:40	0.1073
72	12	10/06/93	07:59:12	08:02:27	0.0924
13	12	10/06/93	08:10:53	08:12:02	0.2721

The feeding pattern traits calculated were daily food intake (DFI), food intake per visit and meal (FIV, FIM), number of visits / meal per day (NV, NM), time per visit / meal (TV, TM), Feeding Rate (FR) and the number of non-feeding visits per day (NFV) which was defined as a visit where less than 5g of food was taken, as the margin of error of the recording system was approximately 5g. Any two visits of an individual animal separated by less than four minutes and not interrupted by another animal was counted as one meal. This value of four minutes as a meal criterion was a literature average (De Haer 1992). Feeding pattern traits and daily feed intake were computed for the whole test and also as bi-weekly means excluding the first week of test.

Performance test traits of P_2 backfat depth (BF), lean percentage (L%), food conversion ratio (FCR) and average daily gain (ADG) were recorded. Backfat depth and lean percentage were taken at the end of test and daily gain and feed conversion ratio were averages of the whole test period. Lean tissue growth rate (LTGR) and lean tissue feed conversion ratio (LTFC) were also estimated from predicted lean contents at the end and start of test.

Lean percentage at the end of test (95kg) was estimated using the following equations from the thesis of Jones (1996). These prediction equations were based on regression analysis of dissected carcasses from the same line of pigs as used in this study, so gave the most accurate estimates of lean percentage available.

$$L\%_{\text{boars}} = 100\times(0.55 + 0.0012W - 0.0043P_2 - 0.0058MB)$$

$$L\%_{\text{gilts}} = 100\times(0.57 + 0.0006W - 0.0057P_2)$$

where W was the cold carcass weight, estimated as 0.708 of liveweight for boars and 0.701 of liveweight for gilts, P_2 was the P_2 backfat depth and MB was the loin backfat depth.

Pre test estimates of lean percentage were also predicted using similar equations for pigs of 45kg liveweight (Jones 1996):

$$LP\%_{\text{boars}} = 100\times(0.52 + 0.0002W)$$

$$LP\%_{\text{gilts}} = 100\times(0.54 + 0.0001W)$$

Lean tissue feed conversion was the ratio of daily feed intake and lean growth rate. Lean tissue growth rate was estimated by the following equation:

$$\text{LTGR} = \frac{\left[\left(\frac{L\%}{100}\right)\ \text{end weight}\right] - \left[\left(\frac{LP\%}{100}\right)\ \text{start weight}\right]}{\text{days on test}}$$

The data were then combined with pedigree and performance test trait information to create the data file used in all subsequent analysis.

Means and standard deviations (s.d.) of all traits were estimated for all pigs tested and for boars and gilts separately. The difference between sexes for feeding pattern and performance test traits were also estimated, and their significance tested using the t-test procedure of MINITAB (1991).

$$T = \frac{\mu_1 - \mu_2}{\text{s.e.}}$$

where: μ_x = mean of trait x

s.e. = pooled standard error

2.2.2 *Normality of traits*

Coefficients of skewness and kurtosis were estimated for all feeding pattern traits and daily feed intake by the method outlined in Snedecor and Cochran (1989). Coefficient of skewness will be positive if the low values of X (see equations below) are close to the mean and high values are far from the mean. The coefficient of kurtosis is positive when the distribution has longer tails than a normal distribution with the same standard deviation.

$$\text{Coefficient of Skewness} = \frac{(X - \mu)^3}{\sigma^3}$$

Coefficient of Kurtosis $= \frac{(X - \mu)^4}{\sigma^4}$

where: X is the individual measurement of the trait

μ is the mean of the trait

σ is the standard deviation of the trait

2.2.3 *Estimates of Repeatability*

To use these traits in pig breeding a high repeatability between daily and weekly measurements is required so we know that measurements during part of the test period are good indicators of the whole. To obtain estimates of repeatability of these traits over the 9 week test period the data were analysed by restricted maximum likelihood (REML) using the algorithm from Genstat REML (Genstat committee 1989). The model included fixed effects of sex, pen, parity of the dam, week of test (1 to 9) and year and week finishing test, covariates of weight at the start of test and litter size at birth, with animals as a random effect. The model is outlined below:

$$y = \mathbf{X}b + \mathbf{Z}a + e$$

where y = the vector of observations

b = the vector of fixed effects

$\mathbf{X}$ = the incidence matrix for fixed effects

a = the vector of random animal effects

$\mathbf{Z}$ = the incidence matrix for random animal effects

e = vector of random residual effects

Repeatability (r_e) was calculated in the usual way using the equation from Falconer and Mackay (1996): $r_e = \sigma^2_b / (\sigma^2_b + \sigma^2_w)$ where σ^2_b is between animal variance and σ^2_w is within animal variance.

2.3 Results

2.3.1 *Description of feeding patterns*

Mean and standard deviations for feeding pattern traits and performance test traits are represented in Table 2.2. Pigs ate approximately 2 kg of feed per day over 10 visits (7.9 meals). The coefficients of variation (CV) were much lower for performance test traits than for feeding pattern traits. This suggested that feeding pattern traits are more variable between individuals with, potentially, some extreme values which may be of use in selection. There was no significant difference in the daily feed intake between boars and gilts although boars did appear to eat more. Boars had fewer, longer visits to the feeder, but less visits per day and were more efficient and faster growing than gilts.

A strong diurnal pattern of feeding behaviour was observed. The distribution of mean proportion of visits and mean proportion of feed intake, as proportions of daily total are presented in Figure 2.1 and feeder occupation time in minutes per hour in Figure 2.2. The majority of visits and therefore feed intake occurred between 06.00 and 20.00, which corresponds to the light period in the test station. There may, however have been seasonal differences, although no effect of them was detected. Although most visits occurred during the early peak of feeding behaviour most food was eaten during the late afternoon peak.

Table 2.2: *Means, standard deviations (s.d.) and coefficients of variation for traits averaged over the total test period*

Trait	Mean	s.d.	CV
Daily feed intake (kg)	2.06	0.270	0.13
Feed intake per visit (kg)	0.198	0.072	0.35
Feed intake per meal (kg)	0.257	0.096	0.22
Number of visits per day	10.1	2.82	0.28
Number of meals per day	7.90	2.46	0.31
Time per visit (min)	6.01	3.66	0.61
Time per meal (min)	8.11	4.82	0.59
Time per day (min)	58.3	26.5	0.45
Number of non-feeding visits per day	0.88	0.730	0.83
Feeding rate (kg/min)	0.042	0.032	0.77
Backfat depth (mm)	11.9	2.50	0.21
Feed conversion ratio (kg/kg)	2.11	0.230	0.11
Average daily gain(kg)	0.994	0.130	0.13
Lean percentage	57.3	2.05	0.05
Lean tissue growth rate	0.508	0.063	0.12
Lean feed conversion ratio	4.11	0.598	0.15
Days on Test	51.0	4.48	0.10
Start Weight (kg)	45.3	2.76	0.06
End Weight (kg)	95.4	6.78	0.07

Figure 2.1: *Feed intake per visit (% feed) and number of visits (% visits) as percentages of the daily total over a 24 hour period*

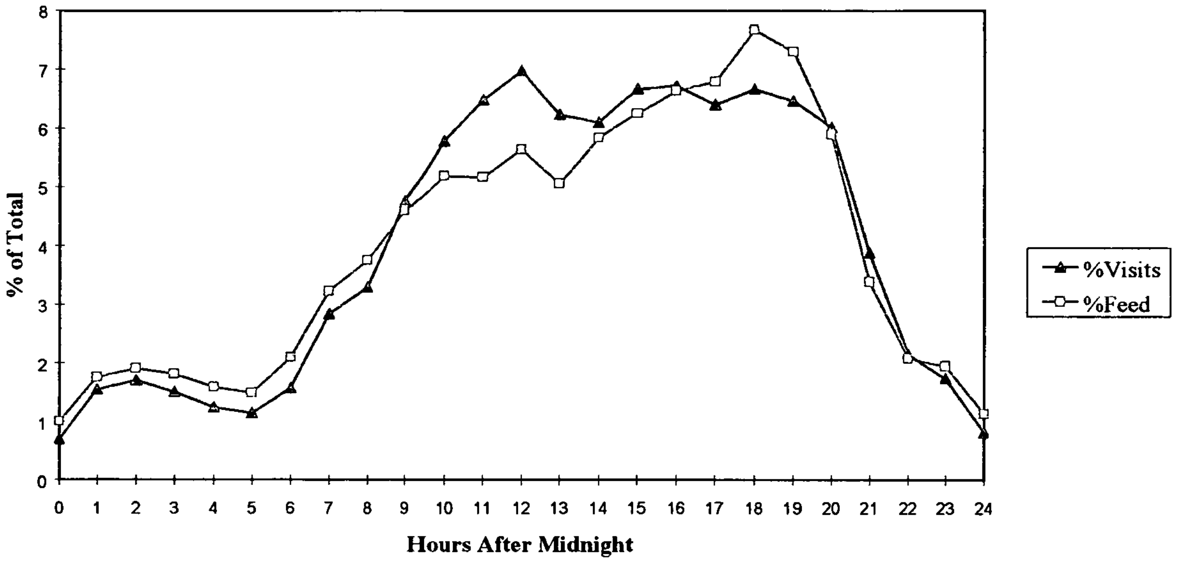


Figure 2.2 : *Mean feeder occupation time in minutes per hour over a 24 hour period*

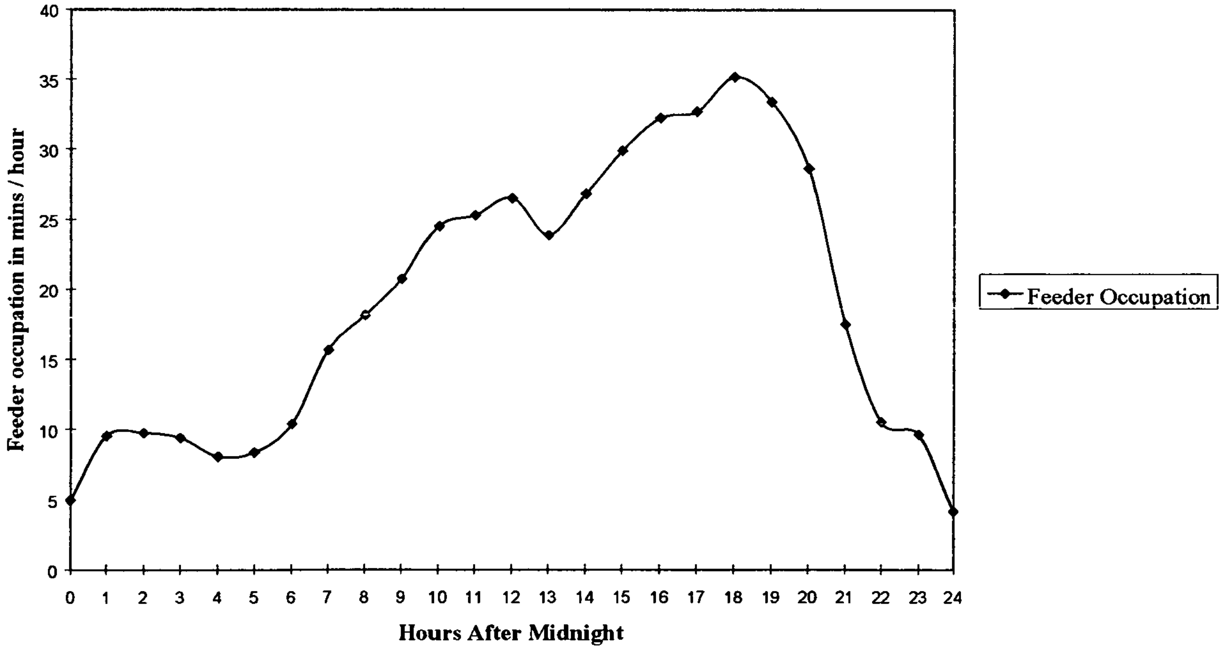


Table 2.3: *Means of sexes, and significant differences between sexes for feeding pattern and performance test traits.*

Trait	Boars	Gilts
Daily Feed Intake (kg)	2.07	2.04 ^{ns}
Feed Intake per Visit (kg)	0.201	0.170 **
Feed Intake per Meal (kg)	0.268	0.229 **
Number of Visits per Day	10.0	10.9 **
Number of Meals per Day	7.82	8.45 **
Time per Visit (min)	6.10	5.40 **
Time per Meal (min)	8.17	7.73 *
Time per Day (min)	58.1	56.0 ^{ns}
Feeding Rate (kg/min)	0.0477	0.0407 *
Non-Feeding Visits per Day	0.847	1.11 **
Backfat (mm)	11.7	12.9 **
Feed Conversion Ratio (kg/kg)	2.08	2.29 **
Average Daily Gain (kg)	1.01	0.887 **
Lean percentage	52.1	52.6 ^{ns}
Lean tissue growth rate	0.520	0.470**
Lean feed conversion ratio	4.08	6.36**

^{ns} not significant * $p<0.05$ ** $p<0.01$

2.3.2 *Normality of traits*

All feeding pattern traits, except daily feed intake, were not normally distributed, however log$_e$ and square root transformations resulted in normality for most traits (Table 2.4).

Table 2.4: *Coefficients of skewness and kurtosis for transformed and untransformed feeding pattern traits.*

	Un-transformed		Log$_e$ transformed		Square root transformed	
Trait	skewness	kurtosis	skewness	kurtosis	skewness	kurtosis
DFI	0.009	0.106	-0.199**	0.844**	0.186**	0.944**
FIV	0.529**	-0.230**	-0.008	0.0049	0.342**	0.006
FIM	0.516**	0.212**	0.007	-0.108	0.397**	-0.111
NV	0.286**	-0.195**	-0.479**	0.381**	0.007	-0.105
NM	0.473**	-0.128**	-0.248**	-0.232**	0.101	-0.141*
TV	0.622**	-0.001	-1.65**	5.06**	-0.120*	0.002
TM	0.563**	0.000	-0.337**	-0.402**	-0.118*	0.010
TD	0.491**	0.212**	-0.912**	1.55**	-0.004	-0.009
NFV	1.582**	2.643**	0.797**	0.349**	0.001	0.181**
FR	0.671**	0.950**	0.111	0.139*	0.731**	1.742**

* $p<0.05$ ** $p<0.01$

2.3.3 *Estimates of Repeatability.*

Estimates of repeatability, over the test period, for both the transformed and untransformed data can be seen in table 2.5. The untransformed estimates were very similar to the transformed estimates although transformed estimates were generally slightly higher.

Table 2.5: REML *Repeatability Estimates over whole test period.*

Trait	Repeatability	Trait	Repeatability
DFI	0.35		
FIV	0.48	$\log_e$ FIV	0.51
FIM	0.51	$\log_e$ FIM	0.49
NV	0.53	$\sqrt{NV}$	0.55
NM	0.55	$\sqrt{NM}$	0.57
TV	0.15	$\sqrt{TV}$	0.17
TM	0.16	$\sqrt{TM}$	0.15
TD	0.18	$\sqrt{TD}$	0.20
FR	0.14	$\log_e$ FR	0.15
NFV	0.37	$\sqrt{NFV}$	0.32

2.3 Discussion

The means of feeding pattern traits found in this study are compared to those found in other studies in Table 2.6. The daily feed intake found in the current study was similar to that of Von Felde *et al.* (1996b) and De Haer and Merks (1992). The study by Von Felde *et al.* (1996b) used ACEMO feeders which have an entirely closed race which protects the pig during feeding whereas all the other studies used either FIRE or IVOG feeders which have an open race allowing other pigs to interrupt the feeding pig during a visit to the feeder. Nielsen *et al.* (1995a) and De Haer (1992) suggested that these single space feeders led to a reduction in daily feed intake due to competition within the pen for feed, when compared to multi-spaced feeders or individual penning, but this was not found in the current study. Generally the ACEMO feeders showed fewer, longer visits with more feed intake per visit than either FIRE or IVOG, but the daily feed intake was not significantly different, however it is difficult to compare these results across environments. These observations were supported by Nielsen *et al.* (1995b) who found that pigs which had high protection from other pigs when in the feeder had longer, fewer visits and larger meals. Young and Lawrence (1994), however suggested that the variation in the frequency of visits was due to the size of the animal with heavier pigs having more visits, but this study was done on mature sows fed a restricted diet. However there may be some breed or line effects such that pigs selected for lean growth, typical of breeding company lines, may have different feeding patterns to pigs bred and used on experimental farms.

Table 2.6: *Means (and s.d.) of feeding pattern traits in other studies on group housed Large White pigs using electronic feeders*

Trait	*Von Felde 1996a*$^{(1)}$	*De Haer 1992*$^{(2)}$	*Nielsen 1995*$^{(3)}$	*Hyun et al. 1997*$^{(3)}$	*Current study*$^{(3)}$
DFI	2.4	2.0	1.4	1.7	2.06
(kg)	(0.5)	(0.3)	(0.5)	(0.03)	(0.27)
FIV	0.47	0.16	0.13	0.15	0.198
(kg)	(0.19)	(0.05)	(0.11)	(0.069)	(0.072)
NV	5.1	14.4	13.4	11.6	10.1
(per day)	(1.9)	(5.0)	(7.7)	(0.49)	(2.82)
TV	9.6	4.7	4.6	6.6	6.01
(min)	(3.6)	(1.5)	(3.8)	(0.27)	(3.66)
TD	49.0	63.5	53.5	73.4	58.3
(min)	(11.0)	(13.0)	(8.9)	(2.61)	(26.5)
FR	0.049	0.032	0.027	0.024	0.042
(kg/min)	(0.011)	(0.005)	(0.007)	(0.009)	(0.054)

$^{(1)}$ACEMO feeders, $^{(2)}$IVOG feeders, $^{(3)}$FIRE feeders

The bimodal distribution of visits, feed intake per visit and feeder occupation during the day (Figures 2.1 and 2.2) could be due to high competition for the feeder earlier in the day, leading to more evictions from the feeder by other pigs and hence increasing the number of pigs visits but reducing the intake per visit. This is supported by the percentage of feeder occupation time following the plot of feed intake, which indicates that, although more visits occurred during the early peak, the feeder was occupied more in the late peak. Similar results were noted by De Haer and Merks (1992), Eddison and Roberts (1995) and Nielsen, Lawrence and Whittemore (1995). However Hyun *et al* (1997) and Young and Lawrence (1994) only observed one peak of feeding behaviour, between 9 and 10 am, on Large White boars using electronic feeders. Feddes *et al* (1989) suggested that the two peaks, observed in some studies, are a response to the pattern of light and dark within the accommodation. In the study by Hyun *et al.* (1997) the lighting was 24 hours per day and the Young and Lawrence (1994) was on restricted fed sows so this hypothesis may be true.

Most traits had non-normal distribution and generally were highly positively skewed and showed positive kurtosis. This means that there are many extreme values which, if they have a genetic background, may be of use for animal breeding purposes. Transformations to reduce non-normality were successful for most traits.

Repeatability estimates were generally high (0.2 to 0.5) especially for number of visits / meals and feed intake per visit / meal. The estimates for transformed traits were similar to those for untransformed values. These high repeatabilities are upper limits of the heritabilities so would suggest that these feeding pattern traits may be heritable.

2.4 Conclusions

Feeding behaviour appears to have a diurnal pattern with the majority of feeding visits taking place during the light period with two peaks of behaviour one in the morning and one in the evening. The differences in feeding patterns between boars and gilts were significant, with boars eating larger, fewer meals per day, but there was no significant difference in daily feed intake or eating time per day between the sexes.

Feeding pattern traits are not normally distributed but are easily transformed to reduce this non-normality. The estimates of repeatability, being the upper limits of heritability, suggest that there is some potential to include these traits in a breeding program. Most have a moderate to high repeatability which could allow them to be selected effectively.

Chapter 3

Genetic aspects of feed intake patterns in group housed growing pigs using single spaced electronic (FIRE) feeders

Abstract

The main aim of this chapter was to determine the genetic relationship between feeding pattern traits and performance test traits by estimating the genetic and phenotypic parameters between them.

The data used in these analyses were compiled from individual feeding records of 1832 pigs from 70 sire families using FIRE (feed intake recording equipment) system from Hunday Electronics Ltd at the Cotswold Pig Development Company. Pigs were on test between 45 kg (s.d. 2.76) and 95 kg (s.d. 6.78). Daily feed intake (DFI kg), feed intake per visit (FIV kg), number of visits per day (NV), duration of each visit (TV mins.), time in the feeder per day (TD mins.), feeding rate (FR kg/min) and number of non-feeding visits per day (NFV), were measured as means of test and DFI was also recorded as means of bi-weekly periods of test. Performance test traits of backfat depth off test (BF mm), food conversion ratio (FCR kg/kg) and average daily gain (ADG kg), over the test period, were also measured.

Parameters were estimated by restricted maximum likelihood with a multivariate individual animal model. DFI had a heritability of 0.21 ranging from 0.18 to 0.26 over the four test periods. Correlations between DFI in each test period were high (r_g = 0.75 to 0.99). DFI was highly correlated with performance test traits (0.61 to 0.78) but had low correlations with feeding pattern traits (0.0 to 0.24). The heritability of feeding pattern traits was low (0.06 to 0.11) with the exception of FIV (0.27) and NV (0.34), but correlations among feeding pattern traits were high. FIV, NV and TV

were moderately correlated with ADG ($r_g = 0.49, -0.29, 0.33$ respectively), BF ($r_g = 0.35, -0.15, 0.17$ respectively) and FCR ($r_g = -0.12, 0.31, -0.27$ respectively). Feeding patterns may be substantially changed by selection and the genetic correlations with performance test traits indicate that feeding patterns traits can be usefully incorporated in selection criteria to improve the accuracy of selection.

3.1 Introduction.

Selection for feed conversion ratio (FCR) based on its component traits (daily feed intake and daily gain) requires accurate measurement of feed intake. One method was to record feed intake of pigs penned individually, but with group penning practiced in production units there may be genotype by environment interaction which may have affected the rate of genetic improvement (Merks 1989). Automatic feeders enable accurate measures of individual feed intake in a group penning system and also provide information on feeding pattern traits, such as the number and size of meals. Information on feeding pattern traits could be of use to improve the accuracy of selection for FCR and other production traits. Selection on FCR, however may lead to a reduction in feed intake due to a correlated response of its components, feed intake and growth rate (Webb and King 1983; Gunsett 1986; Cameron and Curran 1994). This reduction of daily feed intake may not be desirable so including feeding pattern traits as selection criteria may allow the breeder to select more efficient pigs without the corresponding loss in daily feed intake.

The main aims of this study were to describe these feeding pattern traits and to estimate the genetic and phenotypic parameters between them and performance test traits.

3.2 Materials and Methods.

3.2.1 *Data*

The data used in these analyses comprised 1832 records from 70 sire families of growing pigs on test at Cotswold Pig Development Company. More details about this data were given in Chapter 2. The data was analysed twice. The first analysis was on the untransformed data and the second when traits had been either $\log_e$ or square root transformed to reduce non-normality. Details and reasons for this procedure are given in Chapter 2.

3.2.2 *Statistical analysis*

Heritabilities, common litter effects and correlations between feeding pattern and performance test traits were estimated by restricted maximum likelihood (REML) with a multivariate individual animal model using the algorithm by Groeneveld (1994) in the VCE REML version 3.2 package. Standard errors of heritabilities, common litter effects and genetic correlations were also estimated.

The model for each trait included fixed effects of sex, pen, parity of the dam and year and week finishing test, covariates of weight at the start of test and litter size at birth, with animal and litters fitted as random effects. The model was:

$$y = \mathbf{X}b + \mathbf{Z}a + \mathbf{W}c + e$$

where y = the vector of observations

b = the vector of fixed effects

X = the incidence matrix for fixed effects

a = the vector of random animal effects

Z = the incidence matrix for random animal effects

c = the vector of random litter effects

W = the incidence matrix for random litter effects

e = vector of random residual effects

The mixed model equations can be expressed as follows:

$$\begin{pmatrix} X'R^{-1}X & X'R^{-1}W & X'R^{-1}Z \\ W'R^{-1}X & W'R^{-1}W + \lambda_1 I & W'R^{-1}Z \\ Z'R^{-1}X & Z'R^{-1}W & Z'R^{-1}Z + \lambda_2 A^{-1} \end{pmatrix} \begin{pmatrix} b \\ a \\ c \end{pmatrix} = \begin{pmatrix} X'R^{-1}Y \\ W'R^{-1}Y \\ Z'R^{-1}Y \end{pmatrix}$$

where A = numerator relationship matrix

R = matrix of residual (co) variances

I = identity matrix

$\lambda_1 = \sigma^2_e / \sigma^2_c$

$\lambda_2 = \sigma^2_e / \sigma^2_a$

3.3 Results

3.3.1 *Heritability and common litter effect estimates*

Estimates of heritability (h^2) and common litter effects (c^2) are shown in Table 3.1. The heritability of mean daily feed intake for the whole test period was 0.21. Heritabilities for feed intake per visit and number of visits were higher than for other feeding pattern traits. Common litter effects accounted for 0.1 of phenotypic variance for daily feed intake but less than 0.05 for feeding pattern and performance test traits.

3.3.2 *Genetic and phenotypic correlation estimates*

Tables 3.2 and 3.3 shows the phenotypic (r_p) and genetic (r_g) correlation estimates, respectively, for feed intake pattern and performance test traits. The pattern of genetic and phenotypic correlations between feed intake per visit, time per visit and number of visits indicated that high feed intake per visit was associated with longer, fewer visits. The high correlations between feeding rate and time per day implied that feed intake per day was relatively constant, which is also indicated by the lower coefficient of variation for daily feed intake (0.13) relative to feeding rate (0.58) and time per day (0.45). The high correlations, both genetic and phenotypic, between respective meal and visit traits (*e.g.* FIV & FIM) suggests that there is little difference between them.

Table 3.1: *Heritabilites and common litter effects for feeding pattern and performance test traits.*

Trait	h^2	(s.e.)	c^2	(s.e.)
Daily feed intake (kg)	0.21	(0.02)	0.12	(0.02)
Feed intake per visit (kg)	0.27	(0.08)	0.05	(0.02)
Feed intake per meal (kg)	0.26	(0.08)	0.09	(0.02)
Number of visits per day	0.34	(0.08)	0.05	(0.03)
Number of meals per day	0.36	(0.07)	0.05	(0.03)
Time per visit (mins)	0.11	(0.05)	0.00	(0.01)
Time per meal (mins)	0.09	(0.09)	0.03	(0.03)
Time per day (mins)	0.13	(0.08)	0.00	(0.00)
Number of non-feeding visits per day	0.06	(0.04)	0.02	(0.02)
Feeding rate (kg/min)	0.04	(0.10)	0.00	(0.00)
Feed conversion ratio	0.12	(0.03)	0.04	(0.02)
Average daily gain (kg)	0.25	(0.04)	0.01	(0.01)
Backfat depth (mm)	0.38	(0.10)	0.00	(0.02)
Lean percentage	0.56	(0.09)	0.00	(0.02)
Lean tissue growth rate	0.38	(0.09)	0.00	(0.01)
Lean feed conversion ratio	0.52	(0.11)	0.02	(0.03)

At both the genetic and phenotypic level, daily feed intake was highly associated with daily gain and had positive correlations with backfat depth and feed conversion ratio (r_g = 0.61, 0.78, 0.65 respectively). Similarly feed intake per visit, time per visit and time per day were positively associated with daily gain and backfat depth. The high genetic correlations, relative to the phenotypic correlations, of non-feeding visits with other feeding pattern traits may be a result of environmental noise or measurement error, giving a low heritability, rather than a reflection of the true correlations.

3.3.3 *Parameter estimates for normalised traits*

Parameter estimates for transformed feeding pattern traits are presented in table 3.4. These transformations were to reduce non normality. There were few differences between these estimates and the non-transformed estimates in tables 3.1 to 3.3.

Table 3.2: *Phenotypic correlation estimates*

	DFI	*FIV*	*FIM*	*NV*	*NM*	*TV*	*TM*	*TD*	*NFV*	*FR*	*FCR*	*ADG*	*BF*	*L%*	*LTGR*
FIV	0.24														
FIM	0.29	0.95													
NV	0.08	-0.58	-0.54												
NM	0.04	-0.60	-0.63	0.93											
TV	0.06	0.39	0.37	-0.32	-0.32										
TM	0.09	0.40	0.47	-0.26	-0.35	0.81									
TD	0.10	-0.04	-0.01	0.15	0.11	0.81	0.84								
NFV	-0.08	-0.39	-0.37	0.27	0.20	-0.13	-0.16	0.03							
FR	0.03	0.02	0.01	0.02	0.03	-0.69	-0.71	-0.47	0.02						
FCR	0.41	0.07	0.08	0.08	0.09	-0.16	-0.15	0.08	0.08	0.09					
ADG	0.63	0.21	0.19	0.07	0.04	0.05	0.05	0.03	-0.14	0.07	-0.24				
BF	0.36	0.15	0.16	0.03	0.00	0.02	0.05	0.08	-0.11	0.06	0.03	0.39			
L%	-0.45	-0.12	-0.09	-0.04	-0.02	-0.01	-0.02	-0.01	0.04	-0.04	-0.30	-0.21	-0.85		
LTGR	0.17	0.09	0.10	-0.14	-0.16	0.15	0.12	-0.03	-0.04	0.02	-0.49	0.65	-0.46	0.50	
LTFC	0.23	0.11	0.09	-0.07	-0.05	0.07	0.09	0.03	-0.06	0.01	0.77	0.16	0.37	-0.42	-0.46

† Key: DFI = daily feed intake, FIV/M = feed intake per visit/meal, NV/M = number of visits/meals, TV/M = time per visit/meal, TD = time per day, FR = feeding rate, NFV = number of non-feeding visits, FCR = feed conversion ratio, ADG = average daily gain, BF = backfat depth, L% = lean percentage, LTGR = lean tissue growth rate, LTFC = lean tissue feed conversion ratio

Table 3.3: *Genetic correlation estimates (and standard errors).*

	DFI	*FIV*	*FIM*	*NV*	*NM*	*TV*	*TM*	*TD*	*NFV*	*FR*	*FCR*	*ADG*	*BF*	*L%*	*LTGR*
FIV	0.22														
	(0.08)														
FIM	0.28	0.96													
	(0.07)	(0.09)													
NV	0.07	-0.86	-0.78												
	(0.11)	(0.10)	(0.08)												
NM	0.03	-0.90	-0.87	0.96											
	(0.06)	(0.12)	(0.10)	(0.06)											
TV	0.09	0.93	0.84	-0.79	-0.84										
	(0.07)	(0.08)	(0.10)	(0.09)	(0.08)										
TM	0.09	0.78	0.86	-0.60	-0.75	0.90									
	(0.10)	(0.10)	(0.13)	(0.11)	(0.09)	(0.08)									
TD	0.31	0.13	0.21	0.10	0.12	0.45	0.48								
	(0.13)	(0.13)	(0.12)	(0.14)	(0.12)	(0.14)	(0.11)								
NFV	-0.44	-0.46	-0.69	0.38	0.62	-0.35	0.52	-0.19							
	(0.10)	(0.12)	(0.09)	(0.12)	(0.13)	(0.10)	(0.12)	(0.13)							
FR	0.15	-0.06	-0.04	0.06	0.09	-0.63	-0.58	-0.76	-0.07						
	(0.07)	(0.10)	(0.11)	(0.14)	(0.13)	(0.09)	(0.07)	(0.05)	(0.11)						
FCR	0.65	-0.12	-0.14	0.31	0.24	-0.27	-0.25	-0.14	0.13	0.13					
	(0.07)	(0.08)	(0.09)	(0.09)	(0.10)	(0.08)	(0.13)	(0.09)	(0.11)	(0.11)					
ADG	0.61	0.49	0.39	-0.29	-0.24	0.33	0.23	0.46	-0.59	0.27	-0.15				
	(0.09)	(0.09)	(0.08)	(0.10)	(0.08)	(0.07)	(0.11)	(0.12)	(0.08)	(0.12)	(0.09)				
BF	0.78	0.35	0.35	-0.15	-0.17	0.17	0.16	0.08	-0.17	0.29	0.29	0.42			
	(0.11)	(0.08)	(0.08)	(0.09)	(0.06)	(0.08)	(0.09)	(0.04)	(0.13)	(0.09)	(0.05)	(0.06)			
L%	-0.72	-0.29	-0.25	0.01	0.02	0.07	0.01	-0.03	0.09	-0.25	-0.86	-0.31	-0.97		
	(0.12)	(0.10)	(0.08)	(0.07)	(0.10)	(0.09)	(0.09)	(0.05)	(0.12)	(0.07)	(0.07)	(0.07)	(0.10)		
LTGR	0.20	0.11	0.13	-0.21	-0.19	0.26	0.21	-0.07	0.10	0.05	-0.67	0.69	-0.47	0.52	
	(0.08)	(0.05)	(0.07)	(0.09)	(0.10)	(0.11)	(0.08)	(0.04)	(0.08)	(0.09)	(0.07)	(0.06)	(0.12)	(0.09)	
LTFC	0.29	0.15	0.13	-0.05	-0.02	0.12	0.09	0.05	-0.08	0.09	0.80	0.07	0.46	-0.51	-0.56
	(0.12)	(0.06)	(0.08)	(0.06)	(0.03)	(0.10)	(0.07)	(0.05)	(0.04)	(0.06)	(0.11)	(0.08)	(0.12)	(0.09)	(0.06)

† see table 3.2 for key to traits

Table 3.4: *Heritabilities (bold) and genetic (above) and phenotypic (below) correlation estimates for normalised feeding pattern traits*

	DFI	$\log_e$ *FIV*	$\sqrt{NV}$	$\sqrt{TV}$	$\sqrt{TD}$	$\log_e$ *FR*	$\sqrt{NFV}$	*BF*	*FCR*	*ADG*
DFI	**0.21**	0.22	0.07	0.09	0.34	0.17	-0.38	0.78	0.65	0.61
$\log_e$ FIV	0.24	**0.28**	-0.90	0.81	0.15	-0.06	-0.44	0.38	-0.15	0.38
$\sqrt{NV}$	0.10	-0.62	**0.31**	-0.77	0.06	0.04	0.33	-0.11	0.18	-0.26
$\sqrt{TV}$	0.04	0.41	-0.34	**0.12**	0.51	-0.61	-0.29	0.14	-0.09	0.23
$\sqrt{TD}$	0.10	-0.01	0.10	0.83	**0.09**	-0.79	-0.08	0.10	-0.11	0.32
$\log_e$ FR	0.08	0.09	0.01	-0.78	-0.43	**0.04**	-0.06	0.31	0.12	0.33
$\sqrt{NFV}$	-0.02	-0.21	0.22	-0.15	-0.01	-0.03	**0.08**	-0.19	0.10	-0.55
BF	0.36	0.13	0.04	0.02	0.07	0.08	-0.06	**0.38**	0.29	0.42
FCR	0.41	0.09	0.03	-0.15	0.02	0.08	0.11	0.03	**0.12**	-0.15
ADG	0.63	0.18	0.09	0.01	0.05	0.09	-0.14	0.39	-0.24	**0.25**

† see table 3.2 for key to traits

standard errors of h^2 between 0.01 and 0.08. standard errors of r_g between 0.03 and 0.14

3.4 Discussion

Estimates of heritabilities and genetic correlations for feeding pattern traits indicate that there is substantial genetic variance in some of these traits, such that feeding pattern traits could be incorporated in a breeding program to increase the accuracy of selection.

Heritability estimates of feeding pattern traits from other studies (Roehe *et al.* 1994, Von Felde *et al.* 1996a,b, Kalm *et al.* 1996, Labroue *et al.* 1996, De Haer and De Vries 1993) are shown in Table 3.5. All studies used Large White pigs although Von Felde *et al.* (1996a,b), Kalm *et al.* (1996) and Labroue *et al.* (1996) had higher end test weights of 120 kg. Higher heritability estimates were reported for ACEMO feeders, which had an entirely enclosed race, for all feeding pattern traits than for IVOG or FIRE feeders, which had an open race. The only other study to use feeders with an open race (IVOG) in the estimation of genetic parameters was that of De Haer and De Vries (1993), who found estimates similar to those in the current study. The open race of FIRE or IVOG systems allows a pig to be evicted from the feeder by a dominant pen mate so the social interaction within a pen may well play a larger part in determining the feeding patterns of an individual. In ACEMO feeders there were also fewer, longer visits per day, although the daily feed intake was similar to that of other electronic feeders. The pattern of few long visits is probably a result of a pig being uninterrupted whilst in the feeder as opposed to the FIRE system where evictions are common.

Table 3.5: *Estimates of heritability of feeding pattern traits from other studies*

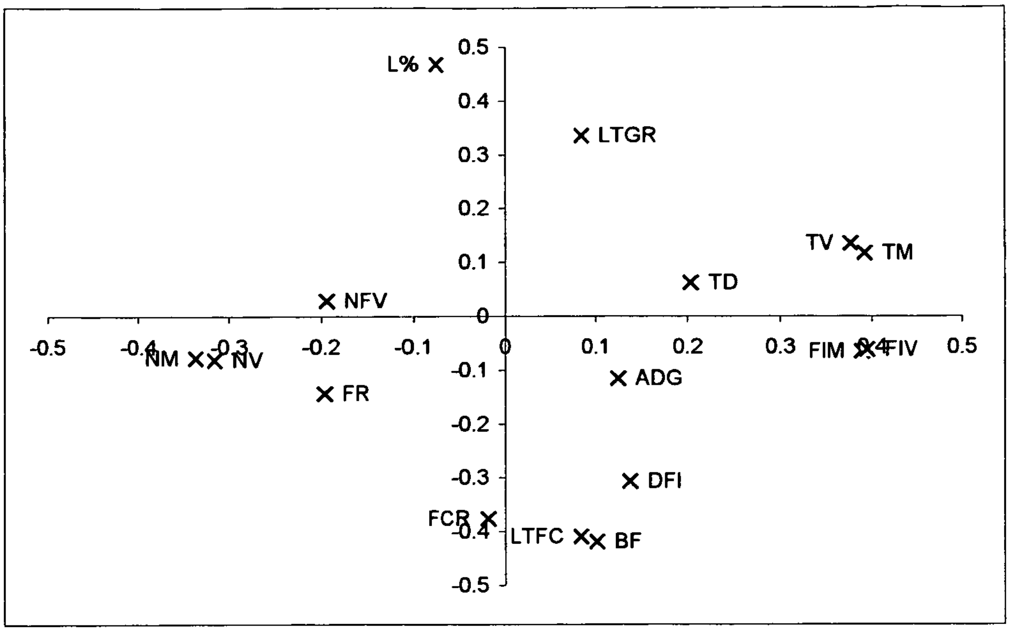
Trait	*Von Felde et al.*	*Kalm et al.*	*Labroue et al.*	*De Haer et al.*	*Current Study*
	1996b(1)	*1996*(1)	*1996*(1)	*1993*(2)	*1997*(3)
Daily Feed Intake	0.22	0.20	0.42	0.16	0.21
Feed Intake per Visit	0.51	0.50	0.28	0.35	0.27
Number of Visits	0.43	0.47	0.23	0.38	0.34
Time per Visit	0.42	0.39	0.23	0.27	0.11
Time per Day	0.43	0.45	0.36	0.24	0.08
Feeding Rate	0.44	0.46	0.49	0.29	0.04

(1) *ACEMO feeders* (2) *IVOG feeders* (3) *FIRE feeders*

There is also some evidence that single space electronic feeders partially restrict feed intake compared to multispace trough feeders due to higher competition within the pen for feed (Nielsen, Lawrence and Whittemore 1996).

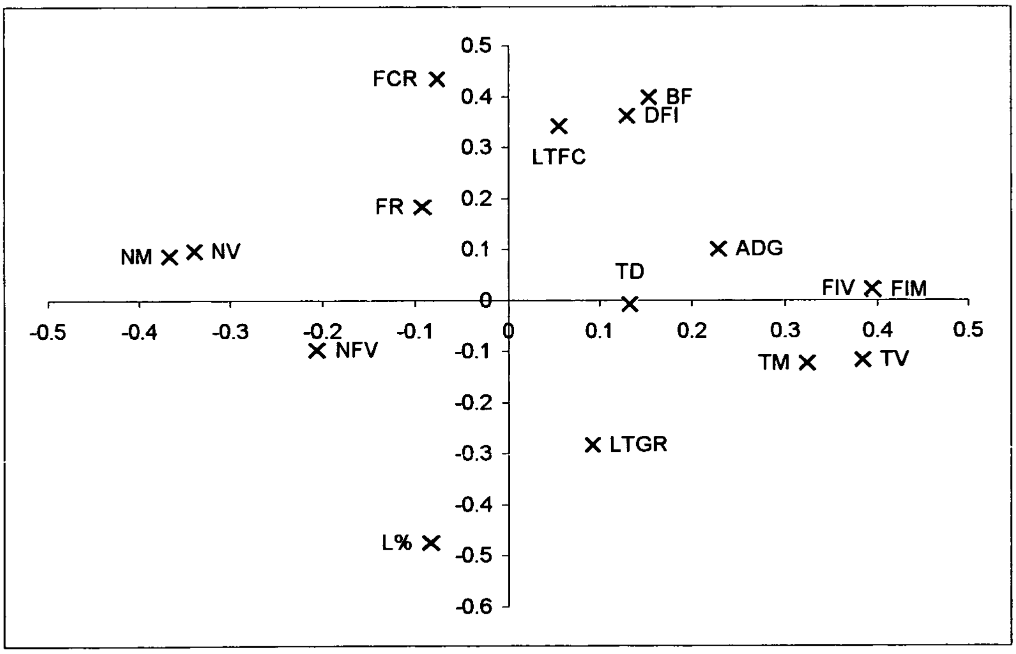
The highest estimated heritabilities were for number of visits (0.34) and food intake per visit (0.27). These high heritabilities would make it possible to select effectively for these traits in a breeding programme. In preliminary analyses feeding rate was positively skewed and had a heritability of 0.49, which is similar to that found in most other studies (Von Felde *et al.* 1996b, Labroue *et al.* 1996). Logarithmic transformation to reduce non normality resulted in a heritability estimate of 0.04. When investigated it was found that the removal of extreme values of feeding rate (over 350 g/min) resulted in a heritability estimate of 0.04 for untransformed values and gave correlations with other traits similar to those using the log transformation of the original data. These individuals with extreme values of feeding rate also had much lower than expected daily feed intake and very low time per day in the feeder, so it was assumed that they were the result of errors in the feed intake recording system, so were removed from all analyses in this thesis.

Daily feed intake had a small association with other feeding pattern traits but high correlations with performance test traits, indicating that feeding pattern traits had little influence on overall daily feed intake. The high negative genetic correlations between feed intake per visit and number of visits suggest that there are two extremes of feeding behaviour, those animals that take many, short, small meals and those that eat few, large, long meals per day. It can also be noted that the genetic correlations



† see table 3.2 for key to traits

Figure 3.1 *Principal components analysis of phenotypic correlation matrix*



† see table 3.2 for key to traits

Figure 3.2 *Principal component analysis of genetic correlation matrix* between time per visit and daily feed intake and between number of visits and daily feed intake are very similar (0.09 and 0.07) suggesting that there is little difference in overall feed intake in either extreme of feeding behaviour. However many pigs also exhibit feeding patterns between the two extremes with a moderate number of visits and moderate time per visit. Given the genetic correlations between the three major feeding pattern traits (feed intake per visit, number of visits and time per visit) and performance test traits, it would appear that pigs which have few large meals per day have higher daily gain and lower FCR, even though they have more backfat.

To test which traits would be most useful in selection the genetic and phenotypic correlations were examined by principal components analysis (Rao 1973) to determine linear functions, which describe the overall pattern of correlations between the traits. Results of this analysis are presented in Figures 3.1 and 3.2. The distance from the origin of each point reflects the precision with which this two-dimensional plot reflects the full sixteen dimensional plot (further from the origin is better). The relationship between traits is represented as the angle between two points when joined by straight lines via the origin. If the angle between two points is less than 90° then the traits are positively correlated (more positive as it approaches zero) and if the angle between two points is greater than 90°, then the traits are negatively correlated. Angles near 90° represent uncorrelated traits. For example FIV and TV are highly positively correlated and have only a small angle between them.

From the principal components analysis it can be noted that the associations between respective mean and visit traits (*e.g.* FIV and FIM) are very high, which suggests that it is not necessary to include both as selection criteria. Visit traits are easier to measure, so from a practical point of view it was decided to use these in favour of meal traits. There are strong associations between daily gain and three feeding pattern traits (FIV, NV and TV) both phenotypically and genetically, but they were uncorrelated with daily feed intake and backfat. For these reasons they were considered to be the most suitable for inclusion as selection criteria in a breeding program.

3.5 Conclusions

In conclusion feeding pattern traits could be substantially changed by selection. They may also be used to improve production traits and may add additional accuracy to existing selection criteria. From our results it would seem that the most useful traits to include in a selection index to improve the accuracy of selection would be feed intake per visit, number of visits per day and time per visit. This is due to their very low correlation with daily feed intake and backfat and, in the case of number of visits, negative correlation with daily gain. However due to the high correlations between these traits there may be little new information gained by including all of them in the index. The most effective and robust method may be to include number of visits per day alone with the production traits because it has the highest heritability of the feeding pattern traits and can be negatively weighted in an index to improve food conversion ratio and daily gain.

Chapter 4

A.D. Hall. ② 1998.

cs of feeding patterns in single spaced electronic feeders

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Abstract

The aims of this chapter were to determine the affect of period of test on the genetic and phenotypic parameters of daily feed intake and feeding pattern traits and hence to assess if a part test record of feed intake is a good predictor for the whole test period.

Means and standard deviations and genetic and phenotypic parameters were estimated for feeding pattern traits and daily feed intake in each test period and for the whole of test. Genetic and phenotypic parameters were estimated by restricted maximum likelihood with a multivariate individual animal model. The model for each trait included fixed effects of sex, pen, parity of the dam and year and week finishing test, covariates of weight at the start of test and litter size at birth and random effects of animals and litters. Daily feed intake increased over the test period by 0.51 kg, with a rise in feed intake per visit, number of visits and feeding rate, but a decrease in time per visit and time spent in the feeder per day. Genetic and phenotypic correlations between part and whole test records for daily feed intake and feeding pattern traits were very high. The genetic and phenotypic correlations between the test periods were also high for all traits but test periods that were closer together had a stronger association. The genetic correlations between part test records for daily feed intake and performance test traits were not significantly different from those between whole test daily feed intake and performance test traits.

It was concluded that there was potential for shortening test period for accurate measures of daily feed intake and feeding pattern traits. This may result in more pigs being tested in a given number of electronic feeders so increasing the selection intensity.

4.1 Introduction

Much work has been done on modeling the effect of age on various traits, most notably on the lactation curve in dairy cattle and growth curves in most other livestock species. It has been demonstrated by several authors that there are general trends of feeding patterns during the test period. Bigelow and Houpt (1988) showed that meal frequency declined with age from approximately ten meals per day at 30-40 kg to eight at 60-70 kg. Von Felde *et al* (1996b) also showed a decrease in the number of visits per day over the test period with little change in the time per visit or time per day in the feeder. There was however, an increase in the daily feed intake due to an increase in the feeding rate and feed intake per visit. These changes in feeding patterns over the test period may be important when considering the analysis of such data. It has already been found that daily feed intake and feeding pattern traits are correlated with performance test traits, but it may be possible to shorten the test period necessary for accurate predictions of feed intake if the correlations between part and whole test records for feeding pattern traits and daily feed intake are high. This would be useful, however only if there was no significant reduction in the heritability of these traits or a reduction in their correlations with performance test traits.

The aims of this chapter were to determine the affect of period of test on the genetic and phenotypic parameters of daily feed intake and feeding pattern traits and hence to assess if a part test record of feed intake is a good predictor for the whole test period.

4.2 Materials and Methods

4.2.1 *Data*

The data used in these analyses was the same as that in the previous chapters. Feeding pattern traits and daily feed intake were computed for the whole test and also as bi-weekly means excluding the first week of test. Test periods 1, 2 ,3 and 4 corresponded to weeks 2 to 3, weeks 4 to 5, weeks 6 to 7 and weeks 8 to 9 respectively. All pigs did not have records for the full 9 weeks, because entire pens of pigs were removed from test when most animals reached 95 kg liveweight. There were only 702 animals with records in week 8 and thus had a record in period 4 and of those only 46 had a record in week 9. The remaining pigs were given the mean of week 8 as the mean of period 4. Feed intake per meal, number of meals and time per meal were not included in the analysis due to their high association with feed intake per visit, number of visits and time per visit.
Means and standard deviations were calculated for daily feed intake and feeding pattern traits in each test period, adjusted for the effects in the model.

4.2.2 *Statistical analysis*

Genetic and phenotypic parameters were estimated by restricted maximum likelihood (REML) with a multivariate individual animal model using the algorithm of Groeneveld (1994) in the VCE REML version 3.2 package. The model for each trait included fixed effects of sex, pen, parity of the dam and year and week finishing test, covariates of weight at the start of test and litter size at birth and random effects of animals and litters. This model was described in more detail in Chapter 3. Due to the high correlations between test periods multivariate analysis did not provide sufficiently accurate results, so all correlations were calculated from bivariate analysis.

4.3 Results

4.3.1 *Mean and s.d. of feeding patterns in each test period*

Feed intake and feeding pattern information are given in Table 3.1 for each bi-weekly period and the mean of the whole test period. Over the test period daily feed intake increased by 0.51 kg, with a rise in feed intake per visit, number of visits and feeding rate, but a decrease in time per visit and time spent in the feeder per day. Coefficients of variation for each test period are similar to that in the whole test period for all traits. This homogeneous variance between test periods is important when considering the validity of any analysis.

Table 4.1 *Means (and s.d.) of feeding pattern traits for each test period and total test mean (and s.d.).*

Trait	Period of Test				
	1	*2*	*3*	*4*	*Total*
Daily Feed Intake (kg)	1.65 (0.23)	1.94 (0.26)	2.11 (0.28)	2.16 (0.32)	2.06 (0.27)
Feed Intake per Visit (kg)	0.189 (0.071)	0.201 (0.073)	0.209 (0.071)	0.217 (0.080)	0.198 (0.072)
Number of Visits per Day	9.59 (2.91)	10.6 (3.21)	11.0 (3.33)	11.0 (3.12)	10.1 (2.82)
Time per Visit (min)	6.76 (5.45)	5.96 (4.23)	5.02 (3.46)	4.71 (2.98)	6.01 (3.66)
Time per Day (min)	64.8 (26.2)	63.1 (27.8)	55.3 (23.4)	52.0 (21.9)	58.3 (26.5)
Feeding Rate (kg/min)	0.029 (0.013)	0.034 (0.016)	0.044 (0.022)	0.046 (0.024)	0.042 (0.032)
Non-Feeding Visits per Day	0.80 (0.75)	0.89 (1.07)	1.02 (1.06)	0.99 (0.87)	0.88 (0.73)

Table 4.2: *Heritability estimates (with standard errors) of bi-weekly means and total test means of feeding pattern traits.*

Traits	Period 1	Period 2	Period 3	Period 4	Total
DFI	0.26 (0.08)	0.22 (0.09)	0.24 (0.08)	0.18 (0.14)	0.21 (0.02)
FIV	0.31 (0.06)	0.31 (0.10)	0.27 (0.08)	0.25 (0.09)	0.27 (0.08)
FIM	0.38 (0.09)	0.37 (0.10)	0.38 (0.03)	0.31 (0.05)	0.26 (0.08)
NV	0.33 (0.10)	0.32 (0.08)	0.36 (0.07)	0.32 (0.10)	0.34 (0.08)
NM	0.34 (0.08)	0.37 (0.09)	0.35 (0.07)	0.31 (0.11)	0.36 (0.07)
TV	0.08 (0.08)	0.12 (0.05)	0.15 (0.09)	0.10 (0.07)	0.11 (0.05)
TM	0.11 (0.04)	0.13 (0.08)	0.16 (0.06)	0.12 (0.08)	0.09 (0.09)
TD	0.11 (0.06)	0.12 (0.08)	0.11 (0.07)	0.09 (0.08)	0.13 (0.08)
NFV	0.06 (0.10)	0.11 (0.08)	0.04 (0.07)	0.06 (0.10)	0.06 (0.04)
FR	0.09 (0.08)	0.08 (0.10)	0.06 (0.07)	0.07 (0.12)	0.04 (0.10)

Key: DFI = daily feed intake, FIV = feed intake per visit, NV = number of visits, TV = time per visit, TD = time per day, NFV = number of non-feeding visits, FR = feeding rate,

4.3.2 *Heritability estimates for feeding pattern traits and daily feed intake in each test period*

The heritability estimates for each test period are presented in Table 4.2. The heritability of the total test period was similar to that in each test period for most traits, although the highest heritabilities were generally found in period 3. The heritabilities of time per visit and time per meal appear to increase until period 3 with a reduction in period 4, but this observed difference may not be significant.

4.3.3 *Correlations between part and whole feed intake records and with performance test traits.*

Genetic and phenotypic correlations of daily feed intake during the whole test with daily feed intake during each test period were high, particularly in period 3 (Table 4.3). Correlations between daily feed intake in each test period with performance test traits were similar. The phenotypic correlations, however between daily feed intake during the whole test with FCR and daily gain were higher than for each test period.

Table 4.3 *Genetic (below) and phenotypic (above) correlations of bi-weekly means of daily feed intake (DFI) with performance test traits.*

	DFI 1	DFI 2	DFI 3	DFI 4	DFI total	FCR	ADG	BF
DFI 1 [†]		0.87	0.74	0.32	0.68	0.16	0.39	0.28
DFI 2 [†]	0.96 *(0.07)*		0.85	0.44	0.71	0.13	0.39	0.32
DFI 3 [†]	0.90 *(0.08)*	0.96 *(0.07)*		0.57	0.83	0.24	0.44	0.35
DFI 4 [†]	0.68 *(0.21)*	0.72 *(0.17)*	0.81 *(0.19)*		0.38	0.11	0.24	0.23
DFI total	0.89 *(0.09)*	0.94 *(0.10)*	0.99 *(0.07)*	0.75 *(0.18)*		0.41	0.63	0.36
FCR	0.65 *(0.07)*	0.64 *(0.07)*	0.68 *(0.07)*	0.61 *(0.16)*	0.65 *(0.07)*		-0.24	0.03
ADG	0.40 *(0.03)*	0.53 *(0.10)*	0.49 *(0.06)*	0.44 *(0.18)*	0.61 *(0.09)*	-0.15 *(0.09)*		0.39
BF	0.66 *(0.05)*	0.69 *(0.08)*	0.78 *(0.10)*	0.82 *(0.16)*	0.78 *(0.11)*	0.29 *(0.05)*	0.42 *(0.06)*	

[†] number refers to period of test

Key: FCR = feed conversion ratio, ADG = average daily gain, BF = backfat depth, DFI = daily feed intake

Tables 4.4 to 4.9 show the genetic and phenotypic correlations between the test periods for each feeding pattern trait. The genetic correlations between each test period and the total test were very high, but phenotypic correlations for feeding pattern traits, except feed intake per visit and number of visits, were slightly lower. The genetic and phenotypic correlations between the test periods were generally lower than that with the total test particularly for time per day and number of non-feeding visits. The closer together test periods were, the higher the genetic and phenotypic correlations between them (for example test period 4 was most highly correlated with test period 3). Similar results were noted by Atkins (1990) where correlations between fleece weight in sheep were higher for consecutive years than over longer periods of time. Correlations of test periods with performance test traits were similar to whole test correlations in most cases, but correlations of part test records of feeding patterns with feed conversion ratio were generally lower than full test estimates.

Table 4.4: *Genetic (below) and phenotypic (above) correlations between four test periods and total test for feed intake per visit (FIV)*

	FIV 1	*FIV 2*	*FIV 3*	*FIV 4*	*FIV total*	*FCR*	*ADG*	*BF*
FIV 1		0.82	0.78	0.87	0.94	0.12	0.18	0.16
FIV 2	0.99		0.86	0.83	0.95	0.12	0.17	0.15
FIV 3	0.92	0.93		0.86	0.91	0.10	0.22	0.21
FIV 4	0.98	0.96	0.94		0.97	0.08	0.18	0.16
FIV total	0.99	0.99	0.96	0.97		0.09	0.18	0.15
FCR	-0.11	-0.13	-0.11	-0.09	-0.15		-0.24	0.03
ADG	0.43	0.41	0.45	0.44	0.38	-0.15		0.39
BF	0.41	0.36	0.33	0.32	0.38	0.29	0.42	

standard errors of r_g between 0.01 and 0.06

Table 4.5: *Genetic (below) and phenotypic (above) correlations between four test periods and total test for number of visits per day (NV)*

	NV 1	*NV 2*	*NV 3*	*NV 4*	*NV total*	*FCR*	*ADG*	*BF*
NV 1		0.79	0.77	0.78	0.90	0.06	0.03	0.07
NV 2	0.95		0.83	0.81	0.93	0.04	-0.02	-0.05
NV 3	0.90	0.97		0.91	0.93	0.06	-0.01	-0.02
NV 4	0.92	0.98	0.97		0.98	0.07	-0.04	-0.04
NV total	0.93	0.99	0.97	0.99		0.31	-0.29	-0.15
FCR	0.06	0.08	0.13	0.09	0.31		-0.24	0.03
ADG	-0.28	-0.23	-0.25	-0.20	-0.29	-0.15		0.39
BF	-0.16	-0.15	-0.09	-0.12	-0.15	0.29	0.42	

standard errors of r_g between 0.01 and 0.06

Table 4.6: *Genetic (below) and phenotypic (above) correlations between four test periods and total test for time per visit (TV)*

	TV 1	*TV 2*	*TV 3*	*TV 4*	*TV total*	*FCR*	*ADG*	*BF*
TV 1		0.62	0.59	0.54	0.79	-0.11	0.02	0.01
TV 2	0.90		0.71	0.61	0.77	-0.08	0.02	0.03
TV 3	0.87	0.94		0.71	0.76	-0.09	0.07	0.02
TV 4	0.91	0.89	0.89		0.87	-0.05	0.08	0.01
TV total	0.90	0.92	0.91	0.93		-0.16	0.05	0.02
FCR	-0.15	-0.14	-0.15	-0.11	-0.27		-0.24	0.03
ADG	0.34	0.36	0.30	0.28	0.33	-0.15		0.39
BF	0.12	0.15	0.13	0.14	0.17	0.29	0.42	

standard errors of r_g between 0.01 and 0.06

Table 4.7: *Genetic (below) and phenotypic (above) correlations between four test periods and total test for time in the feeder per day (TD)*

	TD 1	*TD 2*	*TD 3*	*TD 4*	*TD total*	*FCR*	*ADG*	*BF*
TD 1		0.74	0.50	0.42	0.84	0.03	0.04	0.06
TD 2	0.91		0.75	0.66	0.71	0.08	0.07	0.07
TD 3	0.59	0.88		0.88	0.65	0.02	0.06	0.09
TD 4	0.51	0.77	0.97		0.66	0.01	0.08	0.02
TD total	0.96	0.93	0.88	0.81		0.08	0.03	0.08
FCR	-0.04	-0.08	-0.09	-0.03	-0.14		-0.24	0.03
ADG	0.32	0.28	0.35	0.27	0.46	-0.15		0.39
BF	0.03	0.04	0.09	0.10	0.08	0.29	0.42	

standard errors of r_g between 0.03 and 0.07

Table 4.8: *Genetic (below) and phenotypic (above) correlations between four test periods and total test for number of non-feeding visits per day (NFV)*

	NFV 1	*NFV 2*	*NFV 3*	*NFV 4*	*NFV total*	*FCR*	*ADG*	*BF*
NFV 1		0.61	0.56	0.54	0.78	0.05	-0.09	-0.07
NFV 2	0.77		0.62	0.59	0.78	0.06	-0.12	-0.10
NFV 3	0.85	0.76		0.65	0.85	0.08	-0.16	-0.09
NFV 4	0.63	0.80	0.98		0.85	0.03	-0.13	-0.11
NFV total	0.99	0.93	0.89	0.98		0.08	-0.14	-0.11
FCR	0.10	0.11	0.11	0.09	0.13		-0.24	0.03
ADG	-0.43	-0.47	-0.45	-0.39	-0.59	-0.15		0.39
BF	-0.12	-0.11	-0.18	-0.15	-0.17	0.29	0.42	

standard errors of r_g between 0.02 and 0.08

Table 4.9: *Genetic (below) and phenotypic (above) correlations between four test periods and total test for feeding rate (FR)*

	FR 1	*FR 2*	*FR 3*	*FR 4*	*FR total*	*FCR*	*ADG*	*BF*
FR 1		0.69	0.67	0.50	0.71	0.05	0.05	0.08
FR 2	0.75		0.69	0.62	0.74	0.06	0.05	0.07
FR 3	0.87	0.77		0.73	0.78	0.08	0.07	0.07
FR 4	0.71	0.81	0.87		0.81	0.04	0.06	0.03
FR total	0.82	0.83	0.89	0.91		0.09	0.07	0.06
FCR	0.09	0.12	0.15	0.08	0.13		-0.24	0.03
ADG	0.21	0.24	0.25	0.19	0.27	-0.15		0.39
BF	0.23	0.21	0.26	0.21	0.29	0.29	0.42	

standard errors of r_g between 0.03 and 0.10

4.4 Discussion

The genetic analysis of feeding pattern traits in different time periods showed that there was genetic variation in these traits over time. This distinction between time periods is important in optimising the performance test of feeding pattern traits because genetic (co) variances may change.

It has been suggested by several authors (Brascamp *et al.* 1985, Merks 1988, Atkins 1990) that if the genetic correlation between the selected (correlated) trait and the trait of interest falls below 0.8 then the extra accuracy achieved by using a correlated trait is negated so selection is better on the trait of interest. Genetic and phenotypic correlations between total daily feed intake and daily feed intake in each test period imply that test period 3 may be the most informative period of test because it had the highest correlations with overall daily feed intake and high heritability. The high correlations of performance test traits with bi-weekly periods of daily feed intake indicate that it may be possible to shorten the test period for measuring feed intake without losing too much accuracy. The heritability of bi-weekly means for daily feed intake are also moderate and similar to the whole test period so selection on test period 3 would be effective. Von Felde *et al* (1996b) also found that the most informative test period corresponded to week 7 of test when pigs weighed approximately 85 to 95 kg.

The high genetic and phenotypic correlations between whole test and part test records, for all feeding pattern traits and daily feed intake, would suggest that it may be possible to shorten the test period of these animals so more pigs can be tested on the same feeders and thereby reducing overhead costs and increasing the selection intensity possible from a given number of feeders. The heritability estimates across test periods indicate that the heritability in any one period is similar to that in the whole test period so part records would be good predictors of the whole and would not result in much loss of accuracy. There is, however the problem that if pigs were only tested for one period these assumptions may not hold. Other studies on FIRE feeders (Nielsen *et al* 1995) have shown that the pigs need a few days to adjust to the electronic feeding system and establish a social hierarchy before reliable estimates of feeding patterns and feed intake can be made, so a minimum test period would still be three weeks.

Von Felde *et al.* (1996a,b) found genetic correlations between the mean of the entire test period and bi-weekly means for daily feed intake ranging from 0.71 to 0.94 with the greatest values corresponding to week 7 of test at approximately 85-95 kg liveweight. These weights are similar to the end of test weights achieved in the current study by period 3 for most animals. Both of Von Felde's studies continued test to 120 kg. Roehe *et al.* (1995) found lower correlations between part test and overall daily feed intake of 0.32 in early test to 0.76 in week 5. All these other studies also found that test periods which were closer together had higher correlations (*e.g.* correlation between periods 2 and 3 was higher than that between 1 and 4). The highest correlations of part feeding pattern records with overall means were generally in late test (periods 3 and 4). Heritability estimates over the test periods also changed, with the highest estimates generally being in period 3, some of which were higher than the heritability of overall means for the traits. This would be important in determining the optimum performance test for these traits especially if the test period were to be shortened because selection on feeding patterns at this particular stage of growth may lead to greater response than using other test periods.

A greater emphasis in selection for early feed intake than late feed intake may indirectly affect the body composition of the resulting animals since later test periods of daily feed intake have higher correlations with backfat depth. This hypothesis is supported by the results of Von Felde *et al.* (1996b), where genetic correlations between feed intake and backfat increased from 0.15 in the first period of test to 0.57 in the last test period. The higher correlation of feed intake in period 4 with backfat, however may be due to slower growing animals taking longer to complete test than their fast growing counterparts. Given the very high correlations of part test records for daily feed intake with overall daily feed intake, selection for high feed intake in early test would probably result in high overall feed intake. This may not be desirable as it may lead to a reduction in feed efficiency and lean percentage, although daily gain would probably be higher. The best way to limit feed intake in late test would be to impose restricted feeding for the final few weeks of test.

4.5 Conclusions

Genetic correlations between part and whole test records are high and mostly not significantly different from unity for most feeding pattern traits and daily feed intake. Genetic correlations between daily feed intake in each test period and performance test traits are not significantly different from the genetic correlation between performance test traits and daily feed intake over the whole test period. The same is true of most feeding pattern traits. It can be concluded that there is potential to shorten the test period for accurate measures of daily feed intake and feeding pattern traits.

Chapter 5

Responses to selection from indices incorporating feeding pattern traits as selection criteria

Abstract

The main aims of this chapter were to predict the increase in the accuracy of selection achieved by including feeding pattern traits as selection criteria and to investigate the effect of errors in parameter estimates for these traits on the accuracy of selection.

Genetic and phenotypic parameters were estimated for feeding pattern and performance test traits by multivariate restricted maximum likelihood with an individual animal model using data on 1832 pigs fed *ad libitum* using single space electronic feeders (Chapter 3). The feeding pattern traits were included as selection criteria in indices to improve growth rate, lean percentage and feed conversion ratio. This resulted in an increase of up to 20% in the predicted accuracy of selection for the selection objective. The greatest increases were seen in daily gain (17%) and feed conversion ratio (55%). The inclusion of part test records for feeding patterns resulted in similar predicted correlated responses and predicted accuracy of selection to those when whole test records of daily feed intake were used. The inclusion of feeding patterns as selection criteria, however resulted in indices which were less robust to inaccurate parameter estimates.

It was concluded that feeding pattern traits could be used to improve the predicted accuracy of selection, but the most effective and robust index would include only daily gain, backfat depth, daily feed intake and number of visits. They may also be useful in reducing the length of the test period necessary for accurate measures of feed intake, so increasing the potential intensity of selection on a given number of feeders.

5.1 Introduction

Selection indices can be used in improvement schemes where information is available on several traits for each animal. Even those traits which have no direct economic value may be incorporated into an index to improve the accuracy of selection. Selection indices, combining information on several traits, were proposed by Hazel (1943) as a weighted combination of observed measurements, constructed so as to maximise genetic gain. In order to construct an index, estimates of genetic and phenotypic parameters are required, as well as the economic values of traits in the selection objective. These are usually obtained from a sample of the population under study, but can be taken from previous studies. The selection criteria are the traits which are measured to predict the breeding value of the animal. The selection objective contains the traits to be improved, which are not necessarily the same as those in the selection criteria.

Selection for feed conversion ratio generally results in reduced daily feed intake (Cameron and Curran 1994). In the short term this is not a problem, but in the long term reduced feed intake can constrain further improvement in growth rate. The common method to select for feed conversion ratio is to obtain accurate measures of daily feed intake and then include this as a selection criterion in an index along with daily gain. Feeding pattern traits may provide new information which can be used to reduce this loss of daily feed intake while increasing the accuracy of selection for feed conversion ratio. Studies by Labroue *et al.* (1996) and Von Felde *et al.* (1996a,b) indicated that feeding pattern traits have little value when trying to limit the loss in daily feed intake, but may be of use in shortening the period of time we need to measure feed intake and may allow more accurate selection of performance test traits.

Sales and Hill (1976) suggested that the inclusion of economically non-important traits, such as feeding patterns, in selection resulted in the index being less robust to errors in parameter estimates. This has implications in the practical application of using these traits in selection. De Haer (1992), Von Felde *et al.* (1996a,b) and Labroue *et al.* (1996) found that feeding behaviour traits had moderate to high heritabilities and moderate genetic correlations to production traits. Correlations were higher in De Haer's and the current study, where FIRE feeders were used, than in other studies which used ACEMO feeders. An explanation for this could be that FIRE feeders, which have a more open race, result in more competition for feed as dominant pigs evict subordinates from the feeder.

The aims of this chapter were: to predict the increase in the accuracy of selection from including feeding pattern traits as selection criteria; to determine the potential for shortening the test period using feeding pattern traits; and to investigate the effect of inaccurate parameter estimates for these traits on the accuracy of selection.

5.2 Materials and Methods

5.2.1 *Predicted responses to selection when feeding pattern traits were included as selection criteria*

5.2.1.1 Effect on genetic gain of the inclusion of feeding pattern traits

Heritabilities, genetic and phenotypic correlations of feeding pattern and performance test traits were estimated by multivariate individual animal model REML using the algorithm by Groeneveld (1994) in the VCE REML version 3.2 package from Chapters 3 and 4. Estimated parameters were used to construct matrices to predict the genetic merit of certain selection indices using standard index theory (Cameron 1997), as outlined below:

P is the (co) variance matrix of the traits in the selection criteria, with elements $\mathbf{P}_{ij}$ being the phenotypic (co) variance of traits in the selection criteria.

G is the (co) variance matrix between the traits in the selection criteria and those in the selection objective, with elements $\mathbf{G}_{ij}$ being the genetic (co) variance of the traits.

C is the (co) variance matrix of the traits in the selection objective, with elements $\mathbf{C}_{ij}$ being the genetic (co) variance of traits in the selection objective

a is the vector of economic weights, with elements $\mathbf{a}_i$, where $\mathbf{a}_i$ is the relative economic weight of trait **i** in the selection objective

b is the vector of selection criterion coefficients and is estimated by the following equation: $\mathbf{b} = \mathbf{P}^{-1}\mathbf{G}\mathbf{a}$

The correlated response in the selection objective to selection on each index was predicted along with the correlation between the selection objective and the index, which is a measure of the accuracy of selection. All responses and indices were based on mass selection using only individual records. Response to selection is the product of the selection intensity (**i**), the phenotypic standard deviation and the heritability of the trait. This can be adapted for use in index selection such that the correlated response to selection in trait **j** (CR_j), measured in both the individual and relatives, can be predicted for the optimum index, in general terms, using the equation below:

$$CR_j = i \frac{b' G_j}{\sqrt{b' P b}}$$

where $\mathbf{G}_j$ is the j^{th} column of **G**

b' is the transpose of **b**

i is the selection intensity (standardised to units in this study)

Other predicted values such as the accuracy of selection (r_{ih}) (Cameron 1997), which is basically the correlation of the index with the selection objective were also obtained as shown below.

$$r_{ih} = \frac{b'\,G\,a}{\sqrt{b'\,P\,b \quad a'\,C\,a}}$$

The effect on genetic gain of including feeding pattern traits as selection criteria was predicted using various indices (Table 5.1). The first combination of traits (selection criterion 1) included backfat (BF), daily gain (ADG) and daily feed intake (DFI). Selection criterion 2 incorporated feeding pattern traits of feed intake per visit (FIV), number of visits (NV) and time per visit (TV). These traits were chosen because they had the highest heritabilities and favourable correlations with performance test traits (see Figures 3.1 and 3.2) and all other feeding pattern traits were functions of them, so would add no new information to the index. Selection criterion 3 included number of visits as the only feeding pattern trait along with daily gain, backfat and feed intake. All three of the feeding pattern traits used in criterion 2 were included separately with performance test traits (ADG, BF and DFI), but NV had the highest predicted response, so is the only one shown here.

Cameron (1997b) showed that indirect selection for feed efficiency could be more effective than direct selection. If a trait has a heritability of h^2_x and a genetic correlation with feed conversion ratio of r_a then the ratio of indirect to direct response, per unit of selection differential, is given by: $r_a\ h_x / h_{fcr}$. Genetic parameter estimates from the current study would suggest that the use of daily feed intake to select for feed conversion ratio would be less efficient than direct selection (ratio = 0.85), so feed conversion ratio was preferred to feed intake in the selection objective.

5.2.1.2 Part versus whole test records of feed intake

The relatively high cost of electronic feeders may result in a limited number of feeders being available. To maximise the use of these feeders a breeder may wish to shorten the test period to allow more pigs to be tested in a given time span. To determine the potential of shortening the test period to allow more pigs to be tested on a limited number of feeders, part test records of feeding patterns and feed intake were also included as selection criteria. Criteria 4 and 5 (Table 5.1) include the same traits as criterion 2 but feed intake and feeding patterns were only from periods 1 and 3 of test respectively.

Responses to selection on part test records were predicted along with those for whole test records. To estimate the most effective way to utilise a limited number of feeders responses to selection were also predicted for three different breeding programmes. All three scenarios were assumed to be a multi-site nucleus with a central test station containing 30 FIRE feeders. All were assumed to require 50 boars for replacement and sale every eight weeks, so the proportion selected would be 50/*n* where *n* is the number of pigs tested

The first programme had 30 FIRE feeders and tested pigs on these feeders over an eight-week test period. All selected pigs were tested on FIRE feeders, with twelve pigs per feeder. This allowed 360 pigs to be tested every eight weeks. The second programme also had 30 FIRE feeders but used a test period, on the feeders, of three weeks, but still tested daily gain and backfat for 8 weeks on each unit (5 weeks prior to test on feeders). This allowed 900 pigs to be tested on the feeders over the eight-week period, so increasing the selection intensity. The final scenario did not use FIRE feeders, but tested pigs for daily gain and backfat over eight weeks. As the number of feeders did not limit test capacity in this case the selection intensity (number of animals tested) was assumed to be equal to the second scenario (*i.e.* 900 pigs tested). All these responses were predicted using selection objective 1.

5.2.1.3 Response to different selection objectives

Three selection strategies were used with these selection criteria. The first was a traditional index to select for a combination of feed efficiency and lean growth. The latter two objectives select, indirectly, for lean tissue growth rate (LTGR) and lean tissue feed conversion ratio (LTFC) respectively. Selection objectives 2 and 3 were weighted to achieve approximately equal response in each of the two traits in the selection objective, so for example $\frac{\mathrm{CR}_{\mathrm{adg}}}{\sigma_{\mathrm{adg}}} = \frac{\mathrm{CR}_{\mathrm{lean}}}{\sigma_{\mathrm{lean}}}$ in selection objective 2. The relative economic weights of traits in each selection objective are outlined overleaf:

	Daily gain (kg)	Lean percentage (%)	Feed conversion ratio (kg/kg)
Selection objective 1	40	0.7	-10
Selection objective 2 (LTGR)	40	1.3	0
Selection objective 3 (LTFC)	0	0.4	-10

All criteria were tested with all selection objectives, which resulted in predicted genetic gains from eighteen different indices. Indices were individually optimised with respect to genetic gain in the usual way.

5.2.2 *Selection including family records in the selection criteria*

Responses and indices for criteria 1 to 6 were based on mass selection using only individual records. Pigs however are not selected solely on phenotype, so genetic gains for indices A, B and C were also predicted. All three indices contained information on full sibs, half sibs and sires as well as the individual. Index A had information for daily gain and backfat only, index B also had records for daily feed intake and index C included number of visits (see Table 5.1). These three indices all used selection objective 1.

Genetic and phenotypic parameter estimates from previous chapters were used to construct indices including variance and co-variance components for an index including a record on the individual, four full sib records, a sire record and twenty half sib records (sib means did not include the individual). The different indices were based on situations which may be found in practice. Index A being a nucleus unit where feed intake was not recorded. Index B a nucleus unit where feed intake was recorded, but feeding patterns were not. Index C represents a nucleus unit where animals were tested on electronic feeders and records of feeding patterns were used.

The **P** and **G** matrices calculated in the previous sections account only for records on the individual so do not include information from sibs. The method for calculating the (co) variance components of matrices including the mean of n sib records, with the individual excluded, is explained by Cameron (1997) and a summary of this is shown below. In the equations for elements of the matrices the three traits have been coded as follows: 1, daily gain (ADG); 2, backfat depth (BF); 3, lean percentage (L%). The terms σ^2_p, σ^2_a and σ^2_c denote phenotypic, genetic and common litter variance respectively. These matrices were used to predict the accuracies of selection (r_{ih}) for each index using selection objective 1 only. The results are shown in Table 5.5.

Elements in **P**:

	ADG$_I$	BF$_I$	ADG$_{sib}$	BF$_{sib}$
ADG$_I$	$\sigma_{P_1}^2$	$\sigma_{P_{12}}^2$	$t_1 \sigma_{P_1}^2$	$r\sigma_{a_{12}} + \sigma_{c_{12}}$
BF$_I$		$\sigma_{P_2}^2$		$t_2 \sigma_{p2}^2$
ADG$_{sib}$			$\left(t_1 + \frac{1 - t_1}{n}\right)\sigma_{P_1}^2$	$\frac{\sigma_{P_{12}}}{n} + \frac{n - 1}{n}(r\sigma_{a_{12}} + \sigma_{c_{12}})$
BF$_{sib}$				$\left(t_2 + \frac{1 - t_2}{n}\right)\sigma_{P_2}^2$

Elements in **G**:

	ADG$_I$	L%$_I$
ADG$_I$	$\sigma_{a_1}^2$	$\sigma_{a_{13}}$
BF$_I$	$\sigma_{a_{21}}$	$\sigma_{a_{23}}$
ADG$_{sib}$	$r\sigma_{a_1}^2$	$r\sigma_{a_{13}}$
BF$_{sib}$	$r\sigma_{a_{21}}$	$r\sigma_{a_{23}}$

where, for example:

ADG$_I$ is the measurement on the individual

ADG$_{sib}$ is the mean of n sibs (excluding the individual)

t is the intra-class correlation between full or half sibs

t for full sibs = $r h^2 + c^2$ (r for full sibs = ½)

t for half sibs = $r h^2$ (r for half sibs = ¼)

Table 5.1 *Summary of traits included in selection criteria*

	Traits measured													
	Individual						Full sib mean				Half sib mean and sire record			
Criterion	ADG	BF	DFI	FIV	NV	TV	ADG	BF	DFI	NV	ADG	BF	DFI	NV
1	✓	✓	✓											
2	✓	✓	✓	✓	✓	✓								
3	✓	✓	✓		✓									
$4_{(1)}$	✓	✓	✓	✓	✓	✓								
$5_{(3)}$	✓	✓	✓	✓	✓	✓								
6	✓	✓												
Index A	✓	✓					✓	✓			✓	✓		
Index B	✓	✓	✓				✓	✓	✓		✓	✓	✓	
Index C	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓

(1) DFI , FIV, NV, TV only recorded in test period 1 (3) DFI, FIV, NV, TV only recorded in test period 3

5.2.3 *Effect of incorrect parameter estimates on the accuracy of selection*

The accuracy of the selection criterion for a given selection objective will be maximised when the index is constructed using the precise genetic and phenotypic parameter values. In practice this is unlikely to happen as all parameter estimates are based on samples from the population and are subject to errors. Traits in the selection criteria differ from those in the selection objective when the economically important traits (those in the selection objective) cannot be measured directly (*e.g.* sex limited) or which have low heritability, such as litter size. Sales and Hill (1976) determined that indices with many economically non-important traits were less robust to inaccurate parameter estimates. The advantage of including economically non-important traits in the selection criteria depends largely on the genetic correlations with traits in the selection objective, so there is a need for reliable estimates of genetic and phenotypic parameters. The differences between estimated and actual genetic and phenotypic parameters will therefore have an effect on the accuracy of selection and the predicted response to selection. For the estimated parameters the predicted accuracy of selection ($\hat{r}_{ih}$) is given by the following equation:

$$\hat{r}_{ih} = \frac{\hat{b}'\,\hat{G}\,a}{\sqrt{\hat{b}'\,\hat{P}\,\hat{b}\quad a'\,\hat{C}\,a}}$$

However the actual accuracy of selection from these estimated parameters (r_{ih}^{*}) is:

$$r_{ih}^{*} = \frac{\hat{b}'\,G\,a}{\sqrt{\hat{b}'\,P\,\hat{b}\quad a'\,C\,a}}$$

Where: $\hat{b}$ $\hat{P}$ $\hat{G}$ $\hat{C}$ are the estimated genetic and phenotypic (co) variance matrices

b P G C are the true genetic and phenotypic (co) variance matrices

$$\hat{b} = \hat{P}^{-1}\hat{G}a$$

Biases in the parameter estimates of ±0.1 were used to examine the sensitivity of the selection indices to changes in the parameters. Genetic and phenotypic correlations were changed in the same direction (*i.e.* both + or - 0.1). The loss in the accuracy of selection, due to the difference in these parameters (Sales and Hill 1976), was calculated by:

$$\text{loss in accuracy} = 1 - \frac{r_{ih}^{*}}{r_{ih}}$$

5.3 Results

5.3.1 *Predicted responses to selection*

5.3.1.1 Effect on genetic gain of the inclusion of feeding pattern traits

Predicted correlated responses, using the estimated parameters in the indices, are shown in Figures 5.1 to 5.3. The inclusion of feeding pattern traits in the indices (selection criteria 2 and 3) resulted in a higher response in daily gain and feed conversion ratio but a decrease in the response of lean percentage. The predicted difference in daily gain between criterion 2 and criterion 1 was only 3 g/day with a small loss in lean percentage (Table 5.2). These differences are unlikely to be of economic importance, but if daily feed intake was not measured (criterion 6) then there was a considerable decrease in response of all traits particularly feed conversion ratio.

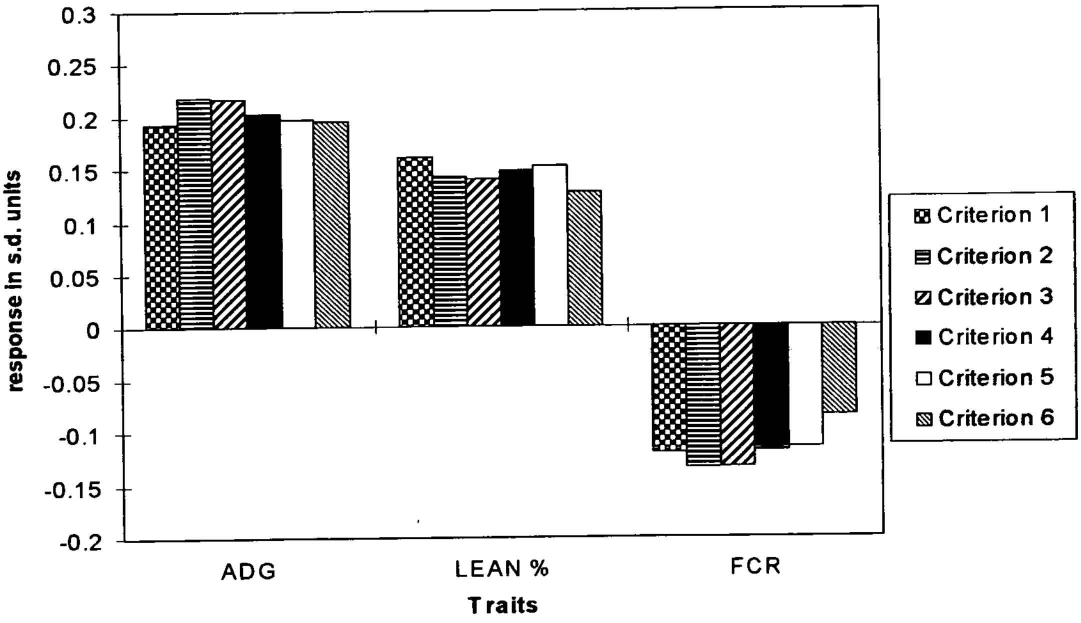

Figure 5.1 *Predicted correlated response (in selection differential units) of traits in selection objective 1(ADG, L%, FCR) to selection on each of the six criteria.*

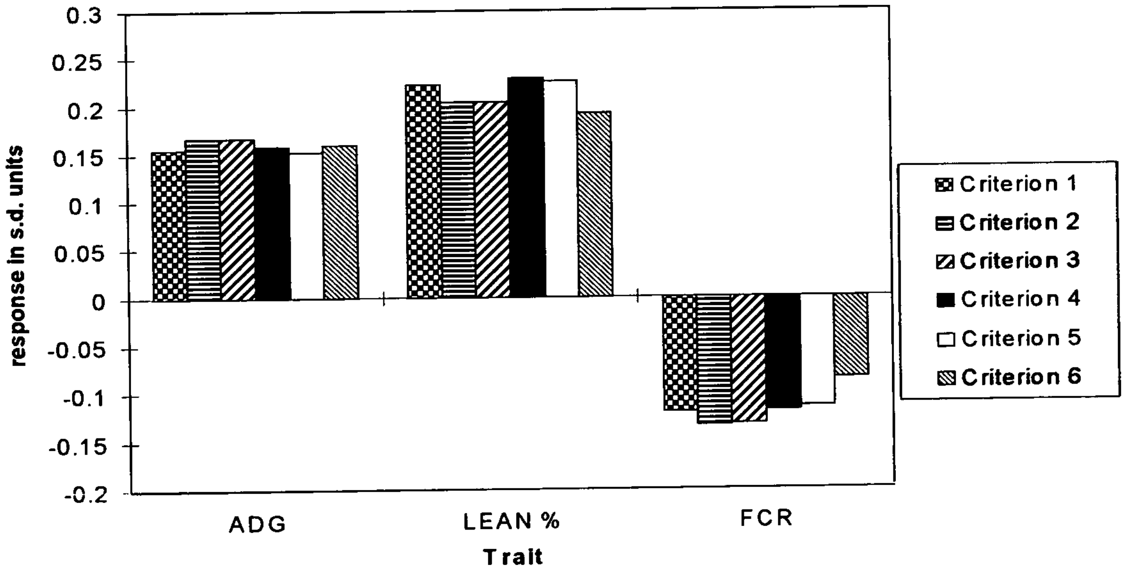

Figure 5.2 *Predicted correlated response (in selection differential units) of traits in selection objective 2 (ADG, L%) to selection on each of the six criteria*

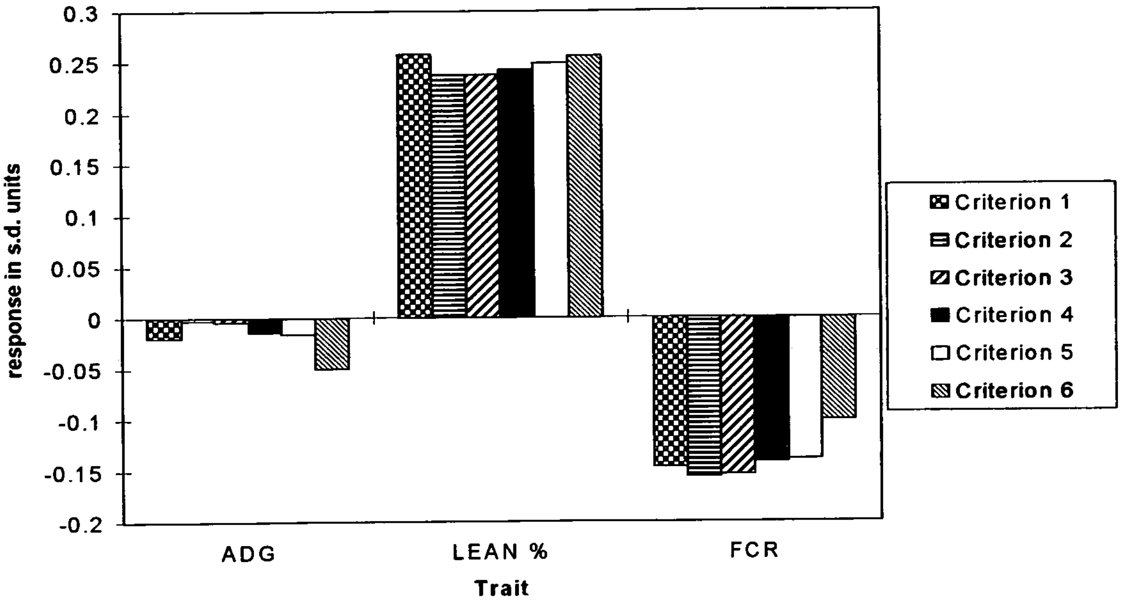

Figure 5.3 *Predicted correlated response (in selection differential units) of traits in selection objective 3 (L%, FCR) to selection on each of the six criteria*

Table 5.2 shows the correlation of each selection objective with each index, which is a measure of the accuracy of selection. These correlations showed a similar pattern to that seen in Figures 5.1 to 5.3 indicating that the most accurate selection was achieved when feeding pattern traits and daily feed intake were included in the selection criteria. The use of feeding pattern traits resulted in up to a 10% increase in the accuracy of selection (criterion 2 versus criterion 1). The last criterion (6) in Table 5.2 shows the predicted accuracy of selection for the selection objective if only daily gain and backfat were included as criteria. This correlation was considerably lower than all other estimates.

5.3.1.1 Part versus whole test records of feed intake

The inclusion of part test records for feeding pattern traits (selection criteria 4 and 5) resulted in little difference in predicted genetic gain, or the accuracy of selection, from the original criterion (criterion 1) of daily gain, backfat and feed intake (Table 5.2 and Figures 5.1 to 5.3). This suggests that it may be possible to shorten the test period required for accurate measurements of feed intake. If a limited number of feeders were available for testing this would enable the breeder to increase the selection intensity on the feeders.

Figure 5.4 shows the comparative responses of three different testing strategies on a limited number of feeders. The use of a three-week test period versus a full eight-week test period, to increase selection intensity, resulted in a 13% predicted increase in response of daily gain (equal to 7g/day improvement). The responses in lean percent and feed conversion ratio were also higher for the shorter test period (26% and 9.4% respectively). The use of FIRE feeders over a shorter test period was also more effective than testing all animals on growth alone (*i.e.* without FIRE feeders). However, when test capacity on the feeders was limited and pigs were tested for the full eight weeks the extra genetic gain, due to higher accuracy of selection provided by the feeders, was lost by the reduction in selection intensity (8 week test vs. no feeders).

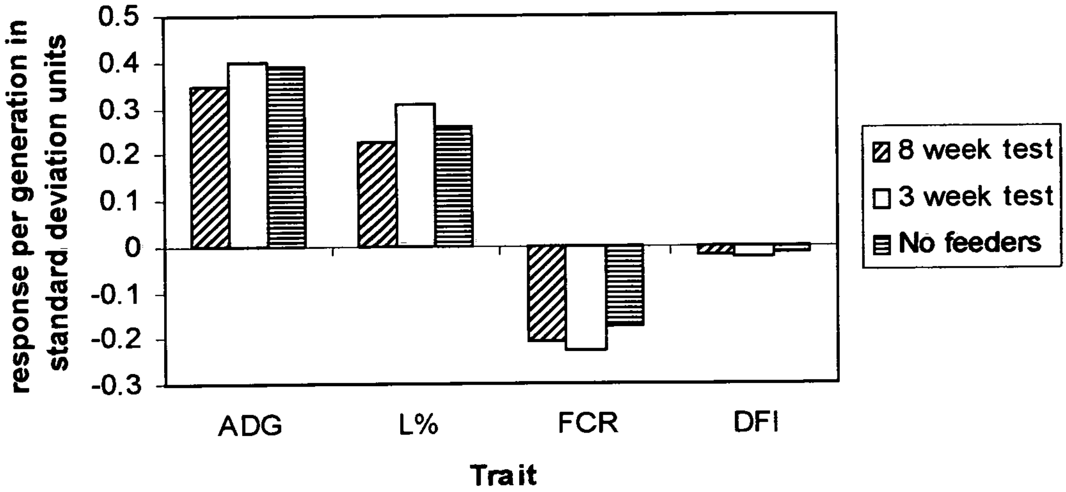

Figure 5.4 *Predicted responses (in standard deviation units) to selection on objective 1 for three different test scenarios.*

5.3.1.2 Response to different selection objectives

There was little difference in genetic gain for all traits between selection objectives 1 and 2, which both included lean growth rate. All selection objectives predicted large responses in feed conversion ratio, although this was apparently achieved by different methods. Table 5.2 indicates that selection objectives 1 and 2 resulted in an increase in daily gain of approximately 25 g/day with a small decrease in feed intake of 2 to 10 g/day, hence decreasing feed conversion ratio. Selection objective 3, however resulted in predicted losses in daily gain (2 to 6 g/day) with high responses in lean percentage and feed conversion ratio and large reductions in feed intake (approx. 45 g/day).

The inclusion of feeding patterns as selection criteria added less extra genetic gain for selection objective 3 than for the other objectives. Selection for all objectives improved feed conversion ratio, but selection for objective 3 achieved this mainly by reducing feed intake whereas selection for objectives 1 and 2 reduced feed conversion mainly by increasing daily gain, which is more desirable in the long term.

Table 5.2 *Accuracy of selection* (r_{ih}) *for each index and predicted genetic gain in each trait*

	Selection objective	r_{ih}	ADG g/d	Lean %	FCR kg/kg	DFI g/d
Criterion 1	1	0.51	25.1	0.330	-0.028	-1.62
	2	0.55	20.2	0.455	-0.030	-2.70
	3	0.52	-2.60	0.529	-0.034	-43.2
Criterion 2	1	0.57	28.3	0.293	-0.030	-3.24
	2	0.59	21.6	0.418	-0.031	-11.7
	3	0.53	-0.39	0.488	-0.036	-48.6
Criterion 3	1	0.55	28.2	0.299	-0.031	-3.24
	2	0.58	21.6	0.418	-0.030	-11.6
	3	0.53	-0.52	0.488	-0.035	-48.6
Criterion 4	1	0.50	26.4	0.303	-0.027	-3.78
	2	0.54	20.5	0.469	-0.028	-12.9
	3	0.53	-1.82	0.498	-0.033	-56.7
Criterion 5	1	0.51	25.7	0.312	-0.026	-3.51
	2	0.53	19.8	0.463	-0.025	-12.7
	3	0.52	-2.08	0.510	-0.032	-54.0
Criterion 6	1	0.46	25.3	0.262	-0.020	-2.16
	2	0.51	20.6	0.394	-0.022	-3.78
	3	0.40	-6.50	0.525	-0.023	-40.5

r_{ih} *is the correlation between the selection objective and the index*

see Table 5.1 for traits in selection criteria

5.3.2 *Selection including family records in the selection criteria*

The predicted accuracy of selection and predicted genetic gain, when information from relatives was included in the selection criterion, is presented in Table 5.4. The highest predicted genetic gain was obtained by including more information from all relatives (Index C). The largest increase in predicted genetic gain was noted for feed conversion ratio (33%), with only small changes for lean percentage and daily gain. The inclusion of sib and individual records of feed intake and feeding patterns in indices B and C resulted in 10 to 15% more predicted overall genetic gain than an index with only individual records.

Table 5.4 *Predicted accuracy of selection (r_{ih}) and predicted genetic gain in each trait of each index with selection objective 1*

	r_{ih}	*ADG (g/day)*	*Lean (%)*	*FCR (kg/kg)*
Index A	0.60	30.2	0.295	-0.024
Index B	0.64	31.3	0.330	-0.028
Index C	0.71	34.6	0.306	-0.032

5.3.3 *Effect of incorrect parameter estimates on the accuracy of selection*

The losses in the accuracy of selection, due to errors in parameters estimates, are presented in Figures 5.5 to 5.10. Criterion 1 showed little difference in the accuracy of selection with differing parameter estimates for daily gain or daily feed intake, with losses of approximately 2%. The accuracy of selection when using criterion 2, however was reduced by up to 12% due to incorrect parameter estimates, especially when the estimated genetic correlations of one or all feeding pattern traits were increased (Figures 5.9 and 5.10). Higher losses of the accuracy of selection (up to 5%) were also observed for criterion 2 with inaccurate parameter estimates of daily gain and daily feed intake. Daily feed intake resulted in less reduction of predicted accuracy of selection than feeding pattern traits. Daily feed intake also has the highest genetic correlations with traits in the selection objective. If a trait contributes little useful information then the errors in estimated parameters of that trait are more likely to lead to wrong decisions in selection because of possible changes in breeding value ranking especially for a multi trait selection objective. This is supported by the results of Sales and Hill (1976).

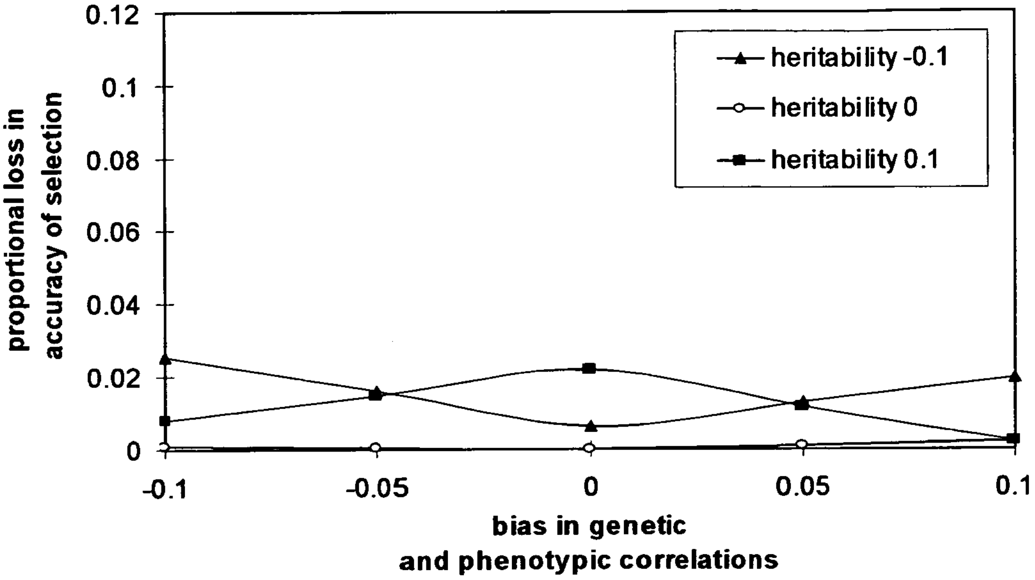

Figure 5.5 *Loss of genetic gain from bias in ADG parameter estimates in criterion 1*

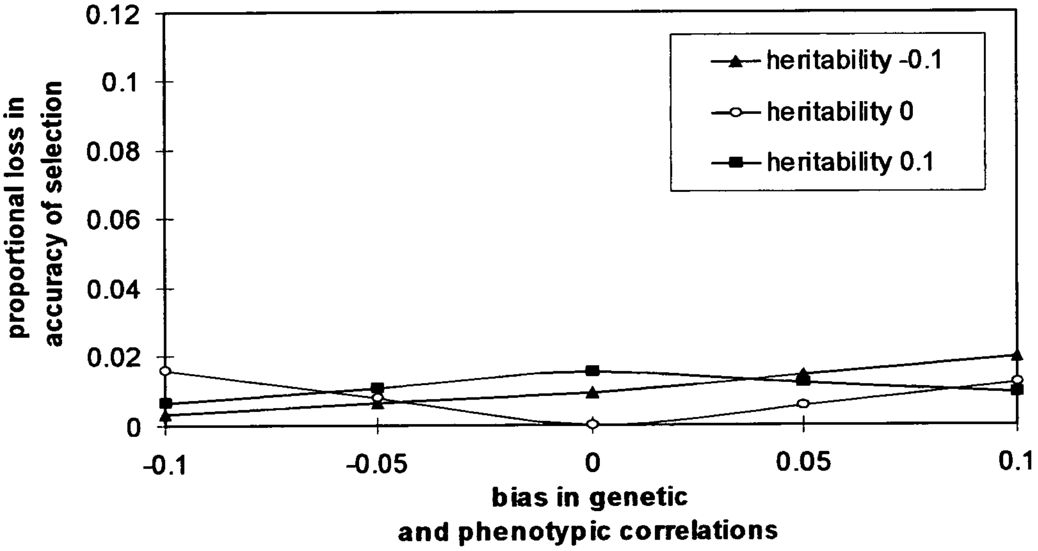

Figure 5.6 *Loss of genetic gain from bias in DFI parameter estimates in criterion 1*

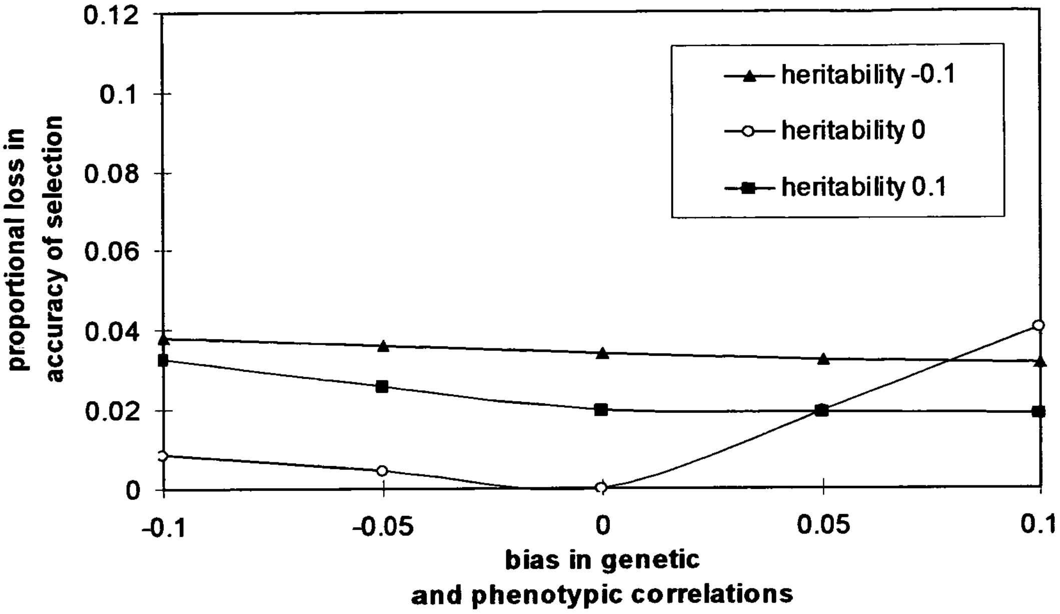

Figure 5.7 *Loss of genetic gain from bias in ADG parameter estimates in criterion 2*

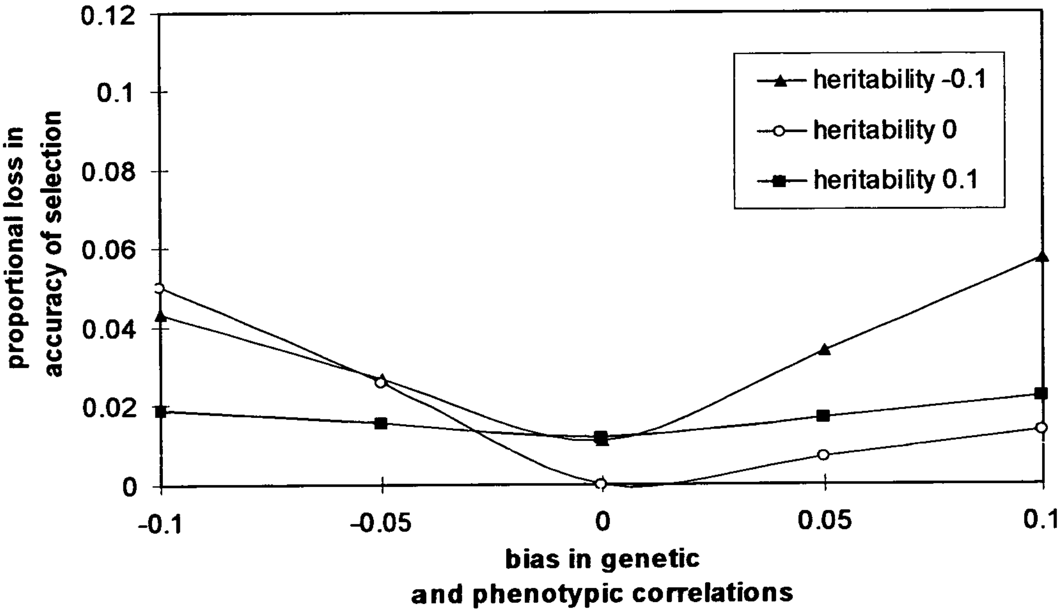

Figure 5.8 *Loss of genetic gain from bias DFI parameter estimates in criterion 2*

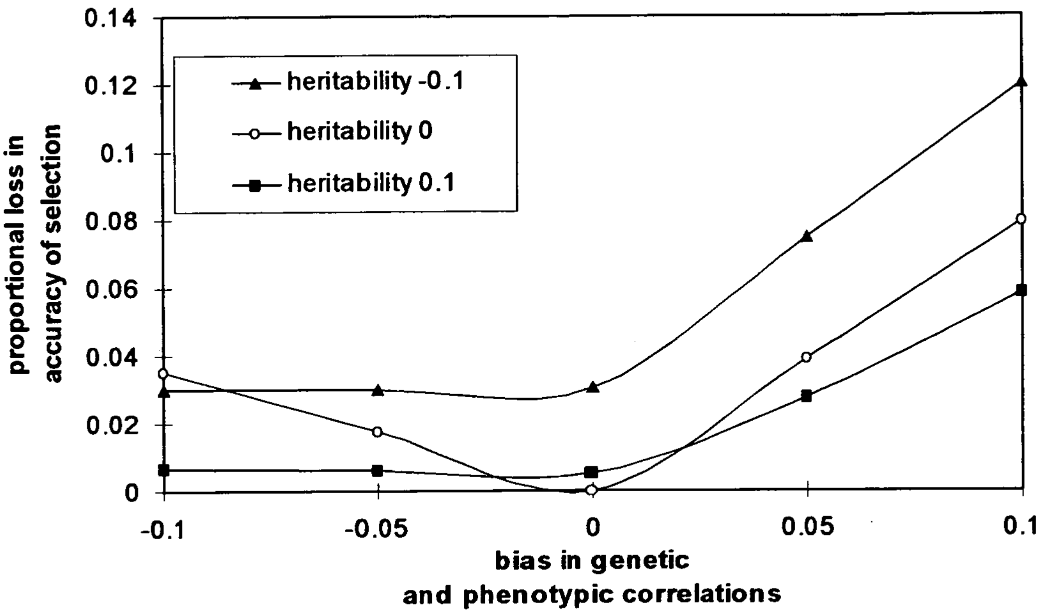

Figure 5.9 *Loss of genetic gain from bias parameter estimates of all feeding pattern traits in criterion 2*

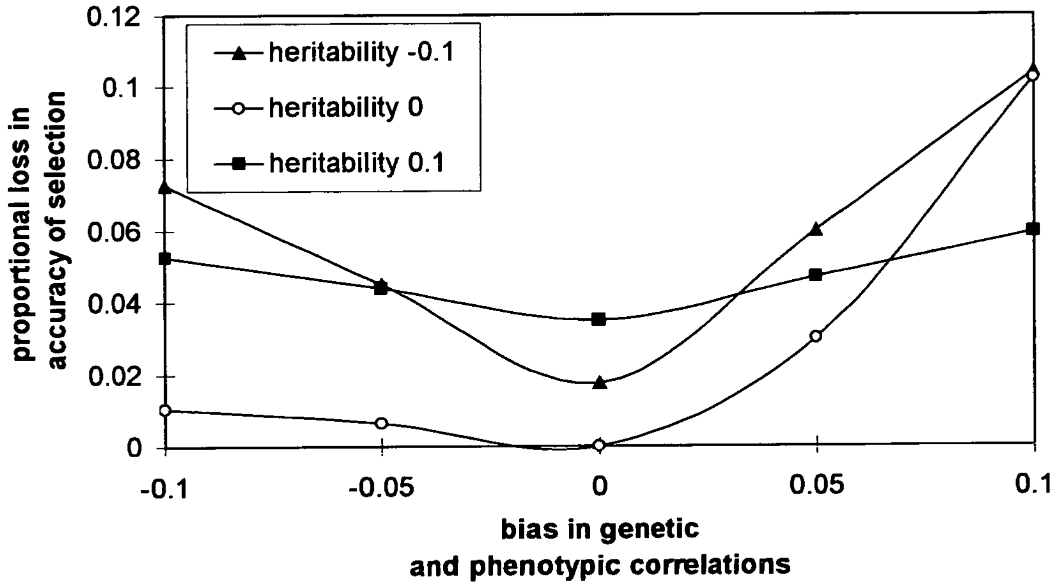

Figure 5.10 *Loss of genetic gain from bias in NV parameter estimates in criterion 2*

In the results presented r_g and r_p were changed in the same direction and magnitude. If the estimate of r_g was increased and r_p decreased, or *vice versa*, with heritability remaining the same, then greater losses in the accuracy of selection were noted.

5.4 Discussion

The inclusion of daily feed intake and feeding pattern traits as selection criteria (criteria 2 to 5) resulted in an increase in predicted overall genetic gain by up to 19% compared to 11% when only daily feed intake was included. There was little difference in the responses to selection in each trait for criteria 2 and 3 for all selection objectives. This indicates that it is not necessary to include all feeding pattern traits as criteria because similar gain can be achieved by including only number of visits per day.

The increase in genetic gain provided by the inclusion of daily feed intake and feeding pattern traits was due to more accurate selection for feed conversion ratio and daily gain. The use of feeding pattern traits and daily feed intake gave up to 50% greater predicted genetic gain in feed conversion ratio than if no record of feed intake or feeding patterns was included, but feeding patterns only provided an advantage of 6% genetic gain over including only daily feed intake. The predicted response in daily gain also changed as feeding patterns were included in the index with feeding patterns providing an extra 7% genetic gain over the inclusion of feed intake alone. Predicted response in daily gain was highest for criterion 2 and was up to 11% higher than criteria without daily feed intake or feeding pattern traits.

The predicted genetic gain for criteria 4 and 5 were similar to that for criterion 1. There was also little difference in the accuracy of selection of each trait in the selection objectives between these three criteria. This suggests that there is potential to shorten the test period necessary to attain accurate measures of daily feed intake and hence select effectively for feed conversion ratio. Both criteria 4 and 5 have records of feed intake and feeding patterns in only one test period. In theory the test period could be shortened to two weeks, but Nielsen (1995) indicated that the pigs require at least one week to adapt to the new feeding system and establish a social hierarchy, so the minimum test period would be at least three weeks. This reduction in the length of test would allow more pigs to be tested on a given number of feeders so making them more cost effective and increasing the potential selection intensity.

A new, two stage selection strategy could be developed where pigs are measured for growth rate and backfat up to, for example, 65 kg then the best animals could be selected for test on the FIRE feeders for a further 3 week test period. The results in Section 5.3.1.2 suggest that this shortened test period is the most effective way to utilise a limited number of feeders, although to achieve maximum genetic gain in an ideal situation (where feeders are not limited) all pigs should be tested on FIRE feeders for the entire test period.

A selection objective for lean growth rate (selection objective 2) or a combination of lean growth and efficiency (objective 1) appears to be more effective than selecting for lean tissue feed conversion (selection objective 3). The latter objective results in reduced daily gain and lower daily feed intake, which in the long term, could limit further improvements in lean growth, whereas responses in the first two objectives are all beneficial. Selection objectives 1 and 2 both gave similar accuracy of selection and responses to selection for all combinations of traits in the selection criteria. This suggests that the inclusion of feed conversion ratio in the selection objective may not be necessary to achieve desired genetic gains in all traits of interest. This may be advantageous due not only to the cost of measuring feed intake to predict feed conversion, but also in reducing possible errors in selection due to inaccurate parameter estimates of selection criteria.

Selection for lean feed conversion (objective 3) resulted in greatly reduced feed intake and consequently a negative response in daily gain. This would be an undesirable situation in practice, but may be corrected by restricting change in feed intake to zero in the selection objective.

It would appear from these results that the most effective method of selection would be for lean growth rate, via selection objective 1 or 2. This results in favourable responses in all economically important traits, although responses in feed conversion ratio and lean percentage are lower than when selecting for lean feed conversion (selection objective 3). Selection objective 2 had a higher accuracy of selection for all criteria than the other objectives, so may be preferred to objective 1. The most effective selection criterion is criterion 3, which includes daily gain, backfat, daily feed intake and number of visits. Criterion 2 was no more effective, so was rejected in favour of criterion 3 because the former included more feeding pattern traits which could lead to more errors.

Although it appears that the inclusion of feeding patterns as selection criteria is beneficial Figures 5.5 to 5.10 indicate that an index with many non-economically important traits, such as feeding pattern traits, will be less robust to inaccurate parameter estimates. Sales and Hill (1976) showed that, for identically distributed traits, the loss in genetic gain, due to inaccurate parameter estimates, was proportional to the number of non economically important traits added to the index, so although deletion of a trait from the selection criteria may be predicted to reduce the efficiency of the index, if the parameter estimates are poor, then the efficiency of the partial index may be higher than that of the full index. This would again indicate that the traits in criterion 3 would be a better than those in criterion 2.

5.5 Conclusions

The increase in genetic gain and accuracy of selection, for the given selection objective, of up to 20%, provided by these traits could be of commercial interest. The most effective and robust method would be to include records of number of visits as the only feeding pattern in the selection criteria to reduce the chance of imprecise predicted responses due to inaccurate parameter estimates.

Selection criteria 4 and 5, which included part test records of feed intake and feeding patterns, also show that shortening the test period for feed intake measurements would be possible with a small loss (2%) of genetic gain or accuracy. This would allow a reduction in capital costs as less feeders would be needed to test a given number of pigs. There is also the potential to increase the selection intensity, by shortening the test period to three weeks and hence testing more pigs on a limited number of feeders. This can provide predicted responses in the traits of interest by up to 20% more than testing over the full eight weeks.

If the selection objective is mainly for lean growth rate (objective 2), then the inclusion of daily feed intake and feeding pattern traits as selection criteria adds less efficiency to the index than for other objectives. Lean growth is a more efficient selection objective than lean feed conversion as the former results in favourable responses in all traits of interest. However lean growth rate can only be predicted in the live animal, so a multi-trait selection objective, to select indirectly for lean growth, would be preferable.

Chapter 6

Feeding order and the affect of the social environment within a pen on feeding pattern traits

Abstract

The aims of the studies reported in this chapter were to determine if feeding order within a pen was a non random, constant behaviour and to determine if the social and physical environment within a pen may adversely affect feeding pattern traits, which may also influence performance test traits.

Boars were kept in pens of 12 individuals between 45 and 95 kg liveweight. They were fed *ad libitum* at electronic feeders. Feed intake and feeding pattern traits, such as number and size of meals per day, were recorded. Weekly records of feed intake, as recorded by the FIRE feeder, were taken for ten pens and the order in which pigs entered the feeder during the day was derived from this raw data for weeks 2, 4 and 6 of test in each of the ten pens. A Chi-square analysis was then undertaken on each weekly record of each pen and between weekly records within each pen to test if feeding order was random and constant over time. Feeding order was found to be a non-random behaviour which varied during the test period, so was not considered a good predictor of social dominance within a pen.

In a separate analysis, variance components of sibs between and within pens were estimated, by REML, for feeding pattern and performance test traits using data on 1410 boars. Sibs in the same pen had more similar feeding patterns, particularly time in the feeder, than sibs in different pens. There were also differences in feeding rate and number of non-feeding visits. Variance components of feed intake and growth traits were not affected by pen. However, these differences in the variance components of feeding

behaviour were also noted in non-related animals within and across pens such that any animal, whether related or not, was more likely to behave like other members of its pen than pigs in other pens. This suggests that a specific pen of animals may change their behaviour according to the social environment within that pen without reducing their feed intake or growth.

6.1 Introduction

In addition to their use in providing information on feeding patterns in group housed pigs, electronic feeders can also provide the opportunity to measure the effect of social factors, such as evictions from the feeder, on feeding behaviour within a pen. Feeding behaviour in pigs has been shown, by several authors, to be strongly affected by social factors. Social interactions within a group can affect feed intake in two ways. Firstly social facilitation (seeing other pigs eating) can result in increased feed intake and may cause peaked distribution of feeding behaviour (Nielsen *et al.* 1995, De Haer and Merks 1992, Hsia and Woodgush 1983), also seen in Figures 2.1 and 2.2 in this study. Secondly agonistic behaviour may lead to a reduced feed intake in subordinate pigs (De Haer and Merks 1992). Hansen *et al.* (1982) found that dominant pigs tend to spend longer in the feeder and may occupy the feeder without eating in order to defend it from subordinate penmates.

Evidence from studies by Nielsen *et al.* (1995b), Von Felde *et al.* (1996a,b) and Labroue *et al.* (1996) suggested that if pigs are protected from dominant pen mates during a feeding visit, such as in the ACEMO feeding system, then these visits will be longer, fewer and result in more feed intake per visit. Another study by Nielsen *et al.* (1996) also indicated that open race single-spaced feeders, which allow eviction from the feeder, may result in restricted feed intake when compared to group housed pigs fed from a multi-spaced trough. This reduction in feed intake may be due to subordinate pigs being evicted from the feeder by dominant penmates, which may then defend the feeder. Other studies by Nielsen (1995) suggested, however that there was no correlation between social rank and feeding patterns or feed intake.

The aims of this study were firstly to determine if feeding order within a pen was a non random behaviour. If so it may be a good predictor of social dominance within a pen, which may help explain some of the variation in feeding pattern traits. The second aim was to determine if the social and physical environment within a pen may adversely affect feeding pattern traits and so also influence performance test traits. This was done by estimating the differences in variance components of sibs between and within pens to estimate any possible genotype by pen interaction. If these variances are similar then it can be assumed that the interaction does not occur.

6.2 Materials and Methods

6.2.1 *Data*

There were data for 1410 boars in this study. Boars were put on test, at weekly intervals, in pens of 12 (s.d. 0.87), at an average weight of 45 kg (s.d. 2.76). All penmates were removed from test, at weekly intervals, when the majority of individuals in the pen reached 95 kg (s.d. 6.78). Each sire contributed, approximately, 22 male progeny, which were tested on the FIRE feeders. This gives a mean (male) 'sire family' size of 21.9 (s.d.

10.7). The mean size of (male) full sib families, tested on the FIRE feeders, was 3.04 (s.d. 1.84). Full and half sibs were randomly assigned to pens, although most full sibs started test in the same week. Each pen contained, on average, 4.8 (s.d. 0.93) half sibs (*i.e.* from the same 'sire family'). Of these half sibs within each pen, approximately 2.5 (s.d. 0.88) were full sibs. For example the pen outlined below has two half sib groups of sizes five and three respectively and a full sib group of size three and the rest are unrelated individuals.

Example pen (pigs numbered 1-10):

|——half sibs——| |—half sibs—|

1 2 3 4 5 6 7 8 9 10

|—full sibs—|

The data structure is summarised in Table 6.1.

Table 6.1 *Summary of data structure*

	mean	*s.d.*
Size of half sib family	21.9	10.7
Size of full sib family	3.04	1.84
Mean number of half sibs in a pen	4.80	0.93
Mean number of full sibs in a pen	2.46	0.88

6.2.2 *Feeding order*

Weekly records of feed intake, as recorded by the FIRE feeder, were taken for ten pens. These data provided information on the number of times each pig visited the feeder in each day and week and the order in which they fed (Table 6.2). The order in which pigs entered the feeder during the day was recorded for weeks 2, 4 and 6 of test in each pen. This was done by recording the number of times a specific pig followed another pig into the feeder, so in the example below (Table 6.2) pig number 13 has followed pig number 144 into the feeder twice.

Table 6.2: *Example of FIRE output*

Animal Tag	Pen	Date	Time in Feeder	Time out of Feeder	Feed (kg)
126	12	10/06/95	07:55:31	07:58:40	0.1073
144	12	10/06/95	08:04:12	08:08:27	0.1924
13	12	10/06/95	08:10:53	08:14:02	0.2721
28	12	10/06/95	08:12:14	08:18:15	0.2134
289	12	10/06/95	08:22:54	08:24:23	0.1471
144	12	10/06/95	08:25:12	08:32:46	0.2682
13	12	10/06/95	08:32:57	08:35:05	0.1673

There were approximately 1000 to 1400 visits for each pen over the three weeks. Data were then incorporated into a contingency table, with the first pig in the feeder being in the first column, as outlined below (Table 6.3). Records of a pig following itself into the feeder were ignored.

Table 6.3 *Example of observed values in contingency table for feeding order*

Pig Tag Number	219	122	376	392	208	176	87	82	282	163	*Row Totals*
219		4	4	3	5	4	1	4	6	0	*31*
122	2		4	8	7	4	6	6	6	4	*47*
376	3	6		3	2	2	4	2	3	2	*27*
392	4	10	3		5	2	2	7	1	1	*35*
208	3	8	3	10		5	8	2	6	6	*51*
176	3	3	3	1	9		2	2	3	7	*33*
87	4	4	6	2	10	4		1	2	4	*37*
82	5	6	1	0	1	7	6		4	3	*33*
282	4	3	4	5	6	4	5	1		3	*35*
163	5	4	0	2	5	3	2	6	2		*29*
Column Totals	*33*	*48*	*28*	*34*	*50*	*35*	*36*	*31*	*33*	*30*	***358***

Estimates of expected frequency of one pig following another into the feeder were calculated using a modification of the Deming-Stephan iterative proportional fitting procedure (Bishop *et al.* 1980) for quasi-independence as outlined below. Initial values were estimated in the usual way. For example the initial expected frequency of pig 122 following pig 219 into the feeder would be: $m_{12}^{(0)} = \dfrac{31 \times 48}{358} = 4.16$

At the v^{th} cycle of the iteration (for all cells):

$$m_{ij}^{(2\nu-1)} = \frac{m_{ij}^{(2\nu-2)}\, x_i}{\sum m_{ik}^{(2\nu-2)}} \qquad \text{and} \qquad m_{ij}^{(2\nu)} = \frac{m_{ij}^{(2\nu-1)}\, x_j}{\sum m_{kj}^{(2\nu-1)}}$$

where m_{ij} is the expected frequency, x_i is the observed row total, x_j is the observed column total, Σm_{ik} and Σm_{kj} are the expected row and column totals, of each iteration, respectively. Iterations were continued until $(x_i - \Sigma m_{ik}^{(2\nu-2)})$ and $(x_j - \Sigma m_{kj}^{(2\nu-1)}) \leq 0.001$

Degrees of freedom for quasi-independence are given by $(r-1)(c-1)-z_e$ were r is the number of rows, c the number of columns and z_e the number of cells with zero probability.

The randomness of feeding order was tested by Chi-square analysis, with the null hypothesis being that the observed feeding order was not significantly different from the expected (random) distribution. This was performed for each week in each pen and on each pen pooling information from all three weeks. This tested if feeding order was random within weeks and over the entire test period. The stability of feeding order over the test period was also tested by pooling the data from all three weeks for each pen. If the feeding order was the same over the three weeks we would expect the chi-square value to increase such that the sum of the chi-square values for the three weeks separately minus that for the three weeks pooled would be no more than expected from the difference in degrees of freedom.

6.2.3 *Estimation of variance components between and within pens*

Social factors have been shown to significantly affect feeding patterns by several authors (Nielsen *et al.* 1995, Hsia and Woodgush 1983, Hansen *et al.* 1982). In order to test if a genotype by pen interaction existed in these data the variance components of sire families within pens were compared with the variance components of entire sire families. This was done using two analyses, the first assessing the degree of resemblance between sire families, the second assessing that between sire families within pens. The second model allows differences between sires to vary from pen to pen; the first does not. Thus differences in the estimates of between group components of variance for the two models would indicate a sire family by pen interaction.

In the first analysis groups were defined as entire sire families, in the second sire families within pens.

Variance components of sire families, from data on all 1410 boars, were estimated using the algorithm in Genstat REML version 5.3 (Genstat committee 1989) of feeding patterns from both models were calculated. A simple ANOVA method could not be used because sires did not have records in every pen. If sire families within a pen have a similar between group component of variance to sire families crossed with pens then there would be no significant effect of pen on feeding pattern traits.

The first analysis (Model 1) included additive random effects of pen and sire family. Fixed effects of week finishing test, parity of the dam, covariates of start weight and litter size at birth were also included. The between group component of variance was estimated as the variance between sire families (σ^2_{fam}). The second analysis (Model 2) nested sire family within pens and included the same fixed effects and covariates as Model 1. The between group component of variance was the variance between sire families within pens ($\sigma^2_{fam/pen}$).

6.3 Results

6.3.1 *Feeding order*

It can be seen in Table 6.4 that feeding order was not random in only five out the ten pens with p values between 0.05 and 0.013 when analysis was done over all 3 weeks of test. When analysis was done for each week separately there was non random feeding order in most pens for each week, although in early test three of the ten pens were not significant.

Although feeding order was shown to be generally non random, there did not appear to be any stable order, especially between weeks. If feeding order was stable then it would be expected that the sum of the chi-square values for all three weeks separately, minus the chi-square value of the three weeks pooled would be no more significant than the individual chi-square values when allowing for differences in degrees of freedom. Results from these analyses suggest that feeding order, in growing pigs, may change over time and not be a stable behaviour as found in sows (Hunter *et al.* 1988).

The number of observations in each cell of the chi-square was less than optimal, so simulations were set up to find out if the chi-square test was valid for this analysis. The simulations were set up to sample from the observed distribution of one pen, including the diagonal elements (when a pig follows itself into the feeder), without replacement until there were no records left in the table. This was done 500 times and gave a chi-square distribution which was similar to that expected from the original data (including the diagonal elements), so it was concluded that the chi-square was a valid test.

Table 6.4 *χ^2 analysis to test randomness of feeding order in each week and for pooled data of all 3 weeks*

Pen Number	Pigs in pen	d.f.	$\chi^2_{(p)}$ all 3 weeks	$\chi^2_{(2)}$ week 2	$\chi^2_{(4)}$ week 4	$\chi^2_{(6)}$ week 6	d.f.^{1}	$[\chi^2_{(6)}+\chi^2_{(4)}+\chi^2_{(2)}] - \chi^2_{(p)}$
1	10	71	89.13	95.92 *	86.40	93.17*	142	186.4 **
2	12	111	133.3	137.2 *	139.7 *	142.3 *	222	285.9 **
3	11	90	119.3 *	127.4 *	126.4 *	121.8 *	180	256.3 ***
4	12	111	123.4	122.1	139.2 *	137.3 *	222	275.2 **
5	10	71	71.31	74.32	79.81	87.39	142	171.2 *
6	12	111	138.4 *	138.3 *	141.6 *	146.7*	222	288.2 **
7	12	111	136.7 *	141.3 *	152.9 *	147.3 *	222	304.8 ***
8	11	90	109.4	114.7 *	119.5 *	113.7 *	180	238.5 **
9	12	111	139.4 *	146.2 *	158.5 *	170.2 **	222	335.5 ***
10	10	71	103.9 *	87.82	98.98 *	92.17 *	142	175.1 *

* = $p < 0.05$, ** = $p < 0.01$ *** = $p < 0.001$

d.f. = degrees of freedom for $\chi^2_{(6)}$ $\chi^2_{(4)}$ $\chi^2_{(2)}$ $\chi^2_{(p)}$ separately d.f.^{1} = degrees of freedom for $[\chi^2_{(6)}+\chi^2_{(4)}+\chi^2_{(2)}] - \chi^2_{(p)}$

6.3.2 *Estimation of variance components between and within pens*

The variance component estimates between sire families (nested and crossed with pens) are presented in Table 6.5. The variance estimates of sire families nested within pens (Model 2) were not different from those crossed with pens (Model 1) for most traits, given that estimates of variance components overlapped when their standard errors were taken into account. This was not the case however, for time per visit, time per day, feeding rate and number of non-feeding visits, where the variance between families nested within pens was greater than the estimated variance between families (crossed with pens). However observed differences outwith the standard errors of variance component estimates are not necessarily indicative of significant differences.

The difference in the between group components of variance of the two models is due to a sire family by pen interaction term which is only included in $\sigma^2_{\mathrm{fam/pen}}$. The results indicate that there is an interaction term in time in the feeder per visit, time in the feeder per day and number of non feeding visits per day only.

Table 6.5 *Variance components for families between and within pens*

	Model 1			*Model 2*		
	σ^2_{pen}	σ^2_{fam}	σ^2_e	σ^2_{pen}	$\sigma^2_{fam/pen}$	σ^2_e
DFI	0.0325	0.00514	0.0476	0.0371	0.00638	0.0470
	(0.0052)	(0.0018)	(0.0025)	(0.0052)	(0.0032)	(0.0034)
FIV	0.000799	0.000480	0.00261	0.000982	0.000474	0.00247
	(0.00013)	(0.00013)	(0.00011)	(0.00016)	(0.00013)	(0.00014)
NV	1.37	0.986	5.86	1.71	1.03	5.28
	(0.24)	(0.26)	(0.23)	(0.29)	(0.28)	(0.29)
TV	2.73	0.311	11.40	2.46	3.05	9.17
	(0.47)	(0.17)	(0.47)	(0.49)	(0.57)	(0.52)
TD	135.7	4.60	909.8	131.1	12.32	888.2
	(26.1)	(0.92)	(78.4)	(25.2)	(1.09)	(71.3)
NFV	0.183	0.00880	0.189	0.181	0.0341	0.169
	(0.023)	(0.0037)	(0.0078)	(0.024)	(0.0093)	(0.0094)
FR	0.00247	0.00035	0.0153	0.00250	-0.00018	0.0157
	(0.00050)	(0.00021)	(0.00062)	(0.00050)	(0.00062)	(0.00082)
ADG	0.00139	0.00078	0.0126	0.00145	0.00068	0.0128
	(0.00034)	(0.00027)	(0.00051)	(0.00032)	(0.00025)	(0.00068)
FCR	0.0277	0.00224	0.02146	0.02719	0.00217	0.0214
	(0.0040)	(0.00082)	(0.0011)	(0.0040)	(0.0011)	(0.0015)
BF	0.769	1.37	3.93	0.540	1.54	4.14
	(0.15)	(0.30)	(0.16)	(0.24)	(0.21)	(0.23)
L%	0.525	0.933	2.84	0.441	0.807	3.04
	(0.10)	(0.21)	(0.12)	(0.15)	(0.16)	(0.17)

σ^2_{pen} is the variance between pens; σ^2_{fam} is the variance between families;

$\sigma^2_{fam/pen}$ is the variance between families within pens; σ^2_e is the residual variance

6.4 Discussion

Feeding order was found to be a non-random behaviour, but varied over the test period. This apparent non-stability of feeding order, in group housed young boars, suggests that it is not a good measure of social dominance, unless the social structure within a pen could also be expected to change over the same time period. Hunter *et al.* (1988) found that feeding order in group housed sows, fed at single spaced electronic feeders, was relatively constant for 3-4 consecutive days and was positively correlated with social dominance. It was not clear, however whether this stable feeding order was maintained over a longer period of time. Another study on group housed sows (Bressers *et al.* 1993) found that although feeding order was not random, it did change over time and no sufficiently stable pattern of feeding order could be established to allow monitoring of the sows using deviations from such patterns. Bressers *et al.* (1993) and Hansen *et al.* (1982) found no association between feeding order and social dominance.

From the analysis of variance components it appears that sibs in the same pen have more similar feeding patterns, particularly time in the feeder, than sibs between pens. There were also differences in the variance component estimates for feeding rate and number of non feeding visits, which suggests a possible genotype by pen interaction in time in the feeder, number of non-feeding visits and feeding rate. Feed intake and growth, however had similar variance component estimates for both the nested and crossed models. This suggests that pigs in different pens altered their behaviour to compensate for any social or physical effects within a pen, but still had similar daily feed intake to pigs in other pens. These results agree with those of Young and Lawrence (1994) who determined that all feeding pattern traits in growing pigs, with the exception of daily feed intake, were significantly affected by pen, particularly time in the feeder per visit. This implies that the pigs were able to compensate for the environmental, social and physical restrictions to their daily feed intake via variation in feeding patterns.

The feeding patterns within a pen may well be controlled, to some degree, by social interactions, but the data provided by electronic feeders cannot prove this. Pigs which are regularly evicted from the feeder may have more visits per day, so the presence of an aggressive pig, which regularly evicts other pigs, would result in more, and shorter, feeding visits. This high competition for feed may also lead to changes in growth and body composition. Large family groups in a pen may be more dominant or less aggressive towards each other than to their non-related penmates, although this is unlikely as only full sibs would have had any previous social contact and most family groups in this analysis were half sibs.

Analysis of the variance components between penmates, regardless of whether or not they were related, was also undertaken. The results of this analysis gave similar estimates for unrelated penmates as was seen in related penmates. This indicates that the difference in the variance component estimates for time per visit and time per day were probably due to the social environment in the pen and not necessarily a genotype by pen interaction. Pen was estimated to account for 4.1% of the variance of time per visit and 3.5% of the variance for time per day. The effect of pen includes not only the social environment between penmates, but also the physical location of the pen. For example a pen which is close to a source of ventilation may be cooler than a pen in the centre of the test house. However physical location of the pen in the test station accounted for only 0.1% of the variance and was not significant. This suggests that the main effect of pen is a result of the social environment experienced by one group of pigs in a specific pen and is not due to the location of the pen in the test station.

6.5 Conclusions

Feeding order within a pen is not random, but may change during the test period, so is not sufficiently stable to allow any monitoring of pigs based on deviations from these patterns. Feeding order is not a good predictor of social dominance within a pen which may have been useful when looking at feeding patterns.

Behavioural differences of relatives between and within pens indicate that the social environment may well play a large part in determining the feeding patterns in pigs. However, these differences in feeding behaviour are not limited to related animals within a pen, but are seen throughout the pen regardless of the relationship between the animals. This suggests that a specific pen of animals may alter their behaviour to adapt to the social environment within that pen. These differences in feeding patterns are not reflected in daily feed intake and growth traits so are unlikely to have any economic implications.

Chapter 7

General Discussion

7.1 Introduction

The main aim of this series of studies was to investigate the genetic relationships between feeding patterns and production traits in growing pigs and to determine their potential for improving the accuracy of selection for the efficiency of lean growth.

Some feeding pattern traits, particularly feed intake per visit and number of visits, were found to have a substantial genetic component of variance which suggests that there is potential to include them as selection criteria. This genetic component of variance was found to change little over time, with heritabilities in each test period being similar to that of the entire test for all feeding pattern traits. This indicates that part test records are good indicators of the entire test period for these traits and may lead to potential reductions in the necessary test period for feed intake.

The inclusion of daily feed intake and feeding patterns as selection criteria gave a predicted increase of approximately 20% in genetic gain, although daily feed intake accounted for at least 12% of this. There was however, less increase in predicted gain if selection was for lean tissue growth rate. Much of the increase in the predicted accuracy of selection was due to more accurate selection for feed conversion ratio and daily gain, but predicted gain in lean percentage was generally reduced by their inclusion. This could indicate that an index for lean growth rate may be more efficient without feeding patterns as selection criteria, especially given the possibility of reduced actual accuracy of selection due to inaccurate parameter estimates.

Although not investigated in this thesis the daily feed intake curve may be of further interest to the breeder. Young pigs have a relatively higher potential for protein deposition than older pigs. Selection could be directed towards pigs with a high daily feed intake in early test and a relatively lower feed intake in later test periods, so the feed intake curve would start steep and level off in a few weeks. This may provide another method of selecting for more efficient lean growth.

7.2 Relationships between feeding patterns and the efficiency of lean growth

In all studies using electronic feeders in young pigs, daily feed intake was positively correlated with faster growth, greater backfat depth and higher feed conversion ratio. Feeding patterns, being the component traits of feed intake, were also correlated with performance test traits. Feed intake per visit and time per visit were positively associated with faster growth and more backfat. The opposite was the case for number of visits per day. Classification of animals according to their feeding patterns may provide new information on the genetic merit of the animal, particularly as feeding patterns are not highly correlated with feed intake, but do have positive associations with performance test traits. The variation in these feeding patterns may reflect variation in the required energy for a given level of production. For example a pig which eats little and often may be more active and will therefore require more energy for maintenance.

An important application of feeding patterns may be to select for more efficient pigs via feeding patterns, without reducing feed intake. This is desirable in the pig breeding industry as appetite can be the limiting factor in growth rate for some pigs. It has been shown, however that the use of feeding patterns to prevent further reduction in daily feed intake is less efficient than increasing the weight on lean growth in a conventional index for *ad libitum* fed growing pigs (Labroue *et al.* 1996). Results from the current study suggest that the inclusion of feeding pattern traits as selection criteria can lead to improvements in the accuracy of selection for the efficiency of lean growth, but if the selection objective is for lean growth rate only they add little extra useful information. Studies by Cameron and Curran (1995) suggested that the most effective selection strategy for improving the efficiency of lean growth was to select pigs for lean growth rate on restricted feed where any improvement in growth would be due to increased feed efficiency without reductions in feed intake. This method of selection does not require the direct measurement of feed intake by electronic feeders and so may reduce overhead costs on performance test. The results of the above studies suggest that the most cost effective method of improving the genetic gain in the efficiency of lean growth would be to select for lean growth rate in either restricted or *ad libitum* feeding regimes.

Cameron (1997b) showed that indirect selection (using correlated traits) for feed efficiency can be more effective than direct selection. If a trait has a heritability of h^2_x and a genetic correlation with feed conversion ratio of r_a then the ratio of indirect to direct response, per unit of selection differential, is given by: $r_a\, h_x / h_{fcr}$. Genetic parameter estimates from the current study result in a ratio of 0.86 which suggests that the use of daily feed intake to select for feed conversion ratio would be less efficient than direct selection. No feeding pattern traits in the current study had both a sufficiently high heritability and correlation with feed conversion ratio to achieve better response than direct selection. When daily feed intake and feeding patterns were used as selection criteria the response to selection of feed conversion ratio and average daily gain was increased.

Another option may be to use a different measure of feed efficiency. The introduction of electronic feeders allows easy measurements of feed intake in group housing systems. Calculation of residual feed intake is based on maintenance and production requirements from metabolic body weights and lean percentage (Foster, Kilpatrick and Heaney 1983, De Haer 1992, Cameron and Curran 1994, Mrode and Kennedy 1993, Roehe *et al.* 1994).

Residual feed intake is basically the daily feed intake minus that predicted for growth and maintenance. A high residual feed intake indicates an inefficient animal and some significant correlations have been found (Von Felde *et al.* 1996b, Roehe *et al.* 1994, De Haer and De Vries 1993) between residual feed intake, feeding patterns and production traits, but as with feed conversion ratio these tend to be variable. De Haer and De Vries (1993) showed that residual feed intake was positively correlated with feeding frequency and daily eating time as well as daily feed intake. This indicates that a high daily eating time and high feeding frequency will result in a less efficient but leaner pig. The inclusion of residual feed intake in an index does not however, provide the breeder with any new useful information because its component traits are already included in selection.

7.3 The effect of selecting for efficiency of lean growth on feeding patterns

Selection for performance test traits will also lead to changes in feeding patterns, assuming that the traits are correlated. Figure 7.1 shows the correlated response of feeding patterns to selection on four of the six selection criteria used in Chapter 5. Criterion 1 had measured traits of daily gain, backfat and feed intake, criterion 2 also included feeding pattern traits of feed intake per visit, number of visits and time per visit. Criterion 3 contained daily gain, backfat and feed intake with number of visits and criterion 6 included only daily gain and backfat depth. All these criteria in Figure 7.1 were intended to improve selection objective 1, which included daily gain, lean percentage and feed conversion ratio. All indices resulted in a predicted decrease in feeding rate and number of visits per day, with corresponding increases in feed intake per visit and time per visit. These accuracies were higher if the feeding pattern traits were included as selection criteria.

Daily feed intake was generally reduced a little by selection except when selecting on criterion 6, although it had similar predicted accuracy of selection as criterion 1 for other feeding pattern traits. This suggests that selection using criterion 6 may lead to altered feeding behaviour without reducing daily feed intake. This may be of interest to the breeder as reductions in feed intake can lead to limitations on the genetic improvement of growth rate in the long term. Criterion 6, however had the lowest predicted accuracy of selection for all selection objectives, although when selecting for lean tissue growth rate only, the difference in genetic gain between criteria 1 and 6 was small (1%).

When selecting for the efficiency of lean growth via selection objective 1 (daily gain, lean percentage and feed conversion ratio) it would appear that the most effective selection criteria would include feeding pattern traits. This is not always the case for other selection objectives, particularly lean growth rate where feeding patterns added only little extra accuracy of selection.

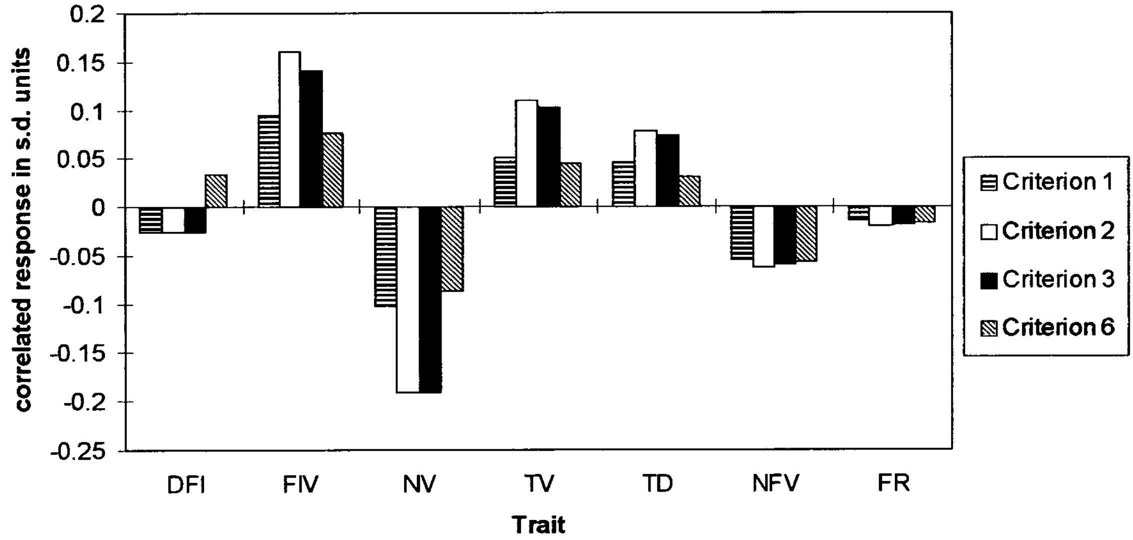

Figure 7.1 *Correlated response of feeding pattern traits (in selection differential units) to each of 4 indices selecting on criteria 1, 2, 3 and 6 using selection objective 1*

Figure 7.2 shows the predicted correlated response to selection of feeding pattern traits, for each of the three selection objectives, using criterion 1. Selection objective 1 is outlined above and selection objective 2 included daily gain and lean percentage whereas selection objective 3 included lean percentage and feed conversion ratio. Both were established to attain approximately equal predicted responses in their respective traits.

Selection for selection objective 3 (lean feed conversion ratio) predicted a large decrease in daily feed intake with corresponding decreases in feed intake per visit, number of visits per day and feeding rate. From Chapter 5 the correlation of daily gain with selection objective 3 was negative in all indices suggesting a reduced growth rate due to selection. This reduction in growth and feed intake indicates that lean feed conversion ratio is not a good selection objective on its own. Selection objectives 1 and 2 had similar predicted correlated responses for all feeding pattern traits with increases in feed intake per visit and time in the feeder. They also had high predicted responses for growth (Chapter 5), although selection objective 2 had more accurate selection for lean percentage than selection objective 1.

It would appear, from the results in this study, that the best selection objectives to improve the efficiency of lean growth would be either lean growth rate alone or a combination of lean growth with feed efficiency (selection objectives 2 and 1 respectively).

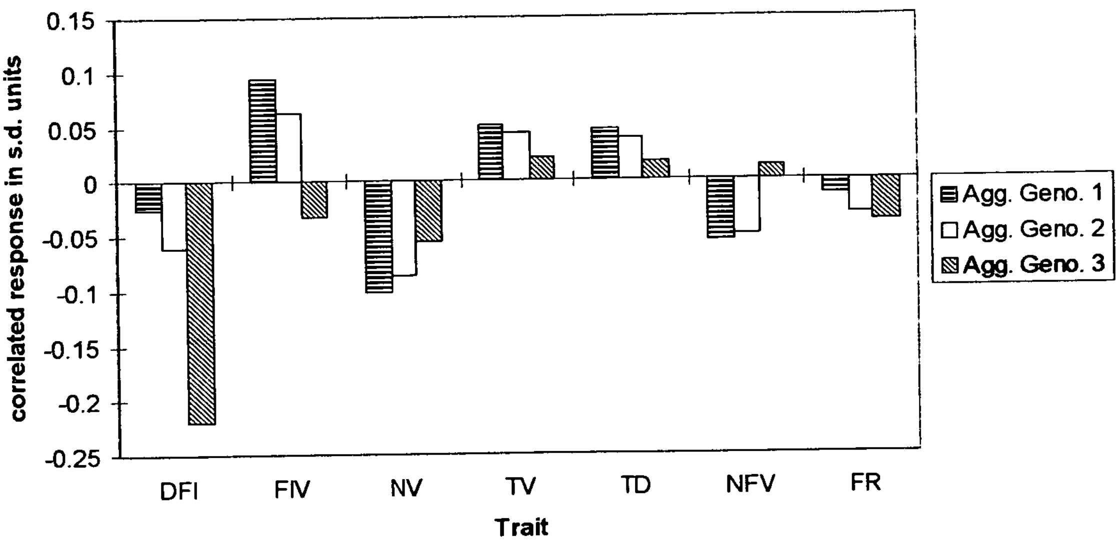

Figure 7.2 *Correlated response of feeding pattern traits (in selection differential units) using three selection objectives*

7.4 Alternative applications of electronic feeders

The main use of electronic feeders at present is to measure individual feed intake in a group housing system. Results from the current study would suggest that the inclusion of feeding pattern traits, as selection criteria, would improve the accuracy of selection for the efficiency of lean growth. Electronic feeders may also allow monitoring of the feeding behaviour of group housed pigs and enable study of how this behaviour changes with selection.

Electronic feeders also provide information about feed intake and feeding patterns over the test period. The relative amounts of daily feed intake between these test periods may be of use to the breeder as young pigs have a greater potential for lean growth than older pigs. It may be possible to select pigs which have a relatively higher feed intake during early test than late test. Analysis of the covariance structure of the feed intake curve, similar to that done for the lactation curve (Kirkpatrick *et al.* 1994), may be possible. Correlations between test periods for daily feed intake however, were very high and most pigs had a linear increase in daily feed intake over the test period which indicates that generally pigs with a large appetite in early test also eat more in late test. The predicted correlated response in performance test traits to selection on a part test record of feed intake (DFI 1, DFI 2 or DFI 3) using the equation $CR_y = i\ h_x\ h_y\ r_a\ \sigma_{py}$, are similar for all traits (Figure 7.3).

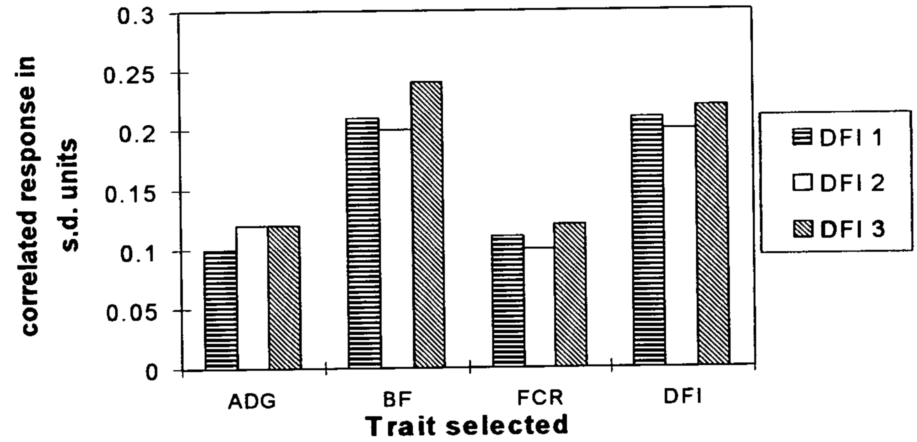

Figure 7.3 *Correlated response (in selection differential units) of performance test traits to selection on partial records of feed intake*

A simple way to test if selection for increased feed intake in one period and reduced feed intake in another period would feasible is to use appropriate economic weights in the selection objective. In the experiment outlined here four indices were established with measured traits of daily gain, backfat, feed intake for the whole of test and feed intake for both the first and third period of test (DFI_1 and DFI_3 respectively). The selection objective for each index was based on objective 1 (Chapter 5) with varied weights for the part test records of feed intake as presented in Table 7.1. These economic weights represent a range of values and are not necessarily optimal.

Table 7.1 *Relative economic weights of traits in the selection objective for each index*

Index	ADG (kg)	Lean (%)	FCR (kg/kg)	DFI_1 (kg)	DFI_3 (kg)
1	40	0.7	-10	5	0
2	40	0.7	-10	5	-5
3	40	0.7	-10	14	-7
4	40	0.7	-10	15	-5

The predicted genetic gain in each index is presented in Table 7.2. Generally as the relative economic weight on DFI_1 increased the daily feed intake in each period and overall daily feed intake for the whole test increased. Predicted responses of both part test records of feed intake (DFI_1 and DFI_3) were in the same direction, and of similar magnitude, in all indices.

Given the very high correlations between test periods for daily feed intake this result is not unexpected. A better way to achieve a change in the feed intake curve may be to use records of feed intake during the entire lifetime of the animal rather than only in a relatively short time on test. This would allow a prediction of the equation of an individual's feed intake curve and selection based on the shape of this curve may be possible.

Table 7.2 *Predicted genetic gain in each trait when selecting on each index*

Genetic Gain in each Trait to Selection on Each Index					
Index	ADG (g/d)	Lean (%)	FCR (kg/kg)	DFI_1 (g/d)	DFI_3 (g/d)
1	29.4	0.14	-0.021	-2.5	0.0
2	24.1	0.39	-0.029	-20.7	-22.9
3	29.0	0.15	0.020	0.05	0.84
4	31.1	-0.001	-0.015	10.8	14.0

It was concluded that the use of electronic feeders to select for high early and low late test feed intake would probably not be effective in *ad libitum* feeding. This is mainly due to the high correlations between test periods for daily feed intake and feeding patterns and the almost linear shape of the feed intake curve during the test period. Restricted feeding regimes could be established using electronic feeders to allow more feed intake in early than late test. In this system faster growth would be a result of higher feed efficiency. Even if these pigs were then produced on an *ad libitum* ration they would still be more efficient, and presumably leaner, than if selected on *ad libitum* feed (Cameron and Curran 1995).

7.5 General Conclusions

Significant genetic correlations between daily feed intake, feeding patterns and performance test traits were found in group-housed growing pigs. Feed intake per visit and time in the feeder were positively associated with daily gain and backfat depth, but negatively correlated with feed conversion ratio. The opposite was found for number of visits per day. Genetic and phenotypic correlations between test periods were high for all traits, particularly daily feed intake, feed intake per visit and number of visits per day.

The use of feeding pattern traits to improve the accuracy of selection for efficient lean growth may be possible, but accurate parameter estimates are essential if losses in actual genetic gain are to be avoided. The discrepancies of these parameter estimates between studies need to be explained fully before they could be used, with any confidence, in a breeding program. If feeding pattern traits are to be used in selection then the most effective and robust method would be to include only one trait (either number of visits or feed intake per visit) to reduce the potential errors in breeding value estimation. Measurement of individual feed intake or feeding patterns is not necessary if the selection objective is primarily for lean growth rate.

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