

Nutritional strategies to optimize reproduction in pigs

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Introduction

The relationships between nutrition and reproduction have been reviewed on many occasions (e.g. Cole, 1982; Hardy & Frappe, 1982; Aherne & Kirkwood, 1985). The approach adopted in this paper is somewhat different in that while it examines, in broad terms, the influences which may be involved within the reproductive cycle and their role in long term strategies, it also seeks to move towards a particular strategy.

The development of a nutritional strategy necessitates the clear identification of objectives followed by the use of sound scientific principles as a basis for realistic application. This may result in some aspect of the science or practice completely outweighing the other or it may result in a compromise between the two. For example, meat is virtually the total saleable product from pigs and considerable emphasis is placed on the production of the pig to slaughter weight. Consequently, no attention is given at this stage to treating the small pig as a potential breeding animal. It is fortuitous that the nutrition of meat pigs gives an adequate basis for future breeding and it is likely that reproduction will be optimized in the early stages (e.g. the gilt litter) by more attention being paid to the tactics to be adopted around puberty and first mating.

However, strategies for sow nutrition imply attention to long term reproductive performance. Consequently, when examining the influences of nutrition at different stages of the reproductive cycle it is important to consider their effect on the whole breeding life-time. In this context, body condition and how it is influenced by the level and pattern of supply of energy and nutrients is generally considered of key importance. Relationships exist between the different phases of the reproductive cycle and their influence needs to be accommodated in developing an appropriate strategy.

Emphasis on body condition may be justified in several ways. For example, support may be sought in the classical work of Hammond (1944) in which he suggested a "priority for nutrients". His theory suggested that the various tissues could be placed in an order of priority for the allocation of energy and nutrients. The order of priority would assume the greatest importance when nutrients were in short supply. In the pregnant or lactating female the brain and central nervous system would have the greatest priority closely followed by the developing litter, in order to ensure the survival of both the individual and the species. Fat would have the lowest priority. Practical support for this has come from the work of Lodge *et al.* (1966a, b) and Elsley *et al.* (1971) in which pregnant sows were so restricted in energy intake that they lost weight but were able to protect the developing litter.

The relevance of body condition may be further influenced by the suggestion that genetically improved strains of lean pigs have low fat reserves at the beginning of their breeding life which may affect reproduction (Whittemore *et al.*, 1980). However, fat stores can be manipulated considerably by nutrition during the breeding cycle and attention needs to be paid to this aspect of sow management.

Strategies for the nutrition of the sow must take account of the maintenance and productive needs of the animal, the nutritional value of the feedstuff and their interaction through the feeding system adopted.

The importance of lactation

In developing a strategy for the long-term nutrition of the sow it has been suggested that lactation should be the focal point with the objective of achieving maximum conservation of tissues (Cole, 1982). There are several reasons why lactation assumes an important role.

Lactation and reproduction

It is well established that loss of weight and condition in lactation can influence subsequent reproductive performance. Influence on some reproductive characteristics appears to be small or non-existent. For example, Hardy & Lodge (1969) reported a loss of 1 ovum together with reduced conception rates at the postweaning oestrus for every 10 kg loss of weight in lactation. However, their results were not supported by a number of other reports, e.g. Hitchcock *et al.* (1971), Pike & Boaz (1972), King *et al.* (1982, 1984), Reese *et al.* (1982), King & Williams (1984a, b), and Hughes *et al.* (1984). It has been suggested (Aherne & Kirkwood, 1985) that the poor conception rate reported by Hardy & Lodge (1969) may have resulted from poor detection of oestrus in sows having uncharacteristic weaning to remating intervals.

The influence of nutrition and weight loss in lactation on subsequent embryo survival is equivocal. Little work has been undertaken on the subject and while Hughes *et al.* (1984) and King *et al.* (1984) have noted adverse effects of high weight loss, others have not (e.g. King & Williams, 1984a, b).

The interval from weaning to oestrus is the characteristic most influenced by large weight and tissue loss, and consequently nutrition, in lactation. Maternal changes which occur in lactation have, for convenience often been measured by change in liveweight. However, it is generally recognized that, firstly, it is more likely to be the depletion of tissues which is important rather than weight loss *per se*. Second, the relationship between liveweight change and fat change, for example, is not good as sows are able to gain weight but lose fat at the same time. Whittemore *et al.* (1980) showed that, while liveweight losses in lactation were paralleled by P_2 ultrasonic backfat losses, liveweight gains in pregnancy were not matched by P_2 increases. Similar responses were found in an experiment lasting five parities (Whittemore *et al.*, 1988) but the relationships for different parities were not reported.

The ability to measure condition changes in the live animal has been improved by the development of condition-scoring techniques and the use of ultrasonic measurement of subcutaneous fat. Work at the University of Nottingham (A. J. Harker & D. J. A. Cole, unpublished) has shown good relationships between ultrasonic P_2 measurement and P_2 on the carcass (particularly when the 'J' measurement was included, $r = 0.93$), dissected fat in the body ($r = 0.82$) and chemically determined lipid in the whole body ($r = 0.96$) as shown in Fig. 1. This work was conducted with first parity animals. Over a number of parities and with the consequent variation in liveweight, P_2 alone may not be as representative of total fat (King *et al.*, 1986; Walak-Janiak *et al.*, 1986). With gilts and fourth litter sows, a good prediction of body lipid was achieved by using both P_2 and liveweight (Whittemore & Yang, 1989).

Fat status in lactation has received most attention in relation to the weaning to remating interval. Most work has been conducted with primiparous sows and indicates that fat loss in lactation increased the weaning to remating interval (Fig. 2), although such a view was not supported by Johnston *et al.* (1989). The work of A. J. Harker & D. J. A. Cole (unpublished) has suggested that care needs to be taken in drawing conclusions from the single first parity and applying them to

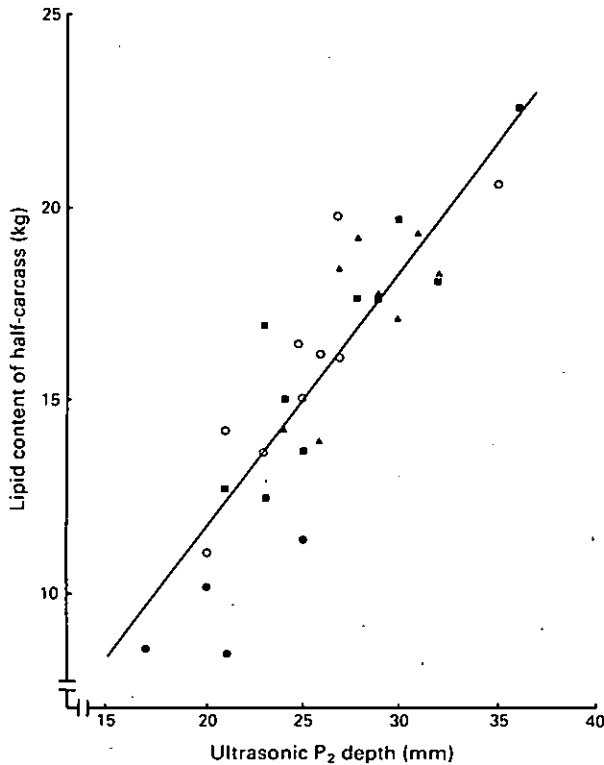


Fig. 1. Relationship between lipid content of the half carcass (y) and ultrasonic P_2 fat measurement (x) (Harker, 1986). ● Day 90 of pregnancy: $y = 0.52^{***} (\pm 0.11)x - 0.1 (\pm 2.90)$, $r = 0.90$; ■ Day 110 of pregnancy: $y = 0.57^* (\pm 0.23)x + 1.14 (\pm 6.42)$, $r = 0.72$; ▲ Weaning: $y = 0.61^{***} (\pm 0.13)x + 0.29 (\pm 3.27)$, $r = 0.89$; ○ Overall regression: $y = 0.67^{***} (\pm 0.07)x - 1.67 (\pm 1.77)$, $r = 0.89$.

the longer term. In their work, lower feed intakes in lactation were not associated with an extended weaning to remating interval and weight and condition losses in the first lactation but these were manifest in the second parity. Suggestions that energy intakes in lactation only influence weaning to oestrus interval when they fall below 45 MJ digestible energy (DE)/day (King, 1987) may therefore need to be revised to take account of long-term effects which may be cumulative over several parities (e.g. Whittemore *et al.*, 1988).

The influence of protein deprivation in lactation and the consequent loss of maternal protein mass are of considerable importance to reproduction (Fig. 3) and there is evidence that the protein effect acts independently of energy intake (King & Williams, 1984b; Brendemuhl *et al.*, 1985; King & Dunkin, 1986). It has been suggested that protein loss may be of greater significance than fat loss (King, 1987) although such a view has not been supported by Whittemore & Yang (1989) who concluded (from work with primiparous sows) that fat content of the body plays a more important role in remating after lactation than does protein content. Earlier, Whittemore *et al.* (1988) had stated that the relationship between total body weight and weight of body protein is a particularly intransigent value, while the relationship between body weight and weight of body lipid is readily altered.

The physiological mechanisms mediating such effects on reproduction are considered by Booth (1990) and include an important involvement of GnRH/LH regulation. While the importance of tissue status in reproduction has been recognized it is not clear whether there is solely a 'static' effect involving a threshold critical mass of fat or muscle below which reproduction is affected or whether there is a

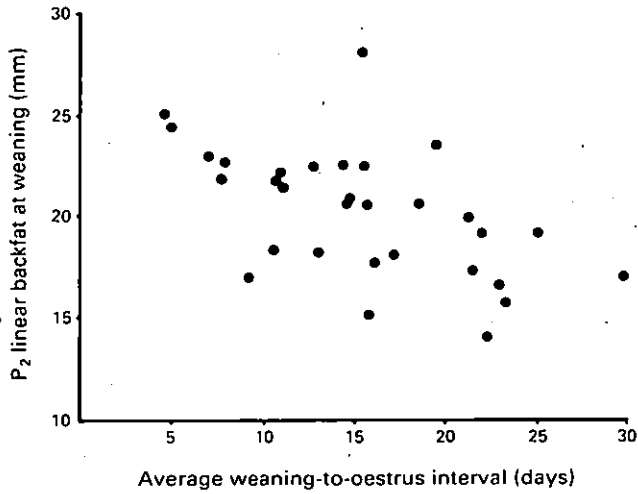


Fig. 2. The relationship between linear backfat (P_2) and weaning to oestrus interval (after King, 1987).

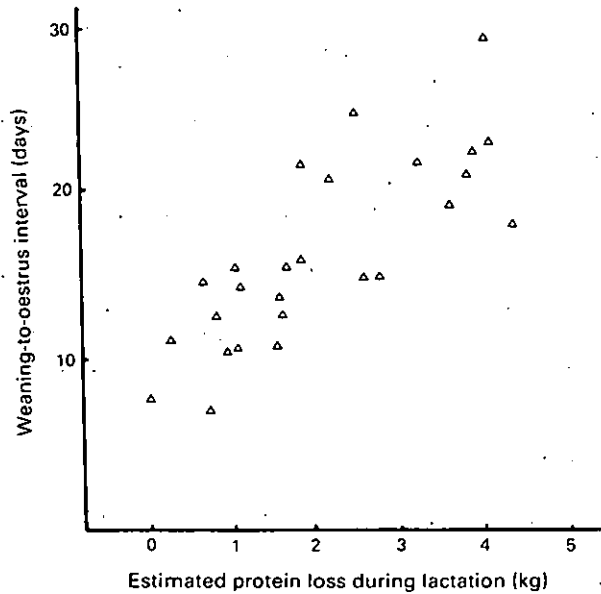


Fig. 3. The relationship between protein loss in lactation and weaning to oestrus interval (after King, 1987).

'dynamic' effect involving the rate of tissue loss in lactation. The data of King (1987) suggested a similar influence of both tissue weight at weaning and tissue loss during lactation (Table 1). Davies *et al.* (1985) obtained correlation coefficients of $r < 0.5$ for backfat level and $r < 0.3$ for backfat loss in lactation when related to subsequent sow productivity traits. The suggestion of a threshold value has attractions as a delay in returning to oestrus would offer a recuperative period to restore tissue depots.

Table 1. The relationships between nutrient intake, bodyweight and fat and protein contents and weaning to oestrus interval of first-litter sows (King, 1987)

Independent variable (x)	Model $y = a + bx$		RSD†	R ² *
	a	b		
Energy intake (MJ DE/day)	28.1	-0.28	4.4	0.49
Protein intake (g CP/day)	32.5	-0.032	3.6	0.68
Weight at weaning (kg)				
Liveweight	60.3	-0.35	3.7	0.62
Estimated body fat	38.6	-0.63	4.2	0.46
Estimated body protein	81.5	-3.58	3.5	0.63
Loss during lactation (kg)				
Liveweight	7.3	0.39	4.0	0.58
Estimated body fat	9.4	0.59	4.4	0.43
Estimated body protein	9.6	3.44	3.5	0.63

y is the weaning to oestrus interval (days) and x is the independent variable.

†Residual standard deviation.

*Correlation coefficient.

Energy and nutrient requirements

Energy and nutrient requirements of the sow are high in lactation. The major influence is milk production which, in practice, is difficult to measure and piglet growth is often used as the parameter of response. Various factors have been used to associate weight gain of piglets with milk production. Several authors have used a conversion factor of 1 kg litter weight gain from the production of 0.8 kg milk dry matter (King & Dunkin, 1986; Lythgoe & Aherne, 1986). This compares well with values of 4.0 g (Lythgoe & Aherne, 1986) and 4.5 g (Lewis *et al.*, 1978) for the conversion of sows milk to piglet gain.

Milk yield information is usually measured by weighing piglets before and after suckling. Disadvantages such as imposition of arbitrary suckling patterns and the poor relationship between piglet weight and milk intake have been summarized by Pettigrew *et al.* (1985). Inaccuracies can occur through urination, defaecation, variation in activity and saliva losses (Klaver *et al.*, 1981; den Hartog *et al.*, 1984; Noblet & Etienne, 1986). Isotope dilution techniques have been used much less to measure milk yield and comparisons with other techniques have given conflicting conclusions about their merits (Pettigrew *et al.*, 1985). It has been suggested that 66–80% of the sow's total dietary energy requirements are for milk production (Table 2). Consequently, litter size will be a major factor determining milk production and hence the nutrient requirements of the sow. The relationship which exists between dietary energy intake, litter size and the mobilization of maternal tissues has been demonstrated (Mullan & Close, 1989) (Fig. 5). At moderate energy and protein intakes (about 70 MJ DE/day, 150 g N/day) a sow suckling 12 piglets was mobilizing fat and lean tissue (184 and 823 g/day respectively) but sows mobilized only a small amount of fat (30 g/day) and deposited lean tissue (399 g/day) when litter size was reduced to 6. The influence of litter size on P₂ fat loss in a 28-day lactation has also been shown by Yang *et al.* (1989).

If nutrition is not sufficient to meet the needs of maintenance and milk production, then the sow will mobilize body tissues. With the current trend towards weaning at about 28 days or less it is likely that in most litters the creep diet would contribute little to piglet growth due to very low consumption (S. Wilson & D. J. A. Cole, unpublished data) (Fig. 4). Consequently, several recommendations are based on the assumption that sow weight loss in lactation will have a 'sparing' effect on nutrient requirements and some suggest that it is inevitable (Whittemore, 1989). For example, ARC (1981) based requirements on liveweight, weaning age and different levels of milk production with the assumption that sows would lose 180 g/day in lactation and that changes

Table 2. The requirements of the lactating sow (Mullan *et al.*, 1989)

	Stage of lactation			
	Week 1	Week 2	Week 3	Week 4
Maintenance				
Energy (MJ ME/day)	21.2	20.9	20.6	20.2
Nitrogen (g digestible N/day)	17.1	16.9	16.6	16.3
Milk production				
Energy (MJ ME/day)	41.6	58.9	72.4	77.2
Nitrogen (g digestible N/day)	74.7	101.7	116.4	118.0
Total requirements				
Energy (MJ DE/day)	62.8	79.8	93.0	97.4
Nitrogen (g digestible N/day)	91.8	118.6	133.0	134.3

in level of feed intake would result in changes in milk production. With intakes of 65–76 MJ DE/day (depending on weaning age and level of milk production) they anticipated a weight loss of 3.6 kg in 21 days or 6.5 kg in 35 days, for a 160-kg liveweight sow. Similar figures (75 MJ DE/day) were suggested by Aherne & Kirkwood (1985) for a 165-kg sow producing 6.2 kg milk/day and losing 6.5 kg body weight in a 42-day lactation. Requirements have been established without the pre-condition of maternal tissue loss, in order to devise feeding strategies which minimize losses (Mullan *et al.*, 1989). Suggested requirements (Table 2) range from 62.8 in the 1st week to 97.4 MJ ME/day in the 4th week of lactation, or 66.1 to 102.5 MJ DE/day, respectively. These are broadly in agreement with findings at the University of Nottingham where requirements were estimated at 85.3, 97.6 and 93.5 MJ DE/day to avoid losses in maternal liveweight, P₂ backfat and condition score, respectively (Table 3). Further work which separated 1st and 2nd parity animals indicated higher levels of dietary energy to maintain equilibrium in gilts (Table 3).

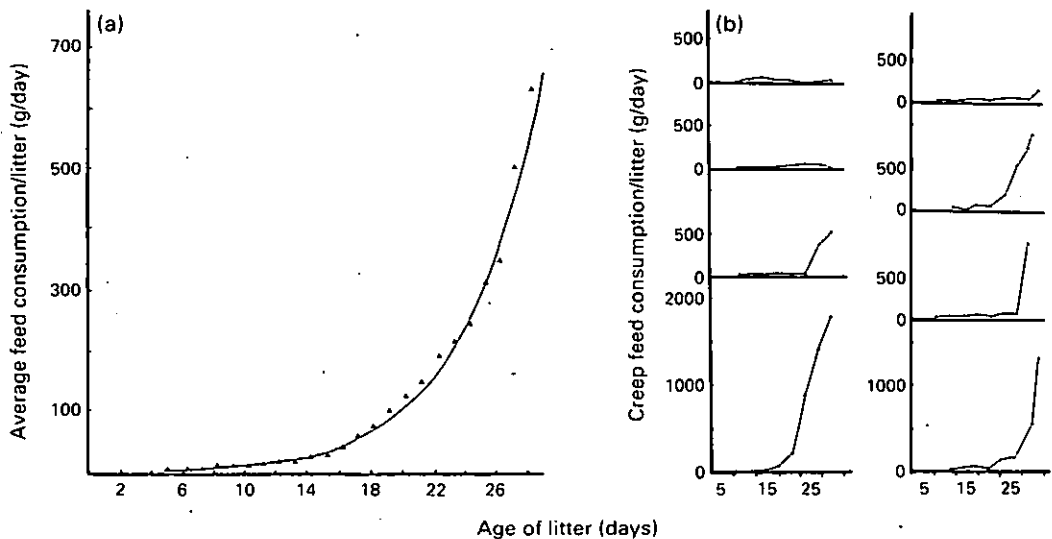


Fig. 4. The creep intake of piglets during lactation; (a) mean values for 24 litters; (b) examples of individual litters. While creep intake appears to be curvilinear when considered on a herd basis, the individual litter appears to learn to eat suddenly. However, in some cases this has not happened by 28 days of age. (S. Wilson & D. J. A. Cole, unpublished data.)

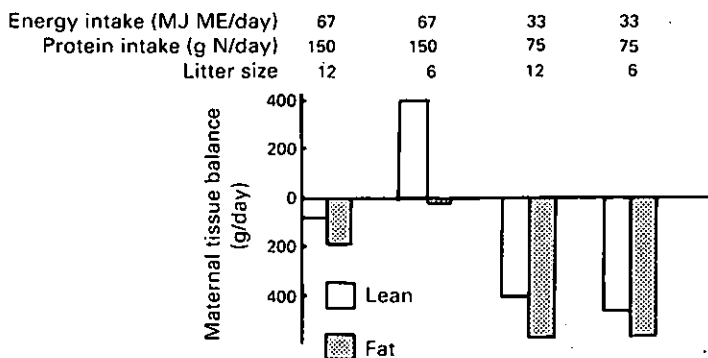


Fig. 5. The relationship between energy and nutrient intake, litter size and tissue loss in lactation (Mullan & Close, 1989).

Table 3. Estimates of the dietary energy intake of sows (MJ DE/day for 28-day lactation) necessary to avoid maternal losses in liveweight and condition during lactation (A. J. Harker & D. J. A. Cole, unpublished)

Trial 1	Liveweight	85.3	} 120 animals of mixed parities (1-8); average post-partum weight of sow = 208 kg; litter size standardized to 9.5 piglets
	Backfat (P ₂)	97.6	
	Condition score	93.5	
Trial 2	Liveweight	122.3	} Parity 1; average post-partum weight = 160 kg; 8 piglets weaned
	Backfat	110.5	
	Condition score	118.7	
Trial 3	Liveweight	77.4	} Parity 2; average post-partum weight = 189 kg; 8.6 piglets weaned
	Backfat	78.5	
	Condition score	92.3	

Feed intake in lactation

Nutritional strategies involve the matching of perceived requirements of the animal to the abilities of the food to meet them. Feed intakes of sows of 7-10 kg/day were attainable in lactation 25 years ago. To-day the inability of sows to consume adequate quantities of food during lactation is a common problem. Many changes have taken place during that period and include breed selection objectives, lactation length, diet and environmental conditions. All of these may influence appetite and consequently the strategies that are available for pig nutrition. It is therefore of prime concern to consider those factors which influence feed intake in lactation.

The animal. It has been suggested (Cole & Chadd, 1989) that the genotypes of pigs used in modern pig production may have been selected in such a way that appetite has been reduced. The change is illustrated by the nature of the relationship between digestible energy intake and liveweight for growing pigs (Cole & Chadd, 1989) (Fig. 6) and it is likely that such reductions would also be manifest in the breeding sow.

Previous nutritional history of the pig influences intake. It has been well known that sows with high feed intakes in pregnancy have reduced feed intake in lactation (Salmon-Legagneur & Rerat, 1962). Work at the University of Nottingham (A. J. Harker & D. J. A. Cole, unpublished data) to quantify this effect with modern pigs (Fig. 7) showed that when energy intake in pregnancy rose above about 2 kg/day (26 MJ DE/day) there was a marked fall in daily feed intake in lactation with 1st and 2nd parity sows. Raising energy intake to 35 MJ DE/day in pregnancy decreased lactation intake by about 25%. However, Yang *et al.* (1989) found only a weak relationship in parity 1 but a much stronger relationship in parities 2, 3 and 4.

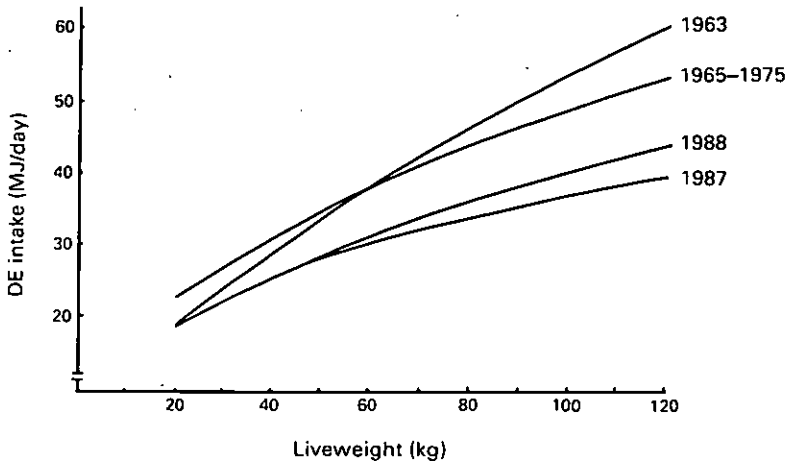


Fig. 6. The relationship between liveweight and daily voluntary energy intake in growing pigs (after Cole & Chadd, 1989).

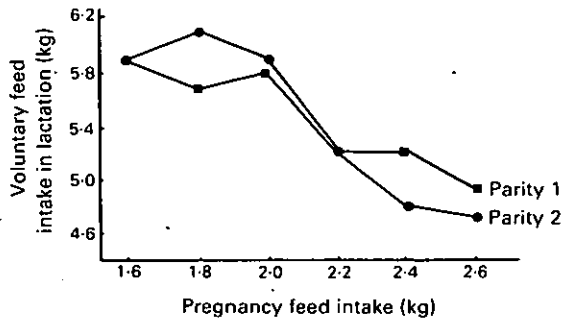


Fig. 7. The relationship between voluntary feed intake in lactation and imposed feed intake in pregnancy during the first two parities. The diet had 13.19 MJ DE/kg and 147 g/kg crude protein (A. J. Harker & D. J. A. Cole, unpublished data).

The environment. Feed intake is markedly depressed in hot climates or when poor building design raises the environmental temperature (Verstegen & van der Hel, 1974). There is a particular problem with first litter sows and daily intakes as low as 2.9 kg (Cox *et al.*, 1983) and 3.1 kg (King *et al.*, 1984) have been reported. Estimates of the reduction of feed intake associated with environmental temperature at the University of Nottingham (A. J. Harker & D. J. A. Cole, unpublished) are:

$$\text{Parity 1: } y = 7.7 - 0.12x$$

$$\text{Parity 2: } y = 8.71 - 0.14x$$

where y = feed intake (kg/day); x = environmental temperature ($^{\circ}\text{C}$); and diet was 13.19 MJ DE/kg and 147 g/kg crude protein. These estimates are in broad agreement with the values of approximately 0.1 and 0.2 kg/day reduction/ $^{\circ}\text{C}$ reported by Lynch (1989) and Stansbury *et al.* (1987).

The diet. Most of the work on the influence of diet on voluntary feed intake in pigs has been done with growing animals up to about 120 kg liveweight. It has long been recognized that dietary energy concentration is an important factor determining the level of feed intake of growing pigs. A

model was proposed to describe this (Cole *et al.*, 1972). It was suggested that there was a range of dietary energy concentrations over which the pig attempted to eat to a constant daily dietary energy intake by eating more of low quality diets (Fig. 8). Eventually this physiological control would give way to physical limitation when the animal was incapable of eating more. At the other extreme there might be a minimum bulk intake needed to avoid gastric hunger contractions. There is now doubt that complete compensation occurs with a range of diets where intake is under physiological control with growing pigs (Cole & Chadd, 1989).

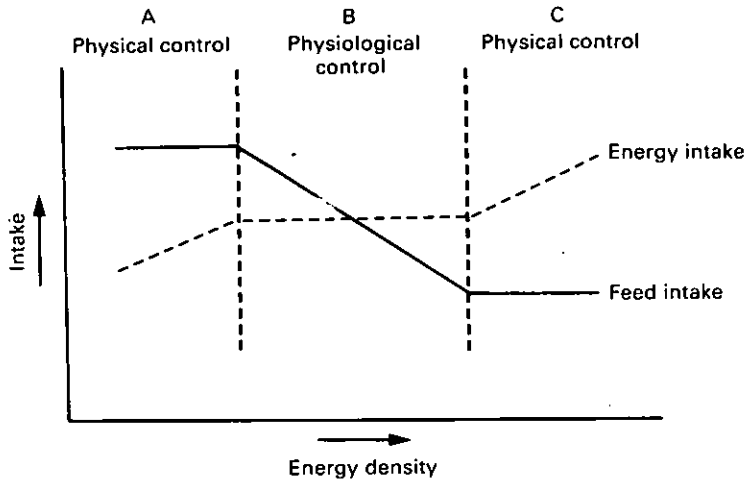


Fig. 8. A proposed model for control of voluntary feed intake in the pig.

As far as lactating sows are concerned there is evidence that they eat considerably more of very low quality diets than of diets of moderate quality. For example, Zoipoulus (1978) showed that, when diets were diluted with 30% barley straw, daily feed intake increased by 19% but digestible energy intake decreased by 16%. These diets may be in the range of physiological control of intake and the phase when physical capacity is beginning to cause a limitation (A and B in Fig. 8). However, with higher quality diets there does not appear to be complete compensation or, in some cases, any compensation at all (Fig. 4). Whether the sow eats to a bulk intake to try to achieve the high levels of requirement resulting from the demands of milk production or whether animals closer to maturity are more influenced by physical than physiological mechanisms is not clear.

Table 4. Voluntary feed intake in lactation

Reference		Dietary DE (MJ/kg)		
		12.5	13.5	14.5
Lynch (1989)	Feed intake (kg/day)	4.92	5.08	
	DE intake (MJ/day)	61.2	70.3	
X. Zhu & D. J. A. Cole (unpublished)	Feed intake (kg/day)		6.01	5.89
	DE intake (MJ/day)		75.13	85.41

The influence of dietary protein on lactation feed intake is well established. The work of Mahan & Mangan (1975) showed that lactating sows eat more of a high than a low protein diet. Furthermore they showed that intake was greatly reduced in lactation when sows had previously been fed a low protein diet in pregnancy. Similarly trends have been reported by Lynch (1989) and they appear to be particularly important in first parity gilts (O'Grady & Hanrahan, 1975).

Interactions with environmental temperature have also been reported (Lynch, 1989) with sows eating substantially less of a high protein diet (20% compared with 14%) at high temperatures (28°C) but more at low temperatures (16°C). Similarly, it has been reported that high fat diets (13%) may reduce lactation feed intakes in hot climates (32°C vs 20°C) (Schoenherr *et al.*, 1989).

There is clearly a case for careful consideration of dietary specifications in lactation as part of the overall nutritional strategy. High energy and nutrient density will be of benefit when feed intake is a problem in temperate climates. In hot climates care should be taken to avoid excessively high protein levels. However, the work on which the last comments were made (Lynch, 1989) used only moderate and high protein levels (14 and 20%) and two temperatures (16 and 28°C) and a similar point could be made about the fat work of Schoenherr *et al.* (1989). Clearly more information is required on these relationships before precise recommendations can be made.

The influence of parity

This article considers largely variations within a breeding cycle in the context of their longer term involvement in the reproduction of the sow. The question arises whether similar recommendations can be made for animals of different parities. Differences between primiparous and multiparous sows have already been mentioned and mainly relate to the influence of true growth which is still occurring in the gilt. Thus, measures of backfat may not have the same relationship with total lipid in the body in gilts as older sows (Mullan *et al.*, 1989).

It has often been suggested that a net maternal weight gain during pregnancy of about 25 kg is adequate for sows (Aherne, 1987; Holden, 1987; Verstegen *et al.*, 1987) while Holden (1987) suggested a different target of 45 kg for gilts. In an attempt to identify targets for body condition at parturition, Yang *et al.* (1989) compared P₂ backfat thicknesses of 12 and 20 mm. Of the two, they concluded that a target of 20 mm was of benefit to primiparous sows. They were not easily able to differentiate targets for multiparous sows as high level feeding (*ad libitum*) in lactation was of greatest benefit in all cases. Whittemore (1989) suggested that P₂ should not fall, at any stage, below 13 mm for gilts and 10 mm for sows for improved hybrid strains.

Primiparous sows can mobilize muscle mass as well as fat in lactation while mature sows lose weight mainly as a result of reduction in fat tissues (King, 1987). It has been suggested that feed intake and tissue loss in lactation, together with fatness at weaning influence weaning to oestrus interval in first parity sows but are less evident in later parities (Reese *et al.*, 1982; Armstrong *et al.*, 1986; King, 1987; Yang *et al.*, 1989). To maintain liveweight and fat status in lactation, a greater energy intake is required for gilts than sows (Table 3).

Metabolic status versus reproductive status

The nutrition of the breeding sow has been considered traditionally and conveniently on the basis of its separate reproductive phases, i.e. pregnancy, lactation and the interval from weaning to remating (e.g. ARC, 1981). Within this approach pregnancy has been regarded as an anabolic and lactation as a catabolic period. This is not entirely true, as the sow often mobilizes body reserves in late pregnancy. In addition, targets for nutrition of the breeding sow are set in terms of body condition, which necessitates that nutrition should take into account the metabolic or tissue status of the sow as well as reproductive status. Therefore, while pregnancy and lactation each have a considerable influence on setting the level of requirement, the meeting of these requirements is modified by the anabolic or catabolic status of the sow with, for example, catabolism having a 'sparing' effect on nutrient supply, as discussed earlier. An approach is suggested which pays more attention to the breeding cycle having potentially anabolic and catabolic phases.

Nutrition during pregnancy needs to ensure good embryo survival and piglet birthweight. Within the bounds of common practice, nutrition is unlikely to influence the developing litter in

early pregnancy but piglet birthweight, if particularly low may be influenced by feeding in late pregnancy (for review, see Cole, 1982). In addition to the products of conception, changes in the maternal body tissues are greatly affected by nutrition. In establishing nutrient requirements for pregnancy it is evident that total intake is of far greater importance than pattern of intake, although the latter can have some small effects (Elsley *et al.*, 1971; Zhu, 1989). In establishing the needs of pregnancy, ARC (1981) clearly overestimated energy requirements. The extent of this was shown by Lee & Mitchell (1989) who suggested that daily energy requirement could be reduced by up to 75 kJ ME/kg W^{0.75} which resulted from an overestimate by ARC (1981) from Day 40 to Day 115 of gestation to account for an increase in maintenance energy requirement with the progression of pregnancy. Close *et al.* (1985) had already shown little change in maintenance requirements at different stages of pregnancy. While NRC (1988) used a similar value for maintenance they did not add an increment for each day after the fortieth.

The sow increases its weight permanently over the period from first mating, which some authors have regarded as true growth, with the accretion of tissues for breakdown at a later part of the reproductive cycle being regarded as pregnancy anabolism (Salmon-Legagneur & Rerat, 1962). Such an approach has value but the extent to which tissues are mobilized is not predestined at the stage of their accretion but determined, at catabolism, by the relative influences of nutrient supply and demand.

The sow can be catabolic in late pregnancy when the demands of the developing fetuses are greatest but whether this happens and when it might occur will depend on energy and nutrient supply. The mobilization of fat in late pregnancy has been well illustrated (Fig. 9) by the work of Close *et al.* (1985). In this case sows having intakes of 20 MJ DE/day lost fat but not protein and sows having intakes of 30 MJ DE/day lost neither. At the lower critical temperature sows would have been in negative energy balance at Day 87 of pregnancy and at 5°C below the critical temperature this would have happened at Day 70 of pregnancy. These losses could account for about 4.8 kg fat and would be equivalent to about 20% of the sow's fat reserves. Work at the University of Nottingham has examined the influence of nutrition in this potentially catabolic phase of late pregnancy. For example, in two experiments a constant feed intake of 2 kg/day (26.4 MJ DE/day) throughout pregnancy was sufficient for sows to increase liveweight but insufficient to maintain ultrasonic P₂ backfat or condition score after Day 90 of pregnancy (A. J. Harker & D. J. A. Cole, unpublished). Raising daily energy intake to 39.6 MJ DE for the period 90–110 days of pregnancy resulted in liveweight, backfat and condition score increasing (Table 5). When increased energy intake in late pregnancy was part of a re-distribution from lactation allowances, so that animals had the same intakes over the whole reproductive cycle, the benefits gained in late pregnancy were lost by weaning. However, the pregnancy gains were maintained when adequate nutrition was given in lactation.

While considerable attention has been paid to the change from an anabolic to a catabolic phase in late pregnancy and early lactation, little attention has been paid to the re-initiation of anabolism at the end of lactation. Clearly the situation needs to be clarified and it has been suggested that the catabolic phase may persist at least through the weaning to oestrus period (Brooks & Smith, 1980). Failure to revert to an anabolic phase at weaning has been suggested to be a major reason for small litter problems in second parity sows through a reduction in ovulation rate (Brooks, 1982). Persistent catabolism has also been cited by Kirkwood *et al.* (1987) as an influence in delayed oestrus after weaning. The extent to which relationships exist between lactation and the subsequent oestrus and pregnancy is not clear and the evidence conflicting. While Reese *et al.* (1982) showed that restriction of energy intake in lactation was associated with increased weight gain in pregnancy, the opposite effect has been reported by O'Grady *et al.* (1975). In both cases lower individual piglet birthweights were reported with restricted energy intake in lactation.

In addition to examination of catabolic/anabolic phases at this stage, attention needs to be paid to the relationships that exist between liveweight and tissue changes together with the possible influence of body water loss (e.g. see Bowland, 1967).

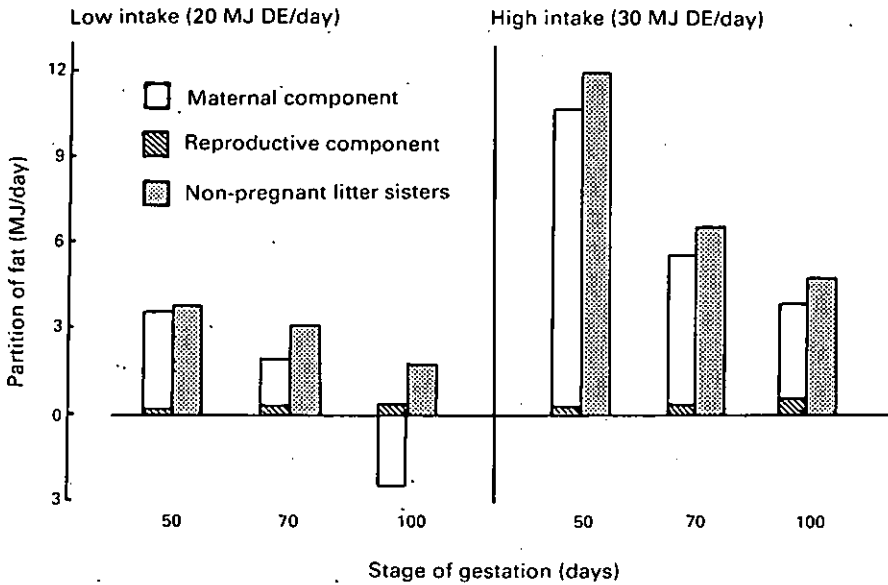


Fig. 9. Partition of total fat into maternal and reproductive components at various stages of gestation and at 2 levels of energy intake (Close *et al.*, 1985).

Table 5. The influence of digestible energy intake in late pregnancy on changes in liveweight, P₂ fat and condition score (Harker, 1986)

	Pregnancy (Days 0-90)	Pregnancy (Days 90-110)		
		A	B	C
Energy intake (MJ DE/day)	26.4	26.4	39.6	52.8
Change in:				
Liveweight (kg)	36.2	10.0	18.9	26.1
P ₂ fat (mm)	4.1	-0.8	0.5	1.7
Condition score*	0.51	-0.11	0.12	0.13

*MAFF, scale from 0 to 5.

Feeding system and environmental conditions

Clearly there are interactions between the animal, its feed and the environment. Simple relationships between temperature, requirement and feed intake have already been discussed. For many reasons housing and feeding systems change and can involve quite different environments. For example, sows in stalls may require different nutrition from groups of sows on straw-based, electronic feeding systems.

In developing relationships between feed intake and liveweight gain in pregnancy during the studies of Williams *et al.* (1985), it was evident that sows at the University of Nottingham gained more weight than did sows at the other centres being considered. They had been housed in groups on deep straw and gained about 10 kg more in the first 4 weeks of pregnancy than did individually housed sows, on the same unit, but not on straw-based systems. In addition to straw consumption, this extra gain may have resulted from differences in the climatic environment, the insulative value

of straw and huddling in groups with their consequent influences on critical temperature. For example, Holmes & Close (1977) suggested, on the basis of the work of Verstegen & van der Hel (1974), that young pigs on straw and asphalt (compared with asphalt alone) would have the lower critical temperature reduced by 1–2°C at low levels of feeding and 3–4°C at higher levels of feeding. The same authors have shown a reduction in heat production of young pigs which were group housed compared with individually housed pigs.

The purpose of recent work at the University of Nottingham (unpublished) was to examine the extent to which straw was consumed and could contribute to the supply of energy and so increase liveweight gain in the first 4 weeks of pregnancy. Digestible energy value of wheat straw was determined as 4.94 MJ DE/kg DM. Chromic oxide studies were used to predict straw intake of the group housed sows on straw bedding. It was estimated that they consumed 0.493 kg/day which contributed about 58 MJ DE over the 28-day period. While this makes some contribution to energy supply it would only account for a small part of the extra increase in liveweight gain of the straw-bedded sows. Observations suggested that intake might be related to supply, freshness and frequency of feeding, and intake may, in other circumstances, be greater than in this work. Intakes of straw are difficult to measure and this exploratory work needs further development.

Care needs to be taken in the general application of experimental results to both hot and cold climates. Attention has already been drawn to possible nutrition × climate interactions. It may be that the solution to nutritional problems (e.g. feed intake in lactation) in hot climates may not lie solely in nutrition. For example, increased evaporative heat loss of the sow through localized cooling of head, neck and snout have been shown to reduce respiration rate and increase feed intake (Stansbury *et al.*, 1987; McGlone *et al.*, 1988; J. P. Murphy, D. A. Nichols & F. V. Robbins, unpublished work at Kansas State University).

Evaluation of requirements

In developing nutritional strategies several approaches, e.g. factorial and empirical, are taken to the quantification of the energy and nutrient requirements of sows. It is common in the application of this information to use published data for the values of the feedstuffs concerned. The values used are almost exclusively obtained with growing pigs in the 25–90 kg liveweight range. There are, however, clear differences between energy values determined with pigs of this weight and mature sows. In recent work at the University of Nottingham (unpublished) a simple compound diet (having a digestible energy content based on published values of 13.19 MJ/kg) yielded a value of 13.38 MJ/kg with growing pigs but when determined with sows it was 10% higher (14.58 MJ/kg). Similar results have been found by Fernández *et al.* (1986) who reported an increase of 9% in energy digestibility and 15% in protein digestibility by sows in the 26 feeds that they examined. Consequently approaches defining a need based on the quantity of a feed will yield lower energy values when based on growing pig values for that feed. The problems created will be largely undetected when these values are used universally and one approach would be to regard the characterization of feedstuffs as a standard evaluated with growing pigs. However, this assumes that differences between types of pigs are the same regardless of diet. This may not be so, particularly with high fibre foods which may be more beneficial, because of greater hind-gut activity, to adult sows than to growing pigs (Fernández *et al.*, 1986), and a move towards greater accuracy in relating diet to requirements may be called for.

Conclusions

Greater recognition is being given to the endocrinology and metabolism of the sow and their relationship with reproductive performance. Of particular importance is the relationship between

metabolism, tissue status and reproduction. Knowledge to date has relied heavily on information obtained in short term experiments, particularly with primiparous sows. There is a need to collect information on the long term reproduction of the sow in order to identify the objectives of nutrition in terms of tissue status and change. Practical applications will depend on easily used techniques for measurement of condition at farm level. The changing nature of pig production greatly influences housing and consequently the total environment of the sow. It and its interactions with the diet and animal will greatly influence the nutritional strategy adopted. Finally, there is a need to consider whether the use of feedstuff values determined with growing pigs is satisfactory for the precise definition of requirements in breeding sows.

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