PREDICTING THE RESPONSES OF SOWS TO NUTRIENT INTAKE: CONSEQUENCES FOR REPRODUCTION

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SUMMARY

From knowledge on nutrient utilisation, aspects of energy and nitrogen metabolism and body composition, a model has been developed using factorial and empirical procedures, to assess the responses of sows to dietary nutritional inputs. The model is iterative and predicts changes in body weight and body composition of the sow as well as the products of conception during pregnancy and milk production during lactation. The predictions from the model provide a good fit to much of the independent empirical data that has been used to validate it. It may therefore be used with reasonable precision to measure the response of sows to dietary nutritional manipulation, to estimate nutrient requirements and to assess the consequences for reproductive performance when nutrient intake fails to meet metabolic needs.

INTRODUCTION

One of the most effective ways of determining the nutritional requirements and responses of farm animals is by simulation models where the animal is represented by a series of mathematical equations linking genetic, metabolic, nutritional, physiological and environmental phenomena. Several have been described and applied with reasonable success for a variety of farm animals; for example, the growing pig (Whittemore and Fawcett, 1974, 1978; Maughan et al., 1987), the sheep (Gill et al., 1984) and the dairy cow (Baldwin et al., 1987a,b). The development of these models is dependent upon sufficient data being available on dynamic aspects of both energy and nitrogen metabolism, especially the relationship between the input and output of nutrients, the efficiency of nutrient utilisation for the various metabolic processes within the body and body composition. It is only recently that such information has become available for the sow to allow integration into a simulation model to describe andpredictanimal responses, for example, pregnancy (Williams et al., 1985; Dourmad, 1987), lactation (Mullan et al., 1989; Noblet et al., 1990) and during a reproductive cycle (Black et al., 1986; Whittemore and Morgan, 1990).

Models may operate at different levels; some are empirical and based on whole-animal prediction equations developed from experimental data sets, whereas others are mechanistic and deal with individual processes within the animal. Mechanistic models operate at a lower level of organisation, are more flexible and can predict responses over a wider range of circumstances than empirical ones. This paper describes such a model, the Shinfield Sow Model, which has been developed to establish nutrient requirements and to predict animal responses over a wide range of nutritional, management, husbandry and environmental inputs.

DESCRIPTION OF THE MODEL

Certain assumptions have to be made, especially when creating a model which is to apply in a wide range of circumstances, as occur in practice. The present model is aimed at imitating the responses of different types of sows under various management procedures and so its basic assumption is a healthy, reproductively-mature female pig. Energy and protein intakes are specifically considered in the model, but it is assumed that other nutrients, such as vitamins and minerals, are adequate for optimum productivity. Certain metabolic criteria, constants and conversion factors are employed within the calculations and these will be highlightedwhere appropriate in the description of the model.

The model operates on the factorial principle that dietary nutrients may be partitioned between the requirements to maintain the animal and to deposit tissue (protein and fat) either in the maternal body or products formed but subsequently lost from the body , that is, in the conceptus tissue, and as milk. A similar approach is taken by AFRC-TCORN (1990) which deals mainly with the energy requirement of the pregnant sow.

For convenience, the model is split into two sections. One part deals with pregnancy, the other with lactation, although it is designed to run the two consecutively in order to follow an animal through each reproductive cycle. Lack of information has made it impossible to model the response of the sow in the post-weaning period but it is assumed that her body weight and composition at mating are similar to that at the previous weaning.

TABLE 1 Abbreviations used in the description of the model

W	weight of sow, kg
FEED	amount of feed, kg
DE	digestible energy content of feed, MJ/kg
ME	metabolisable energy intake, MJ/d
MEm	maintenance energy, MJ/d
PROT	crude protein content of feed, g/kg
NI	nitrogen intake, g/d
NRmax	maximum nitrogen retention, g/d
NR	nitrogen retained, g/d
P	protein deposited, g
F	fat deposited, g
LEAN	lean tissue deposited, g
PE	energy required to deposit protein, MJ
FE	energy required to deposit fat, MJ
DWR	weight of total gravid uterus, g
DER	energy content of gravid uterus, kJ
DPER	protein-energy content of gravid uterus, kJ
Tc	lower critical temperature, °C
TDIFF	difference between environment temp and Tc
FDIFF	fat utilised for heat production, kg
LMEm	lactation maintenance requirement, MJ/d
MILK	energy requirement for milk, MJ/d
MEMILK	ME requirement for milk, MJ/d
TER	total energy requirement, MJ/d
ES/ED	energy surplus/deficit, MJ/d
DNI	digestible nitrogen intake, g/d
NL	obligatory nitrogen loss, g/d
NRMILK	nitrogen requirement for milk, g/d
SN	nitrogen surplus/deficit, g/d
SP	protein surplus/deficit, g/d

Pregnancy

This part of the model follows the progress of the animal from mating through to farrowing, assuming a gestation period of 112 days, and Fig. 1 illustrates the major steps needed to predict the changes in weight and body components of the sow from the information provided.

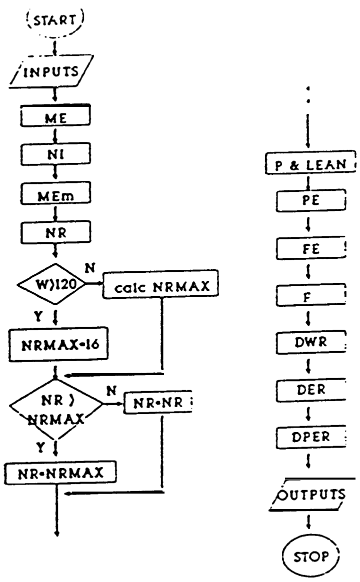


Fig. 1. Flowchart for pregnancy model

(i) Nutrient intake The basic inputs to and outputs from the model are presented in Table 2. Energy (ME) and nitrogen intake (NI) can be calculated from the basic information provided on the digestible energy (DE) and crude protein (Prot) content of the feed:

$$ME\ (MJ/d = (DE\ (MJ/kg) \times FEED\ (kg/d)) \times 0.95 \qquad (1)$$

(This assumes that the conversion factor from ME to DE is 0.95)

$$NI\ (g/d) = (PROT\ (g/kg) \times FEED\ (kg/d)) \div 6.25 \qquad (2)$$

{This assumes that 6.25 g of crude protein provides 1 g nitrogen}

TABLE 2 Inputs and outputs of pregnancy and lactation model

Inputs

1. Initial body weight at mating or post-farrowing (kg)
2. Quantity of feed (kg/d)
3. Digestible energy content of feed (MJ/kg)
4. Crude protein and lysine content of feed (g/kg)
5. Litter size
6. Growth rate of suckling piglets (kg/d)

Outputs

1. Total weight gain of sow during pregnancy and lactation (kg)
2. Maternal weight gain (kg)
3. Maternal lean gain (kg)
4. Maternal fat gain (kg)

(ii) Protein deposition The model first calculates the rate of nitrogen retention of the animal. However, not all the nitrogen consumed is retained and there are various factors which will limit the amount of nitrogen actually available to the sow. Therefore, the model uses the linear-plateau response illustrated in Fig. 2 to predict the amount of nitrogen actually retained within the body. The model therefore assumes a maximum potential for nitrogen retention, NRmax, of 16 g/d for an animal of 120 kg body weight (Williams et al., 1985). Above this body weight, NRmax is reduced by 0.05 g/day per kg increase in body weight.

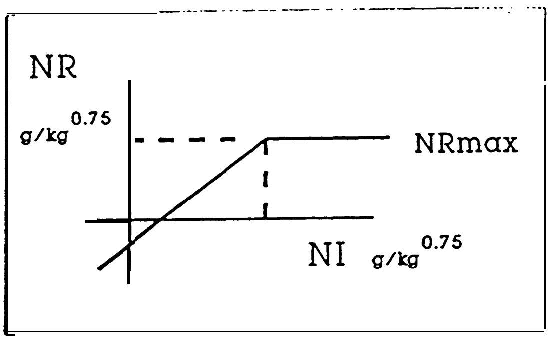


Fig. 2. The relation between the intake and the retention of nitrogen during pregnancy. For a 120 kg sow, NR_{max} = 16.0 g/day at an intake of 50.0 g n/day

The actual nitrogen retained (NR) by the animal is converted to the amount of protein deposited (P), again using the conversion factor 6.25. Deposition of lean tissue can then be calculated on the basis that protein constitutes 23% of lean tissue (AFRC, 1990; Shields and Mahan, 1983).

(iii) Energy partition The model assumes that dietary energy can be partitioned into components for maintenance, for protein deposition and for fat deposition.

The amount of energy required by the sow for maintenance is given as:

$$ME_M \text{ (MJ/d)} = 0.43 \times W \text{ (kg)}^{0.75} \quad (3)$$

This remains constant throughout pregnancy.

The energy requirement for protein deposition (PE) is calculated on the basis that each 1 kg of protein contains 23.8 MJ, and that the energetic efficiency of protein deposition is 0.6:

$$PE \text{ (MJ)} = (0.0238 \times P \text{ (g)}) \div 0.6 \quad (4)$$

The energy requirement for fat deposition (FE) is calculated by subtracting the sum of the energy requirements for maintenance and protein deposition from total ME intake:

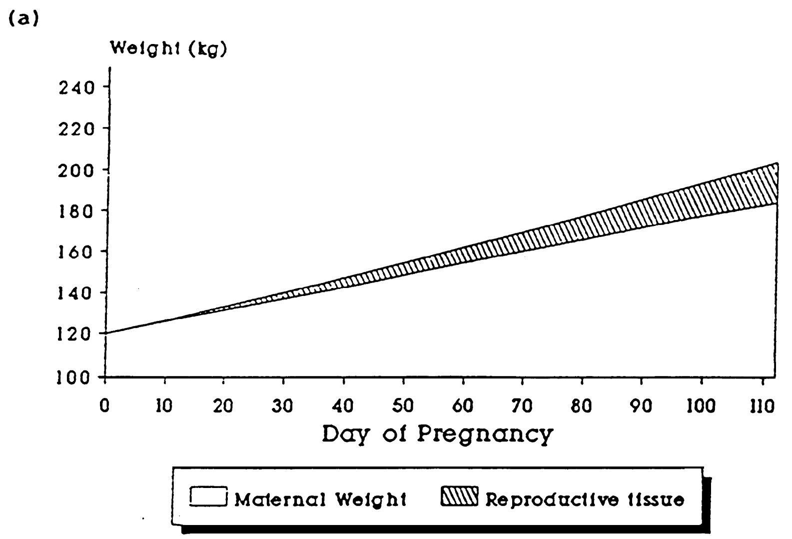
$$FE \text{ (MJ)} = ME - (MEm + PE) \quad (5)$$

(iv) Fat Deposition The quantity of fat deposited (F) is calculated on the basis that the energetic efficiency of fat retention is 0.8 and that each 1 kg of fat contains 39.7 MJ :

$$F \text{ (g)} = (0.8 \times FE \text{ (MJ)}) \div 0.0397 \quad (6)$$

(v) Body weight gain Overall body weight gain is the sum of the amount of lean and fat deposited, having been corrected for increments in both ash and gut fill (ARC, 1981).

(vi) Partition of tissue gain The prediction of total gain represents the response of the animal throughout pregnancy and takes no account of the extent to which body tissue changes during pregnancy or of the partition of the gain into maternal or conceptus components. Hence the model has been made iterative, calculating body gain during each 14-day period. By incorporating into the model the equations of Noblet et al. (1985) to predict the growth of the products of conception, it has also been possible to determine both the total and net body gain of the sow. These equations relate to the rates of energy and protein content of the conceptus tissue and take into account variations in stage of gestation, litter size and feed intake. Since the weight and energy and protein content of the conceptus tissue are known, the weight and composition of the maternal tissues can be calculated by subtraction from total body weight gain and composition. An illustration of the extent to which the body weight and lean and fat content change during pregnancy is presented in Fig. 3.



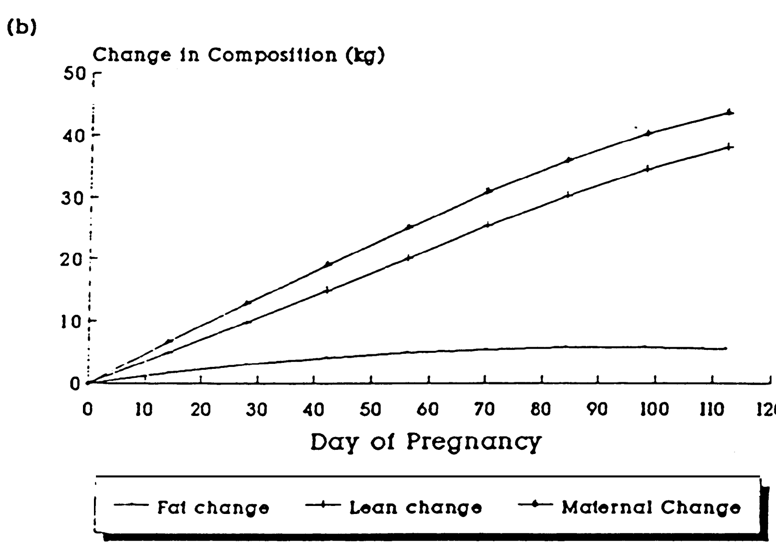


Fig. 3. Weight change and composition of change during pregnancy for an animal receiving 2.0 kg/day of a diet containing 13.0 MJ DE/kg and 160 g CP/day

(vii) Environmental considerations The model assumes that the animal is in 'a 'comfortable' environment, that is, within its zone of thermal neutrality. However, it is possible to include environmental variations into the model. Thus the model requires information on environmental temperature, windspeed, and basic housing conditions, such as the absence or presence of bedding and group- or single-housing, in order to calculate the animal's lower critical temperature (Tc) and hence establish whether extra thermoregulatory heat is produced.

The first step is, therefore, to calculate the critical temperature for a normal animal:

$$Tc = 23 - \left[\left(\frac{ME \times 1000}{W^{0.75}} - 430\right) \div 80\right] - \left[\frac{(W - 120)}{60}\right] \quad (7)$$

23°C represents the critical temperature 'of a 120 kg sow at its maintenance energy intake of 430 kJ ME/kg body weight$^{0.75}$ per day and each 80 kJ ME/kg body weight$^{0.75}$ per day increase in ME intake reduces Tc by 1°C. Similarly, Tc is reduced by 1°C for each 60 kg increase in body weight above 120 kg (Close, 1987).

This calculation of critical temperature allows for the variation associated with both energy intake and body weight. For fat animals, with high internal insulation, Tc is decreased by 2°C whereas for thin animals, with poor internal insulation, it is increased by 2°C. The provision of straw bedding reduces the Tc by 4°C compared with a cold concrete floor and above a windspeed of 20 cm/sec Tc is increased by 1°C for each additional 20 cm/sec increase.

If the environmental temperature is within the zone of thermal neutrality then no changes to thermal demand or in body composition will occur in relation to the environmental circumstances. However, if the animal is kept below its calculated critical temperature then heat output is increased and if energy intake is constant, less energy will become available for retention within the body. It is assumed that heat output increases by 18 kJ ME/kg body weight$^{0.75}$ per day per each 1°C below Tc and that this occurs solely at the expense of fat deposition (Close, 1987). Thus,

$$FDIFF = (TDIFF \times 18 \times W^{*0.75}) \div 39.7 \quad (8)$$

where TDiff is the difference in temperature between that of the environment and the critical temperature of the sow. The value of FDiff must then be subtracted from the value for the previously calculated value of fat deposition (F) to give the rate of fat deposition in environmental conditions where the animal is kept below its critical level.

Lactation

The lactation model uses the information predicted by the pregnancy model. Alternatively, new information such as body weights and litter size can also be used. A lactation length of 3 or 4 weeks is assumed.

A flowchart to describe the genesis of the lactation model is given in Fig. 4, and is based on the recent publication of Mullan *et al.* (1989).

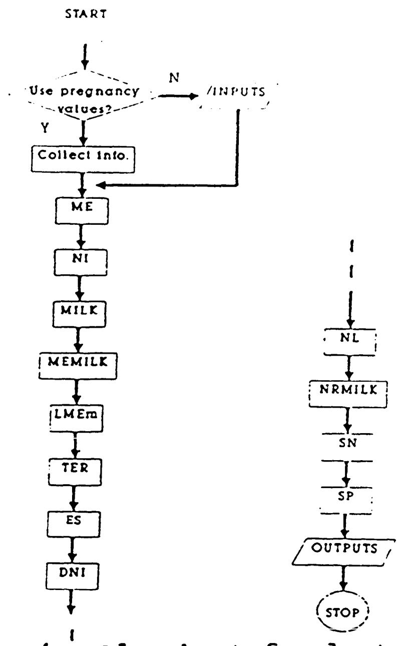


Fig. 4. Flowchart for lactation model

(i) Nutrient intake Energy and nitrogen intake are calculated as for the pregnancy model.

(ii) Energy During lactation the requirements of the sow are to maintain herself, to produce milk and to deposit tissue in her maternal body. The maintenance requirement for lactation is 540% higher than that for gestation (NRC, 1988) and so the equation becomes :

$$LMEm = 0.47 \times W^{0.75} \qquad (9)$$

The ME requirement for milk is found by calculating the growth of the litter (from rates of tissue accretion in piglets) and estimating the energy content of milk required to sustain this growth. The energy available for maternal tissue deposition, or mobilised from the body, is then calculated as the difference between total intake and that required for maintenance and milk production (Mullan et al., 1989).

(iii) Protein, fat and body weight change The gain or loss of nitrogen (protein) by the animal is calculated in a manner similar to that of energy. The energy requirement for protein deposition is then subtracted from the energy available for maternal retention to calculate the energy available for fat retention and hence the gain or loss of body fat. The conversion factor used to calculate lean and fat and total body weight change are similar to those previously described during pregnancy.

VALIDATION OF THE MODEL

Once the equations have been formulated and integrated into the model it is important to validate the performance of the model and to determine whether, compared to a real situation, it accurately predicts animal responses and performance in as wide a range of circumstances as possible. However, to test its accuracy independent data must be available which has not previously been used to develop the model.

One set of data available was from experiments recently carried out at the University of Nottingham by Zhu and Cole (unpublished). This work covered the nutrition of multiparous sows and involved several experimental designs.

One trial. compared two different feeding patterns during pregnancy. The total energy for all sows was the same according to their mating liveweight, but one set of animals was fed at a constant level, whereas the other was given a reduced amount up to day 84 and then given at a higher level for the remainder of pregnancy. Figure 5 gives a graphical representation of the results, comparing observed weight gain with the predicted values.

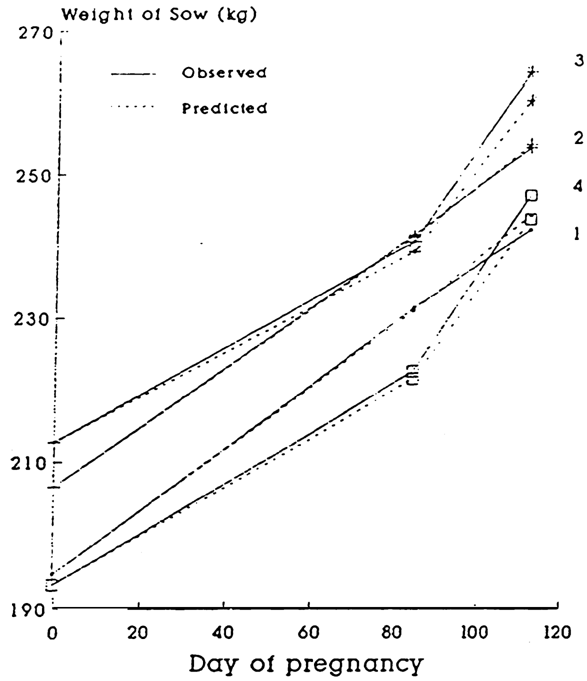


Fig. 5. Comparison of observed and predicted body weights during pregnancy from the experiments of Zhu and Cole (unpublished)

Another trial included lactation responses; the actual experiment was designed to investigate how feed applications in pregnancy affected voluntary feed intake during lactation but the data provided can be used for validation of the lactation part of the model. The comparison between the observed and predicted values of the body weight of the sows for the treatments are presented in Fig. 6.

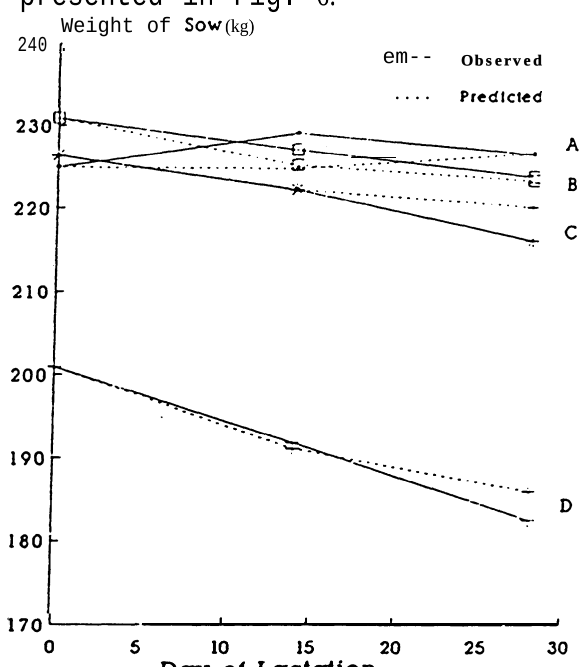


Fig. 6. Comparison of observed and predicted body weights during lactation from the experiments of Zhu and Cole (unpublished)

Both Figs. 5 and 6 show that the model accurately predicts the body weight changes of the sows and hence may be used to measure the response of the animal to dietary nutritional manipulation as well as to calculate nutritional requirements.

PREDICTIONS

From an accurate model it is possible to predict the changes in body weight which will occur over a period of time with various inputs.

Thus Table 3 shows predictions for a gilt which weighs 120 kg at mating and is given 2.0 kg/d of feed containing 12 MJ DE/kg and 150 g CP/kg. With a constant feed intake both ME and NI remain the same throughout gestation, but there are significant changes in the rate with which lean and fat are deposited (or mobilised) as pregnancy progresses; values calculated are shown in the table.

TABLE 3 Predicted changes in body weight of a gilt, 120 kg at mating, given 2.0 kg/d of feed containing 12 MJ DE/kg and 150 g crude protein/kg during pregnancy

DE	24.0	MJ/d
ME	22.8	MJ/d
NI	48.0	g/d

Days	0–14	15–28	29–42	43–56	57–70	71–84	85–98	99–112	Av.
MEm, MJ/d	15.6	16.30	17.0	17.7	18.4	19.1	19.7	20.3	18.0
NR, g/d	13.0	13.9	14.7	15.3	15.3	15.3	15.3	15.3	14.8
P, g/d	81.3	86.6	92.0	95.6	95.6	95.6	95.6	95.6	92.2
PE, MJ/d	3.2	3.4	3.6	3.8	3.8	3.8	3.8	3.8	3.7
FE, MJ/d	4.0	3.1	2.2	1.3	0.6	−0.05	−0.7	−1.3	1.1
F, g/d	80.3	61.9	43.4	26.3	12.3	−1.7	−21.8	−40.9	20.0
Total gain kg/14d	7.3	7.4	7.5	7.5	7.3	7.1	6.7	6.5	OVERALL 57.1 kg
Maternal gain kg/14d	6.1	5.6	5.7	5.5	5.0	4.4	3.5	2.6	38.4 kg
Lean gain kg/14d	5.0	4.8	5.1	5.2	4.9	4.5	3.9	3.3	36.6 kg
Fat gain kg/14d	1.12	0.85	0.6	0.34	0.12	−0.09	−0.41	−0.71	1.8 kg

An advantage of modelling is that a series of predictions can be made which involve only one change in input, or several changes. This allows comparisons to be made of different conditions with relative ease. For example, Table 4 shows the predicted response of animals of different body weight and at variable or constant feed intakes in pregnancy. The results are presented in graphical form in Fig. 7.

TABLE 4 Predicted changes in body weight and body composition of animals of various body weights fed at different levels during pregnancy

Weight changes for a gilt, 120 kg body weight at mating given a diet containing 12 MJ/kg and 150 g CP/kg, at various levels of feeding					
Feed Intake kg	DE MJ/d	NR g/d	Lean gain kg	Fat gain kg	Maternal gain kg
1.5	18.0	10.9	25.9	−9.4	16.5
2.0	24.0	15.3	36.6	1.8	38.4
2.5	30.0	16.0	39.1	13.0	52.0
3.0	36.0	16.0	37.5	24.7	62.2

Weight changes of sows of different body weight given 2 kg/d of a diet containing 12 MJ DE/kg and 150 g CP/kg					
Mating Weight kg	DE MJ/d	NR g/d	Lean gain kg	Fat gain kg	Maternal gain kg
120	24	15.3	36.6	1.8	38.4
130	24	15.1	35.7	−0.1	35.6
140	24	15.0	34.7	−2.1	32.6
150	24	14.8	33.7	−4.1	29.6

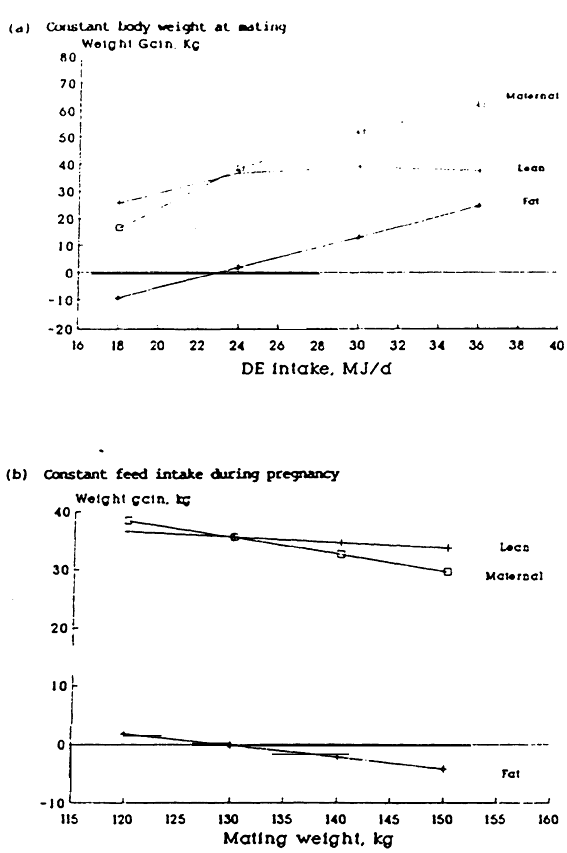


Fig. 7. Predicted changes in body weight and body composition of sows during pregnancy

MODIFICATIONS

The model as it is currently developed, concentrates on the intake of crude protein and energy, and the affect these have on body weight changes and composition. It is becoming increasingly important to look at the body reserves of an animal and it would be useful if the model could include a prediction of, for example, backfat change for the sow over the reproductive cycle as an indication of change in fat status. There have been several recent attempts to relate the backfat measurement of the animal to its energy intake, weight change or body fat content, and the results from these studies will lead to a prediction equation which could be included in the model (Harker and Cole, 1985; Whittemore and Yang, 1989).

Currently, protein is considered only as crude protein intake. The actual quality of this protein will be equally, if not more important and, therefore, some consideration of amino acid pattern of the protein fed could make a significant improvement to the accuracy of the model. Thus lysine will be considered within the model and the 'ideal protein' concept will be applied to assess the essential amino acids relative to lysine intake and retention (ARC, 1981).

Other modifications which are currently being considered include :

- the option to vary the maximum nitrogen retention to take into account the different potential for protein deposition associated with different genotypes;
- some appreciation of voluntary feed intake of the sow, especially in lactation;
- the inclusion of creep feed for piglets;
- the removal of some piglets before others during lactation to allow split weaning techniques to be applied;
- consideration of the weaning to re-mating period to complete the reproductive cycle.

It would also be useful if the model could be applied reciprocally, in order to ask questions. For example, the model could be asked to 'find the nutrient or feed intake required to produce a specific body weight gain under certain conditions. However, by making the model more complicated it can sometimes make it less useful as a tool since it requires much more information which may be inappropriate or, indeed, unavailable. However, if the accuracy and suitability of the model can be improved in simple ways then a more marketable tool of considerable potential to the industry will be produced in the longer term.

SUMMARY AND CONCLUSION

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