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Factorial Approach for Estimating Metabolizable Energy Requirement of Pregnant Swine

Mamoru SAITOH

Abstract

Metabolizable energy (ME) requirements for pregnant swine were estimated by the factorial method on the basis of the proposed model and the available data as well. The results indicated that the ME requirements estimated in the present study were lower by approximately 15% and 9% at 20 kg and 40 kg net weight gain during pregnancy, respectively, as compared with those recommended by the Agricultural Research Council (1981). The daily ME requirements of pregnant swine increased at the rates of 21.9 kcal, 63.8 kcal and 125.4 kcal with an increase of 1 kg in body weight at mating, 1 kg in net weight gain during pregnancy and a head in the number of fetus, respectively. Such information should be highly useful in managing the feeding of pregnant swine. However, the reproductive performance for a long-term must be carefully examined in pregnant swine reared with the amount of ME proposed in the present study.

Discipline: Animal industry
Additional key words: dietary ME, energy retention, maintenance ME, ME efficiency, model equations

Introduction

During the last few years, animal nutrition researchers have increasingly been paying their greater attention to the problems pertaining to feeding of pregnant swine. Their study efforts have provided increased data available for research undertaken in this specific field. However, there is still a serious shortage of experimental evidences to identify nutritional requirements of pregnant swine. First; there is a difficulty in evaluating precisely reproductive efficiency of swine from the relevant measurements which fluctuate to a great deal. For example, a herd of 100 sows reared under identical feeding regimes may include sows producing a wide range of litters varying from 2 to 20 pigs at birth, and birth weight of the pigs may also vary from 0.9 to 1.8 kg. Second; there is another problem in defining adequate criteria for evaluating reproductive performances of pregnant swine. Third; the efficiency of utilization of dietary energy for energy gain in the maternal body and fetus is to be identified yet. Last; the pregnant swine have an ability that protects the offspring against nutritional deficiencies in the diets by drawing on her own reserves to allow the fetal to survive and grow.

In evaluating energy requirements of the pregnant swine, it is necessary to formulate an appropriate index for judging energy situation in the swine during the pregnancy.

Towards this end, a new proposal of employing a factorial method has been proposed by the author to determine a metabolizable energy (ME) requirement of pregnant swine[21–25] This method is expected to contribute to overcoming of such difficulties as mentioned above. The ME requirement of pregnant swine can be estimated by partitioning the ME intake into ME requirement for maintenance, maternal energy gain and energy gain of the gravid uterus.

Prior to the experiments with pregnant swine, a series of studies have been undertaken with rats to establish a theoretical basis of the factorial method

Department of Animal Nutrition, National Institute of Animal Industry (Tsukuba, Ibaraki, 305 Japan)

for determining an ME requirement during pregnancy[11-19]. In order to confirm the applicability of the factorial method to pregnant swine, another series of experiments have been conducted by the author. The main objective of this paper is to review the results of a series of those studies on ME requirement of pregnant swine[21-25].

Equations for estimating an ME requirement of pregnant swine

1) Model equations

The following model equations were used for the factorial estimates of ME requirement in pregnant swine:

$$ME = MEm + (1/kw)ERw \quad \cdots\cdots (1)$$

$$ME = MEm + (1/kp)ERwp + (1/kf)ERwf \quad \cdots\cdots (2)$$

$$ME = MEm + (1/km)ERm + (1/ku)ERu \quad \cdots\cdots (3)$$

where ME: ME requirement, MEm: ME requirement for maintenance, kw: efficiency of utilization of dietary ME for energy retention in the whole body, ERw: energy retention in the whole body, kp or kf: efficiency of utilization of dietary ME for the energy retention as protein or fat in the whole body, ERwp or ERwf: energy retention as protein or fat in the whole body, km or ku: efficiency of utilization of dietary ME for energy retention in the maternal body or gravid uterus, ERm or ERu: energy retention in the maternal body or gravid uterus, respectively in each item above.

2) Estimated values of MEm and efficiencies of utilization of dietary ME for energy retention

Mean values of MEm, kw, kp, kf, km and ku in pregnant swine obtained by the author's experiments[21,22,24] and collected from literatures[2,3,5-7,9] are shown in Table 1. The values of km and ku were taken from limited data reported by the author[24] and Close et al.[3].

Mean values of MEm, kw, kp, kf, km and ku were 105 ± 20 kcal/$W_{kg}^{0.75}$/day[2,3,5-7,9,21,22,24], 76 ± 10%[2,3,6,7,9,21,22,24], 60 ± 17%[3,5,7,24], 87 ± 7%[3,5,7,22,24], 90%[3,24] and 65%[3,24], respectively. Although the data are not presented in the table, the value of MEm in growing-fattening pig (non-pregnant) recommended for use by Agricultural Research Council (ARC, UK)[1] was 109 kcal/$W_{kg}^{0.75}$/ day and mean values of kw, kp and kf in growing-fattening pigs collected by the author were 71 ± 6% (n = 5), 56 ± 13% (n = 23) and 74 ± 7% (n = 23), respectively[20]. There was no significant difference in the values of MEm, kw and kp between the pregnant swine and the growing-fattening pig. However, the value of kf in the pregnant swine was higher by approximately 18% than that of the growing-fattening pig and this difference is statistically significant ($P < 0.001$). This might have been caused by the large difference in body weight and fat deposition between the pregnant swine and the growing-fattening pig used in the experiment.

Table 1. Estimates of metabolizable energy (ME) requirements for maintenance, and efficiencies of ME utilization for energy retention in pregnant swine

	MEm[a]	kw[b]	kp[c]	kf[d]	km[e]	ku[f]
	kcal/$w_{kg}^{0.75}$/day	%	%	%	%	%
Mean ± SD	105 ± 20	76 ± 10	60 ± 17	87 ± 7	90	65
n	12	11	4	5	2	2

a): Maintenance ME[2,3,5-7,9,21,22,24],
b): Efficiency of ME utilization for energy retention in the whole body[2,3,6,7,9,21,22,24],
c): Efficiency of ME utilization for energy retention as protein in the whole body[3,5,7,24],
d): Efficiency of ME utilization for energy retention as fat in the whole body[3,5,7,22,24],
e): Efficiency of ME utilization for energy retention in the maternal body[3,24],
f): Efficiency of ME utilization for energy retention in the total gravid uterus[3,24].

3) Estimation of the ME requirement of pregnant swine

Based on the mean values of MEm and the efficiencies of utilization of dietary ME for energy retention presented in Table 1, the following equations were formulated to estimate ME requirements of pregnant swine:

$$ME = 105W_{kg}^{0.75} + \frac{1}{0.76} ERw \quad \cdots\cdots (4)$$

$$ME = 105W_{kg}^{0.75} + \frac{1}{0.60} ERwp + \frac{1}{0.87} ERwf \quad \cdots\cdots (5)$$

$$ME = 105W_{kg}^{0.75} + \frac{1}{0.90} ERm + \frac{1}{0.65} ERu \quad \cdots\cdots (6)$$

where 105 = MEm, and ERw, ERwp, ERwf, ERm and ERu were referred to earlier. All the units are expressed in kcal/$W_{kg}^{0.75}$/day.

4) Establishment of ERw, ERwp, ERwf, ERm and ERu

In order to calculate ME requirements of pregnant swine using equations (4) through (6), it is necessary to determine the values of ERw, ERwp, ERwf, ERm and ERu. The data of chemical compositions in maternal body of the pregnant swine which had been fed under different amounts of feed, after Kotarbinska[8], are available to determine ERm, ERmp (energy retention as protein in the maternal body) and ERmf (energy retention as fat in the maternal body). On the basis of those data, it was estimated that the rates of protein and fat depositions in net weight gain (excluding the gravid uterus) during pregnancy were approximately 13 and 16% in low net weight gain of 20 kg and approximately 12 and 31% in high net weight gain of 40 kg, respectively.

ERu and ERup (energy retention as protein) in the gravid uterus were calculated by subtracting energy and protein contents (energy: 400 kcal and protein: 61 g) in the non-gravid uterus at mating from those contents in the gravid uterus at 114 days of pregnancy, respectively. Energy and protein contents in the latter stage were estimated by the following equations, respectively[23].

$$\mathrm{Log_e}Ue = -7.2847 + 8.3793e^{0.003531\ (t-80)} + 0.06936N \quad \cdots\cdots (7)$$

$$\mathrm{Log_e}Up = 7.6577 - 1.6056e^{-0.03321\ (t-80)} + 0.05875N \quad \cdots\cdots (8)$$

where Ue and Up: energy (Mcal) and protein (g) contents in the gravid uterus, t and N: days of pregnancy and the number of fetus, e: natural logarithm, respectively. Based on these estimates, ERw, ERwp and ERwf were calculated with formulae of ERm + ERu, ERmp + ERup and ERmf + (ERu − ERup), respectively.

Variation of ME requirements with changes in the net weight gain during pregnancy and in the number of fetus

The ME requirements of pregnant swine with changes in the net weight gain during pregnancy and in the number of fetus are presented in Tables 2–4.

The ME requirement estimated by the equation (5) (Table 3) is in good agreement with that estimated by the equation (6) (Table 4), with a small difference of below 2%. However, the ME requirement estimated by the equation (4) (Table 2) is lower by approximately 5% than those based on the equations (5) and (6). This difference might be caused by the biased estimates with regard to the utilization efficiency of dietary ME for energy retention, which is shown in Table 1. To alleviate this resulting bias, additional data on km and ku are required.

If the ME requirements of pregnant swine are estimated by an appropriate equation with associated variables of the body weight at mating, the net weight gain during pregnancy and the number of fetus, the requirements can easily be identified with a series of information on their quantitative variation caused by the changes in those variables. An equation derived is as follows:

$$ME = -131.5 + 21.9Wm + 63.8WGn + 125.4N \quad \cdots\cdots (9)$$
$$(R: 0.998,\ P < 0.01)$$

where ME: ME requirement in kcal/day, the mean values of which are shown in Tables 2–4, Wm: body weight in kg at mating, WGn: net weight gain in kg during pregnancy, and N: the number of fetus.

Table 2. Metabolizable energy (ME) requirements of pregnant swine determined by ME = $105W_{kg}^{0.75}$ + 1/0.76 ERw, the equation (4) in the text, and their relevant components

BW[a] at mating (kg)	120						140						160					
Net WG[a] (kg/114 days)	20			40			20			40			20			40		
No. of fetus	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
	kcal/day																	
MEm[b]	4,228	4,296	4,399	4,455	4,523	4,624	4,679	4,746	4,845	4,900	4,965	5,063	5,117	5,181	5,278	5,331	5,395	5,490
	(95.5)[c]	(85.8)	(75.5)	(76.9)	(70.9)	(64.3)	(96.0)	(86.9)	(77.3)	(78.5)	(72.8)	(66.3)	(96.3)	(87.9)	(78.8)	(79.9)	(74.4)	(68.1)
ME requirement for ERw[c]	197	713	1,424	1,339	1,855	2,572	197	713	1,424	1,339	1,855	2,572	197	713	1,424	1,339	1,855	2,572
	(4.5)	(14.2)	(24.5)	(23.1)	(29.1)	(35.7)	(4.0)	(13.1)	(22.7)	(21.5)	(27.2)	(33.7)	(3.7)	(12.1)	(21.2)	(20.1)	(25.6)	(31.9)
ME requirement (kcal/day)	4,425	5,009	5,823	5,794	6,378	7,196	4,876	5,459	6,269	6,239	6,820	7,635	5,314	5,894	6,702	6,670	7,250	8,062
Feed provided[d] (g/day)	1,526	1,727	2,008	1,998	2,199	2,481	1,681	1,882	2,162	2,151	2,352	2,633	1,832	2,032	2,311	2,300	2,500	2,780

a): BW; Body weight, WG; Weight gain, b): MEm; Maintenance ME, c): ERw; Energy retention in the whole body, d): Diet containing 2.9 kcal ME/g, e): Figures shown in parentheses denote % of ME requirement.

Table 3. Metabolizable energy (ME) requirements of pregnant swine determined by ME = $105W_{kg}^{0.75}$ + 1/0.60 ER_{wp} + 1/0.87 ER_{wf}, the equation (5) in the text, and their components

BW[a] at mating (kg)	120						140						160					
Net WG[a] (kg/114 days)	20			40			20			40			20			40		
No. of fetus	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
	kcal/day																	
MEm[a]	4,228	4,296	4,399	4,455	4,523	4,624	4,679	4,746	4,845	4,900	4,965	5,063	5,117	5,181	5,278	5,331	5,395	5,490
	(95.3)[d]	(87.9)	(79.2)	(77.9)	(73.3)	(67.6)	(95.7)	(89.0)	(80.7)	(79.5)	(75.1)	(69.5)	(96.1)	(89.8)	(82.0)	(80.8)	(76.6)	(71.2)
ME requirement for:																		
ERp[b]	272	372	513	445	545	687	272	372	513	445	545	687	272	372	513	445	545	687
	(6.1)	(7.6)	(9.2)	(7.8)	(8.8)	(10.0)	(5.6)	(7.0)	(8.5)	(7.2)	(8.2)	(9.4)	(5.1)	(6.4)	(8.0)	(6.7)	(7.7)	(8.9)
ERf[c]	−63	217	645	818	1,103	1,531	−63	217	645	818	1,103	1,531	−63	217	645	818	1,103	1,531
	(−1.4)	(4.4)	(11.6)	(14.3)	(17.9)	(22.4)	(−1.3)	(4.1)	(10.7)	(13.3)	(16.7)	(21.0)	(−1.2)	(3.8)	(10.0)	(12.4)	(15.7)	(19.9)
ME requirement (kcal/day)	4,437	4,885	5,557	5,718	6,171	6,842	4,888	5,335	6,003	6,163	6,613	7,281	5,326	5,770	6,436	6,594	7,043	7,708
Feed provided[d] (g/day)	1,530	1,684	1,916	1,972	2,128	2,359	1,686	1,840	2,070	2,125	2,280	2,510	1,837	1,990	2,219	2,274	2,429	2,658

a): Refer to footnotes a) and b) of Table 2, b): Energy retention as protein in the whole body, c): Energy retention as fat in the whole body, d): Refer to footnotes d) and e) of Table 2.

Table 4. Metabolizable energy (ME) requirements of pregnant swine determined by $ME = 105W_{kg}^{0.75} + 1/0.90\ ERm + 1/0.65\ ERu$, the equation (6) in the text, and their components

BW[a)] at mating (kg)	120						140						160					
Net WG[a)] (kg/114 days)	20			40			20			40			20			40		
No. of fetus	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
	kcal/day																	
MEm[a)]	4,228	4,296	4,399	4,455	4,523	4,624	4,679	4,746	4,845	4,900	4,965	5,063	5,117	5,181	5,278	5,331	5,395	5,490
	(95.2)[d)]	(86.6)	(77.3)	(79.1)	(73.5)	(67.1)	(95.7)	(87.7)	(78.9)	(80.6)	(75.3)	(69.1)	(96.0)	(88.6)	(80.3)	(81.9)	(76.8)	(70.8)
ME requirement for:																		
ERm[b)]	51	437	966	1,016	1,401	1,936	51	437	966	1,016	1,401	1,936	51	437	966	1,016	1,401	1,936
	(1.1)	(8.8)	(17.0)	(18.0)	(22.8)	(28.1)	(1.0)	(8.1)	(15.7)	(16.7)	(21.2)	(26.4)	(1.0)	(7.5)	(14.7)	(15.6)	(19.9)	(25.0)
ERu[c)]	160	229	328	160	229	328	160	229	328	160	229	328	160	229	328	160	229	328
	(3.6)	(4.6)	(5.8)	(2.8)	(3.7)	(4.8)	(3.3)	(4.2)	(5.3)	(2.6)	(3.5)	(4.5)	(3.0)	(3.9)	(5.0)	(2.5)	(3.3)	(4.2)
ME requirement (kcal/day)	4,439	4,962	5,693	5,631	6,153	6,888	4,890	5,412	6,139	6,076	6,595	7,327	5,328	5,847	6,572	6,507	7,025	7,754
Feed provided[d)] (g/day)	1,530	1,711	1,963	1,942	2,122	2,375	1,686	1,866	2,117	2,095	2,274	2,527	1,837	2,016	2,266	2,244	2,422	2,674

a): Refer to footnotes a) and b) of Table 2, b): Energy retention in the maternal body, c): Energy retention in the total gravid uterus, d): Refer to footnotes d) and e) of Table 2.

Partial regression coefficients in the equation (9) are statistically significant ($P < 0.001$). From this equation, it is shown that the daily ME requirements of pregnant swine increase at the rates of 21.9 (95% confidence interval: 20.1 − 23.7) kcal, 63.8 (60.8 − 66.8) kcal and 125.4 (118.1 − 132.7) kcal with an increase of 1 kg in body weight at mating, 1 kg in net weight gain during pregnancy and a head in the number of fetus, respectively. Based on the equation (9), the ME requirement of pregnant swine under a given condition could be determined, providing that the body weight at mating, the net weight gain during pregnancy and the number of fetus are specified. Such information should be highly useful in managing the feeding of pregnant swine.

In applying this equation in practice, it is prerequisite to precisely estimate the number of embryos at the early pregnancy in swine. However, estimation of that number is difficult at the present stage. One of the ways to solve this problem is to calculate ME requirements of the pregnant swine on the assumption that swine conceives mean litters in number, which are 10 in general.

Comparison of the estimated ME requirements among the present study, the Agricultural Research Council (ARC) and the National Research Council (NRC)

As shown in Table 5, the ME requirements of pregnant swine in the present study are lower by approximately 15 and 9% at 20 and 40 kg net weight gain during pregnancy, respectively, than those recommended by the ARC[1)]. The discrepancy might be caused by the differences in the chemical composition of body weight gain as well as in the efficiency of utilization of dietary ME for energy deposition in the maternal body and the gravid uterus[25)].

At the 92nd Meeting of the British Society of Animal Production held in 1987, Close[4)] indicated that the ME requirements of pregnant swine assessed by the ARC in 1981 was overestimated.

On the other hand, in 1988, the NRC demonstrated an amount of 6,100 kcal as a daily ME requirement of pregnant swine of 150 kg body weight at mating and 25 kg net weight gain during pregnancy. Putting the variables of body weight at mating and of net weight gain in NRC[10)] in the equation (9) of this text, the daily ME requirement

Table 5. Comparison between the metabolizable energy requirements of pregnant swine estimated in the present study and the feeding standard recommended by the Agricultural Research Council (ARC)

BW[a] at mating (kg)	120		140		160	
Net WG[a] (kg/114 days)	20	40	20	40	20	40
	kcal/day					
Present study (A)[b]	4,952	6,234	5,402	6,676	5,837	7,106
ARC (B)[c]	5,851	6,837	6,333	7,319	6,814	7,778
B-A (kcal/day)	899	603	931	643	977	672
A/B	0.85	0.91	0.85	0.91	0.86	0.91

a): Refer to the footnote a) of Table 2,
b): Means of the values estimated by the equations (4)–(6) in the text. Number of fetus is 10,
c): Refer to the reference 1).

is estimated at 6,003 kcal, if the number of fetus is 10. This value is in good agreement with the above estimate by the NRC[10].

In improving the proposed factorial approach for more precise estimation, it would be necessary to incorporate the changes of protein and fat depositions in the maternal body which are accompanied by varying body weight at mating and net weight gain during pregnancy.

Reproductive performance in pregnant swine for a long-term basis

Whittemore et al.[26,27] indicated that the daily gestation feed intakes at 1.7 kg (5,100 kcal ME), 2.0 kg (6,000 kcal ME) and 2.3 kg (6,900 kcal ME) maintained for 5 parities had no significant effect on the total number of pigs born. However, sows receiving the lowest level of feed showed a higher overall culling rate.

On the conditions assumed that the body weight at mating is 120 kg, the net weight gain during pregnancy is 20 kg, the number of fetus is 10 and the decrease of maternal body weight during lactation period (28 days) is 10 kg, the average daily ME intake is estimated at 5,398 kcal with the body weight of approximately 170 kg at the finish of 5 parities. These estimates are calculated from the data presented in Table 5. The estimated ME intake above corresponds to the intermediate level of the daily feed intakes at 1.7 and 2.0 kg during pregnancy reported by Whittemore et al.[26,27]. This result suggests that there be neither decline in reproductive performance, nor increase in culling rate of pregnant swine, providing that the body weight at mating and the net weight gain during pregnancy are assumed at 120 kg and 20 kg, respectively. However, the reproductive performance for a long-term must be carefully examined in pregnant swine reared with the amount of ME proposed in the present study.

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