The Rate of Increase in Energy Requirements under a Cold Environment for Individually Reared Pigs

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Abstract A total of 42 pigs weighing about 30 to 120 kg (non-pregnant) were used for the experiments. These animals were kept individually in metabolism cages and fed different amounts of feed in both a cold environment and thermoneutral zone for about a month. Then, respiration trials were conducted for 3 days using an open-circuit type indirect respiration calorimeter. The results obtained are summarized as follows: 1) Metabolizable energy (ME) requirements for maintenance were estimated at 95 kcal/W0.75kg/day. 2) The prediction equation for heat production in the thermoneutral zone was H = 60.0 + 0.37 ME (H: heat production kcal/W0.75kg/day, ME: ME intake kcal/W0.75kg/day). 3) The prediction equation for lower critical temperature (Tc) was Tc = 24.2 - 0.05 W - 0.023 ME (Tc: lower critical temperature °C, W: body weight kg, ME: ME intake kcal/W0.75kg/day). 4) The rates of increase in heat production per 1°C below Tc were estimated at 6.4, 6.0 and 4.8 kcal/W0.75kg/day at 30 to 50 kg, 50 to 100 kg and 120 kg body weight, respectively. 5) Percentages of extra feed per 1°C below Tc needed to maintain energy retention at a rate similar to that within the thermoneutral zone were 2.0, 2.2 and 3.2% at 30 to 50 kg, 50 to 100 kg and 120 kg body weight respectively, assuming that the feed contained 2.8 kcal ME/g air-dry matter.


Key words: pig, cold environment, critical temperature, heat production, energy requirement

Thermal neutrality is the zone of environmental temperature within which an animal's heat expenditure is constant and at a minimum, with a corresponding maximum retention of dietary energy. The lower end of the thermoneutral zone is termed the lower critical temperature (Tc).

When the environmental temperature falls below Tc, heat loss (production) increases and less energy is available for growth.

It is very useful to know the extent to which different combinations of environmental temperature and rate of feed intake influence Tc and heat production when there are variations in the weight of the animal.

Some information1-5) is available regarding Tc and the increased rate of heat production and the amount of extra feed at temperature below Tc in pigs reared individually. However, the considerable differences exist between their values in the
Table 1. Compositions of experimental diets (%)

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>A (for fattening)</th>
<th>B (for gilt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground yellow corn</td>
<td>22.0</td>
<td>36.0</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>12.0</td>
<td>17.65</td>
</tr>
<tr>
<td>Defatted rice bran</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Barley</td>
<td>22.0</td>
<td>27.0</td>
</tr>
<tr>
<td>Soybean meal (CP 46%)</td>
<td>9.0</td>
<td>2.0</td>
</tr>
<tr>
<td>White fish meal (CP 60%)</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Alfalfa meal (dehydrated)</td>
<td>2.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Milo</td>
<td>22.0</td>
<td></td>
</tr>
<tr>
<td>CaCO₃</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Ca₃(PO₄)₂</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Trace mineral premix⁽ᵃ⁾</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td>Vitamin A, D, E premix⁽ᵇ⁾</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td>Vitamin B premix⁽ᶜ⁾</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>DL-methionine</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>15.1</td>
<td>12.4</td>
</tr>
<tr>
<td>Digestible crude protein (%)</td>
<td>12.2</td>
<td>10.1</td>
</tr>
<tr>
<td>Gross energy (kcal/g)</td>
<td>3.89</td>
<td>3.96</td>
</tr>
<tr>
<td>Metabolizable energy (kcal/g)</td>
<td>2.78</td>
<td>2.82</td>
</tr>
</tbody>
</table>

⁽ᵃ⁾CaIO₃1.54, MnSO₄ 137.5, FeSO₄ 136.0, CuSO₄ 20.1 and ZnCO₃ 115.2 g/kg. ⁽ᵇ⁾ vitamin A 10,000 IU, vitamin D₃ 2,000 IU and DL-α-tocopherolacetate 10mg per g. ⁽ᶜ⁾ thiamin mononitrate 1.0, riboflavin 7.0, pyridoxine HCl 0.5, nicotinamide 6.0, D-calciumpan-tothenate 10.9 and choline chloride 57.6 g/kg. These premixes were all purchased from Takeda Scientific Feed Co. Ltd.

This study was mainly conducted to clarify 1) the heat production of pigs kept individually under thermoneutral zone and cold environment with some variations in the level of metabolizable energy (ME) intake of animals and of different body weight, 2) a prediction equation of Tc, and 3) the rate of increase in heat production and extra feed at temperature below Tc required to maintain energy retention at a rate similar to that within the thermoneutral zone.

Materials and Methods

1. Compositions of experimental diets

The compositions of the experimental diets are shown in Table 1. Diets A and B have been generally used for fattening pigs and gilts in this Institute, respectively. Diet A was mainly composed of ground yellow corn, barley and milo, and diet B was mainly composed of ground yellow corn, wheat bran and barley. Digestible crude protein (DCP) and ME contents of diets A and B were 13.9% and 3.16 kcal/g, and
Table 2. Body weights of pigs used for respiration trials and temperature and relative humidity in respiration chamber

<table>
<thead>
<tr>
<th></th>
<th>No. of pig</th>
<th>Body weight</th>
<th>Temperature</th>
<th>Relative humidity</th>
<th>No. of pig</th>
<th>Body weight</th>
<th>Temperature</th>
<th>Relative humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg</td>
<td>°C</td>
<td>%</td>
<td></td>
<td>kg</td>
<td>°C</td>
<td>%</td>
</tr>
<tr>
<td>Fattening pig</td>
<td>16</td>
<td>63.6±12.0</td>
<td>20.3±0.6</td>
<td>61±2</td>
<td>22</td>
<td>46.9±12.0</td>
<td>11.7±3.0</td>
<td>60±4</td>
</tr>
<tr>
<td>Gilts</td>
<td>2</td>
<td>116.1±4.7</td>
<td>19.4±0.0</td>
<td>60±0</td>
<td>2</td>
<td>116.1±4.7</td>
<td>7.7±0.2</td>
<td>63±1</td>
</tr>
</tbody>
</table>

a) Fed diet A.  b) Fed diet B.  c) Mean±SD.

11.5% and 3.20 kcal/g dry matter, respectively. ME and DCP contents in diets A and B were determined by the animal experiment.

2. Animals and managements

As shown in Table 2, a total of 42 pigs weighing about 30 to 120 kg were used for the respiration trials. These were purebred (L and D) and crossbred (LH·W, LHW·L and LW·D) pigs.

Four pigs in the experiment under a thermoneutral zone and 6 pigs under a cold environment were female and the other pigs were castrated male. Diet B was given to gilts (non-pregnant) and diet A was fed to the other pigs. These pigs were reared individually in metabolism cages under various environmental temperatures.

Experimental diets were fed at the levels of about 2.9±0.7% (± SD) of body weight in fattening pigs and about 1.6±0.1% of body weight in gilts once daily at about 8 am. This feeding level was about 30% less in fattening pigs and about 20% less in gilts comparing with those in feed requirements6) of each body weight. Such severe restriction in the feeding level was done to maintain below 2% of CO₂ concentration in the respiration chamber for excluding the harmful effect of CO₂ to animals and to prevent the scattering of feed from the trough. Drinking water was supplied to pigs by pouring water into the trough of the metabolism cage from a 10 l polyethylen tank. The amount of drinking water corresponded to about 3 to 4 times the amount of feed intake.

The experiments were conducted under environmental conditions in which temperature and relative humidity in both the experimental room and the respiration chamber were similarly controlled.

3. Respiration trials

3-1. Respiration trials under a thermoneutral zone

A total of 18 pigs were used for respiration trials under a thermoneutral zone. Average temperature and relative humidity in both the experimental room and the respiration chamber were 20.2 ± 0.6°C and 61 ± 2% (± S.D.), respectively.

3-2. Respiration trials under a cold environmental temperatures

A total of 24 pigs were used for the respiration trials under a cold environment. Respiration trials were conducted using 12 pigs each at 7-9°C and 13-14°C levels. Relative humidity in the respiration chamber was maintained at 60 ± 4%.
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4. Respiration apparatus
An outline of the respiration apparatus used in this study has already been reported by IWASAKI et al.7). This apparatus is the open-circuit type·indirect calorimeter. The measurements of \( \text{O}_2 \) consumption, and \( \text{CO}_2 \) and \( \text{CH}_4 \) productions by the pigs were automatically conducted by the automated gas analyzer apparatus.

5. Calculation of heat production
The heat production was computed by using an equation proposed by BROUWER8): 
\[
H = 3.866 \times \text{O}_2 \text{ consumption (l)} + 1.200 \times \text{CO}_2 \text{ production (l)} - 0.518 \times \text{CH}_4 \text{ production (l)} - 1.431 \times N \text{ excreted in the urine (g)}.
\]
Nitrogen content in the urine was determined using the automated analyzer (Technicon Instruments, Co. Ltd.) after Kjeldahl digestion.

6. Estimation of the lower critical temperature
\[ T_c = TR - \left( \frac{\text{HP} / \text{BSA at thermoneutral zone}}{\text{HP} / \text{BSA at } T - \text{TR} - T} \right) \]
where HP: heat production (kcal), BSA: body surface area (m\(^2\), 0.097 \( W_{kg}^{0.633} \)), TR: rectal temperature (°C), T: environmental temperature (°C).
Rectal temperature of the pigs was assumed to be 39°C9), because rectal temperatures of pigs used for this experiment were not determined.

7. Determination of the rate of increase in heat production and extra ME requirements needed to maintain energy retention at temperature below \( T_c \) at a rate similar to that within the thermoneutral zone
A multiple regression equation for the prediction of thermoneutral heat production of pigs weighing about 30 to 120 kg was determined by using the data in respiration trials under a thermoneutral zone.

The rate of increase in heat production at a temperature below \( T_c \) was determined by subtracting heat production under a thermoneutral zone estimated using above-mentioned multiple regression equation from heat production below \( T_c \).

The increase in heat production at a temperature below \( T_c \) was expressed in kcal per metabolic body weight (\( W_{kg}^{0.75} \)) per day per 1°C below \( T_c \).

The amounts of feed equivalent to the increase in heat production were calculated

<p>| Table 3. Metabolizable energy (ME) intake and heat production in pigs kept individually under a thermoneutral zone and cold environment |
|---------------------------------|--------------|--------------|----------------|--------------|--------------|
|                                 | Thermoneutral zone |                                          | Cold environment |                                  |              |</p>
<table>
<thead>
<tr>
<th>No. of pig</th>
<th>ME intake</th>
<th>Heat production</th>
<th>No. of pig</th>
<th>ME intake</th>
<th>Heat production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatting pig</td>
<td>16</td>
<td>202±37 (^a)</td>
<td>134±15</td>
<td>22</td>
<td>214±54</td>
</tr>
<tr>
<td>Gilt</td>
<td>2</td>
<td>147±5</td>
<td>107±7</td>
<td>2</td>
<td>147±5</td>
</tr>
</tbody>
</table>

\(^a\) Mean ± SD.
assuming that the feed contained 2.80 kcal ME/g air-dry matter.

Results

1. Heat production under a thermoneutral zone and a cold environment

   ME intakes and heat productions under a thermoneutral zone and a cold environment are shown in Table 3.

   Heat production under a thermoneutral zone was related to ME intake by the following equation:
   \[ H = 60.0 + 0.37 \text{ME} \]
   \( n: 18, r: 0.871 (P<0.01), r^2: 0.759 \)

   where \( H \): heat production under a thermoneutral zone (kcal/W^{0.75}/day), ME: ME intake (kcal/W^{0.75}/day).

2. Determination of \( T_c \) values

   The \( T_c \) values were calculated by using the data of heat productions (Table 4) and body weights (Table 2). The results are shown in Table 4.

   A multiple regression equation for the prediction of \( T_c \) was as follows:
   \[ T_c = 24.2 - 0.05 W - 0.023 \text{ME} \]
   \( n: 24, R: 0.611 (P<0.01), R^2: 0.374 \)

   where \( T_c \): lower critical temperature (°C), W: body weight (kg), ME: ME intake (kcal/W^{0.75}/day).

   Equation 2 shows that the value of \( T_c \) decreases with the increase of body weight and ME intake. Although multiple regression coefficient (R: 0.611) in equation 2 was significant (P<0.01), fitness (R^2: 0.374) of regression was unsatisfactory.

3. The rate of increase in heat production below \( T_c \)

   As shown in Table 4, the rates of increase in heat production per 1°C below \( T_c \) averaged 6.24 ± 0.75 in fattening pigs and 4.84 ± 0.06 kcal/W^{0.75}/day in gilts.

   A multiple regression equation for the prediction of the increased rate of heat production below \( T_c \) was determined by using the body weight data in Table 2, ME intake in Table 3 and difference between \( T_c \) and environmental temperature in Table 4.

   A multiple regression equation obtained was as follows:
   \[ H' = -4.44 - 0.51 W + 0.05 \text{ME} + 6.77 (T_c - T) \]
   \( n: 24, R: 0.990 (P<0.01), R^2: 0.980 \)

Table 4. Estimated lower critical temperature (\( T_c \)) and rate of increase in heat production (HP) per 1°C below \( T_c \)

<table>
<thead>
<tr>
<th>No. of pig</th>
<th>HP Cold</th>
<th>Increase of HP under TNZ (^{b1}) cold env.</th>
<th>Environ. temp. (( T_c-T ))</th>
<th>( T_c-T )</th>
<th>Increase HP per 1°C below ( T_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fattening</td>
<td>22</td>
<td>171±30((^c)) 138±20 33±18</td>
<td>16.8±2.4 11.7±3.0 5.2±2.5 6.24±0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gilt</td>
<td>2</td>
<td>151±1 115±2 37±4</td>
<td>16.2±0.8 7.7±0.2 7.6±0.6 4.84±0.06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{a1}\) TNZ: thermoneutral zone. Estimated from equation 1 (\( H = 60.0 + 0.37 \text{ME} \)) in text.

\(^{b}\) See text for calculation.

\(^{c}\) Mean±SD.
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where \( H' \) : rate of increase in heat production below \( T_c \) (kcal/W\(^{0.75}\)kg/day), \( W \): metabolic body size (W\(^{0.75}\)kg), \( ME \): ME intake (kcal/W\(^{0.75}\)kg/day), \( T_c - T \): \( T_c \)-environmental temperature (°C).

Equation 3 indicates that the increased rate of heat production below \( T_c \) decreases with the increase of body weight and increases with the increase of ME intake and \( T_c - T \).

Discussion

1. ME requirement for maintenance

In the present study, it was found that the thermoneutral heat production rate of pigs weighing about 30 to 120 kg could be estimated by equation 1, that is \( H = 60.0 + 0.37 ME \). On the other hand, HOLMES and CLOSE\(^3\) summarized data from several sources regarding swine energetics, and concluded that thermoneutral heat production rate of pigs weighing 20 to 180 kg could be predicted as: \( H = 64.5 + 0.32 ME \) (H: heat production, ME: ME intake, in kcal/W\(^{0.75}\)kg/day. equation 4).

These equations show that the increased rates of heat production under a thermoneutral zone with increasing ME intake are 0.37 (equation 1) and 0.32 (equation 4) kcal/W\(^{0.75}\)kg/day. This fact shows that there is no large difference between both values.

Maintenance ME requirement (\( M_{Em} \)) is defined as ME needed for the animal to maintain a constant body energy content. At a thermoneutral zone, the maintenance ME-fed animal’s heat production rate is equal to the ME intake, so maintenance ME may be calculated using the above equations 1 and 4 by substituting it for both heat production and rate of ME intake. Thus,

From equation 1: \( M_{Em} = 60.0 + 0.37 M_{Em} \) \( \therefore M_{Em} \approx 95 \) (kcal/W\(^{0.75}\)kg/day)

From equation 4: \( M_{Em} = 64.5 + 0.32 M_{Em} \) \( \therefore M_{Em} \approx 95 \) (kcal/W\(^{0.75}\)kg/day)

Therefore, this fact shows the ME requirement (95 kcal/W\(^{0.75}\)kg/day) for maintenance estimated from the present study is just the same as that estimated from equation 4.

Table 5. Calculated values of lower critical temperatures in pigs of different body weights at metabolizable energy (ME) intake of 2 (2M) and 3 times (3M) of maintenance in pigs kept individually

<table>
<thead>
<tr>
<th>Body weight (kg)</th>
<th>Present study(^a)</th>
<th>Holmes and Close(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ME intake (^b)</td>
<td>ME intake (^b)</td>
</tr>
<tr>
<td></td>
<td>2M (^b)</td>
<td>3M (^b)</td>
</tr>
<tr>
<td>20</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>60</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>100</td>
<td>15</td>
<td>13</td>
</tr>
</tbody>
</table>

\(^{a}\)Calculated from equation 2 (\( T_c = 24.2 - 0.05W - 0.023 ME \)). \(^{b}\)Calculated as ME required for maintenance being 95 kcal/W\(^{0.75}\)kg/day. See text.
A review by the Agricultural Research Council (ARC)\textsuperscript{1)} shows that maintenance ME requirement for growing-finishing pigs, based on the values collected from 27 of the literature, was 458 KJ/W\textsuperscript{0.75}kg/day (≈ 109 kcal/W\textsuperscript{0.75}kg/day). The value of the present study was about 13\% lower than that preferred by ARC\textsuperscript{1)}. However, the ME requirement for maintenance collected by ARC\textsuperscript{1)} varied from 85 to 163 kcal/W\textsuperscript{0.75}kg/day. These values covered a very wide range. Since the value (95 kcal/W\textsuperscript{0.75}kg/day) of the present study existed within the range of 85 to 163 kcal/W\textsuperscript{0.75}kg/day, it should be considered that there is no essential difference between the present value and the value preferred by ARC\textsuperscript{1)}

On the other hand, efficiencies of utilization of dietary ME for energy retention were estimated at 63\% \[= (1 - 0.37) \times 100\] and 68\% \[= (1 - 0.32) \times 100\] by using coefficients of ME in equations 1 and 4, respectively. These efficiencies corresponded well with those in the literature\textsuperscript{10-14)}.

2. Estimated values of $T_c$

Calculated values of $T_c$ in pigs reared individually of different body weights at ME intakes of 2 times maintenance ($2 \times M$) and 3 times maintenance ($3 \times M$) are shown in Table 5. These values were calculated by using equation 2. To compare with the values of $T_c$ in the present study and in other studies, the values of $T_c$ estimated by HOLMES and CLOSE\textsuperscript{2)} were also shown in Table 5.

As shown in Table 5, the values of $T_c$ in the present study at ME intake of 3 times maintenance corresponded well with those of HOLMES and CLOSE\textsuperscript{2)}. However, the values of $T_c$ at 2 times maintenance in the present study were 2 to 4\°C lower than those of HOLMES and CLOSE\textsuperscript{2)}.

Table 5 also shows that the values of $T_c$ determined in the present study decrease with the increase of body weight. Further more, the value of $T_c$ at ME intake of 3 M is 2\°C lower than that at ME intake of 2 M.

These results support many results in the literature\textsuperscript{1,2,4,5)} already published on $T_c$.

3. Increased rate in heat production per 1\°C below $T_c$

The results are shown in Table 6. The values of the present study in Table 6 were calculated using the data shown in Table 4.

In order to compare the values in the present study with the values in the

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Body weight range & Present study & ARC\textsuperscript{1)} & VERSTEGEN\textsuperscript{4)} & HOLMES and CLOSE\textsuperscript{2)} \\
\hline
kg & kcal/W\textsuperscript{0.75}kg/day & \(1^\circ C\) & kcal/W\textsuperscript{0.75}kg/day & kcal/W\textsuperscript{0.75}kg/day \\
\hline
30-50 & 6.38 & 4.78 & 4.78-5.32 & 3.50-4.10 \\
\hline
50-100 & 6.04 & 3.11-4.06 & 5.32-5.80 & 3.25-3.50 \\
\hline
120 (non-pregnant) & 4.84 & 4.54 & - & 2.40-4.17 \\
\hline
\end{tabular}
\end{table}

\textit{Table 6. Summary of the rate of increase in heat production per 1\°C below $T_c$ in pigs kept individually}
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Table 7. Extra feed required per 1°C to maintain energy retention at temperatures below Tc at a rate similar to that within the thermoneutral zone in pigs kept individually

<table>
<thead>
<tr>
<th>Body weight range</th>
<th>Present study</th>
<th>ARC(^{1)})</th>
<th>VERSTEGEN(^{4)})</th>
<th>HOLMES and CLOSE(^{2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount(^{a)})</td>
<td>Amount(^{a)})</td>
<td>Amount(^{a)})</td>
<td>Amount(^{a)})</td>
</tr>
<tr>
<td>kg</td>
<td>g/day</td>
<td>g/day</td>
<td>g/day</td>
<td>g/day</td>
</tr>
<tr>
<td>30-50</td>
<td>36</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>50-100</td>
<td>55</td>
<td>33</td>
<td>33</td>
<td>52</td>
</tr>
<tr>
<td>120 (non-pregnant)</td>
<td>63</td>
<td>59</td>
<td>30</td>
<td>43</td>
</tr>
</tbody>
</table>

\(^{a)}\) Assuming feed contains 2.8 kcal ME/g. \(^{b)}\) % of feed requirement \(^{6)}\).

literature, the values cited from ARC\(^{1)}\), VERSTEGEN\(^{4)}\) and HOLMES and CLOSE\(^{2)}\) are also shown in Table 6.

The increased rate in heat production below Tc in 30 to 50 kg and 50 to 100 kg of body weights in the present study were higher than those of ARC\(^{1)}\) and HOLMES and CLOSE\(^{2)}\), but was similar to that of VERSTEGEN\(^{4)}\). On the other hand, the value of about 120 kg of body weight (non-pregnant) was nearly equal to that of ARC\(^{1)}\), but was higher than that of HOLMES and CLOSE\(^{2)}\).

It is pointed out that the reason why the values of fattening pigs in the present study are higher than those of the literature may be due to the restricted feeding level by about 20 to 30% to feed requirement\(^{6)}\) as described in Materials and Methods. It is considered that the restricted feeding at temperature below Tc causes the decrease of body fat and heat production is increased by its decrease\(^{2)}\).

4. Extra feed required per day per 1°C below Tc to maintain energy retention at a rate similar to that within the thermoneutral zone

The amounts of feed equivalent to the increased rate of heat production (Table 6) were calculated by assuming the ME contents of the diet as 2.8 kcal/g air-dry matter. These results are shown in Table 7. Percentages of extra feed to feed requirement\(^{6)}\) of pigs are also shown in Table 7.

The amount of extra feed which was estimated at 36 g/day/1°C below Tc in 30 to 50 kg of body weight in the present study was higher than those of the literature\(^{1,2,4)}\). The value of 50 to 100 kg of body weight was nearly equal to that of VERSTEGEN\(^{4)}\), but was higher than those in the other literature\(^{1,2)}\). On the other hand, the amount of extra feed in gilts of about 120 kg in body weight (non-pregnant) was estimated at 63 g/day/1°C below Tc. This value corresponded well with that of ARC\(^{1)}\), but was higher than that of HOLMES and CLOSE\(^{2)}\).

The percentages of extra feed below Tc in the present study were 2.0, 2.2 and 3.2%/day/1°C below Tc in 30 to 50 kg, 50 to 100 kg and 120 kg of body weights, respectively. The values in the literature were 1.4, 1.3 and 3.0\(^{1)}\), 1.4 and 2.1 (no data at 120 kg of body weight)\(^{1)}\) and 1.1, 1.2 and 2.2%/day/1°C\(^{2)}\) below Tc in respective body weights.
5. Some problems in extrapolating this result to apply to farm conditions

This experiment was conducted under conditions where environmental temperature was maintained at a constant level using pigs kept individually in metabolism cages.

There are difficulties, therefore, in extrapolating such results to apply to farm conditions where other environmental factors may severely affect heat production. These factors include the rate of air movement\(^{11,15}\), relative humidity\(^{16,17}\), bedding and floor type\(^{11,18}\), body fatness\(^2\) and the grouping (individual or group feeding) of pigs\(^1,2,4,5\). A change in one of these components will produce a change in heat production to effect a change in the environmental temperature.

On the other hand, Holmes and Close\(^2\) pointed out that in the majority of experiments in which the effect of environmental temperature on heat exchange has been investigated, the environmental temperature has remained at a constant level during each measurement. This is not normally the situation encountered in an actual situation. However, Morrison et al.\(^{19}\) reported that the effect of cycling temperature on the rate of gain in body weight of pigs was similar to that of a constant temperature equal to the mean value of the cycle.

More research is needed to study the effects of these factors on $T_c$ and heat production.

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References

Cold Environment and Pig’s Energy Requirement


豚を単飼した場合の寒冷環境下におけるエネルギー増給量

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体重が約 30—120 kg の肥育豚および繁殖豚（非妊娠）を総数で 42 頭供試した。これらの豚を代謝ケージに単飼して、個体毎に飼料の給与量を変え、寒冷環境下および熱的中性圏下で約 1 カ月の飼料後間隔測定の呼気試験装置を用いて 3 日間の呼気試験を行ない、熱産生量を算出した。

得られた結果は、次のようになる：(1)維持に要する代謝エネルギー（ME）量は、95 kcal/W0.75/kg/day と推定された。(2)熱的中性圏における熱産生量の推定式として、H = 60.0 + 0.37 ME (H: 熱産生量 kcal/W0.75/kg/day, ME: ME 摂取量 kcal/W0.75/kg/day) が導かれた。(3)下限臨界温度 (Tc) の推定式として、Tc = 24.2

- 0.05 W - 0.023 ME (Tc: °C, W: 体重 kg, ME: ME 摂取量 kcal/W0.75/kg/day) が得られた。(4)Tc より 1℃低下時の熱産生の増加量は、体重 30—50 kg の豚で、約 6.4 kcal/W0.75/kg/day、体重 50—100 kg の豚で 6.0 kcal/W0.75/kg/day、さらに体重 120 kg の繁殖豚で 4.8 kcal/W0.75/kg/day となった。(5)Tc より 1℃低下時の飼料の増給率（飼料の推奨量に対する %）は、給与飼料の ME 含量を 2.8 kcal/g とすると、体重 30—50 kg の豚で 2.0%、体重 50—100 kg の豚で 2.2% および 120 kg の繁殖豚で 3.2% となった。
