Nutrition of the lactating sows in hot conditions

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1. Introduction

Over the last decade, pig production in tropical and subtropical countries has increased rapidly due to increasing population, the consumer’s rising income and, in some countries, availability of local feed ingredients (Delgado et al., 1999). Despite many challenges faced by pig industries in developing countries including price of imported raw materials, economical crisis, environmental problems, it is still predicted that pig production in these areas will continue to sustain future world growth of pig production. In tropical country, production and performance remain generally lower than those obtained in temperate countries in Western Europe and North America. Although many factors can be involved, climatic factors are the first most limiting factors of production efficiency in these warm regions. While heat stress is only an occasional challenge during summer heat waves in temperature climate, it is a constant problem in many tropical and subtropical areas. In addition, in these regions, the effects of high ambient temperature can be accentuated by a high relative humidity (Renaudeau et al., 2003a).

Adequate nutrition of the breeding sows is essential for maximizing herd productivity and profitability. The components of the reproductive performance (weaning to conception interval, prolificacy, sow milk yield and number of weaned piglets per litter) depend of animal related factor (genotype, parity) but are also connected to dietary factors (feeding strategy, quality of the diet) (Dourmad et al., 1994). For example, it is well know that return to estrus and conception rate are partly related to the amount and the nature of body reserve losses over the lactation period. Under heat stress the lactating sow reduces its appetite in order to reduce their heat production with negative consequences on milk yield and further reproductive performance. Moreover, the heat stress related problems are emphasized in modern strains of pigs selected for a reduced level of appetite (Kerr and Cameron, 1996). More generally, the nutritional strategies for maximizing the reproduction performance would be to minimize sow body composition changes at any stages of the reproductive cycle. Compared with other stages, the sows during lactation are more sensitive to heat stress due to their high heat production related to milk yield. Due to the recognition that heat stress is a problem for pig production efficiency in geographical high temperatures regions, the objectives of many research trials in recent years have been to develop solutions to alleviate the negative effects of heat stress. The purpose of this paper is to present available nutritional strategies to alleviate the detrimental effects of heat stress on sow performance during lactation.

2. Hot climate and performance of lactating sows

Pigs are homeothermic animals who maintain a constant body temperature under varying environmental temperature by balancing heat loss and heat production (Holmes et al., 1977). The principles of this thermoregulation have been extensively described in the literature (Curtis, 1983). Under the thermoneutral zone, heat production is independent of climatic conditions but is influenced by other factors such as the feeding level, physical activity and physiological stage (Figure 1). Heat production for metabolic function accounts for approximately 50% of energy intake by a 250 kg lactating sow producing 10 kg/d of milk, and heat production related to digestive and metabolic utilization of feed represents approximately 40 % of total heat production (Figure 1). An important practical consequence of this result is that change of feed composition for decreasing its thermic effect should reduce heat stress in lactating sows (see next section). Within the thermoneutral zone, body temperature is kept constant by regulation of both sensible heat loss (conduction, convection, radiation) and evaporative heat loss. According
to its low density of active sweat glands (Renaudeau et al., 2006), pigs rely mostly on respiration evaporation to lose heat by the latent pathway. From a literature review on the effect of high ambient temperature on respiratory rate, the evaporative critical temperature (i.e., temperature at which respiratory rate begins to increase) is about 22°C (Figure 2). However, this increase of respiratory rate is not sufficient for keeping the rectal temperature constant. Under such conditions, the decrease of heat production via a reduction of feed intake is an efficient mechanism to decrease heat load.

The effect of high ambient temperature on feed consumption during lactation is well described in the literature. In multiparous and mixed parity sows, the average energy intake was reduced by about 2.6 MJ/d for each degree increase in ambient temperature (Figure 3). The high variability of the effect of temperature on energy intake can be explained by difference in lactation length, parity number, and temperature range considered. The effect of temperature on feed intake in lactating sows becomes more pronounced as the ambient temperature increases (Stansbury et al., 1987; Quiniou and Noblet, 1999). In tropical humid conditions, a reduction of 5.7 MJ ME/d°C was reported when ambient temperature increased from 24.5 to 27.0°C at 85% relative humidity (Renaudeau et al., 2003a; Gourdine et al., 2004). High relative humidity limits the animal's ability to dissipate heat by evaporation and therefore, increases the effects of heat stress in pigs. From that, it has been suggested that in tropical conditions, the high relative humidity would emphasize the negative effect of high temperature on sow's feed consumption.

The decreased daily feed intake in heat exposed lactating sows is related first to a reduction of meal size while the meal frequency remains relatively constant; thereafter an additional increase of temperature induces a reduction of both meal size and meal frequency (Quiniou et al., 2000b). The rate of feed intake does not vary when ambient temperature increases. Then, the shorter ingestion time under heat exposure is a consequence of the decrease of feed intake (Renaudeau et al., 2005).

Various studies summarized in Figure 3 reported that chronic exposure to elevated temperature decreases litter BW gain by about 50 g/d°C. The associated reduced milk production is mainly related to a decrease in the ability of sow to produce milk rather than a decrease of nursing demand. In contrast, nursing frequency increases under high temperature in attempt to attenuate the effect of heat stress on milk production (Renaudeau and Noblet, 2001). The decrease of dietary nutrient available for milk synthesis explains the low milk production under heat stress. However, some authors suggested that the redirection of blood flow from the mammary gland to the skin may also contribute to the lower milk production in heat stressed sow (Black et al., 1993; Messias de Bragança et al., 1998).

The reduced feed intake under heat stress was shown to affect body weight loss of sows during lactation: on average each degree increase in ambient temperature leads to increase by about 50 g/d the BW loss (Figure 3). As described for ME intake, the effect of temperature on BW loss is quadratic. According to Quiniou and Noblet (1999), the BW loss doubles between 18 and 29°C. Most of the BW loss during lactation corresponds to lean and fat tissue depletions implied in meeting the nutritional deficit of sow for milk production, and a small variation is associated with variations in the weight of udder, uterus and digestive tract (Noblet et al., 1998). The chemical composition of this BW change is not affected by the temperature level; calculated fat and lean losses represents about 27 to 55% of empty BW loss (Quiniou and Noblet, 1999). This effect is consistent with the fact that high temperature induces a decrease of total feed intake (i.e., of both energy and protein intake).

A delayed return to estrus has been generally reported when a large amount of body reserve is mobilized. According to the review of Prunier et al. (1997), a delayed return to estrus after weaning under heat stress is more frequent in primiparous than in multiparous sows. This result was confirmed by data obtained in tropical climate (Gourdine et al., 2006). These authors suggested that this high susceptibility of primiparous sows is explained by a higher BW loss expressed as percentage of farrowing BW when compared with multiparous sows.

Most of the experimental data available in the literature on the effects of heat stress in lactating sows were obtained in climatic chambers in which temperature was kept constant over
the days. Under farm conditions, ambient temperature in farrowing house can fluctuate over the days and over successive seasons especially in tropical countries where the production system is often characterized by housing in semi open conditions. In order to simulate the effect of diurnal fluctuating temperature on performance in lactating sows, a simplified design of variation of temperature was tested by Quiniou et al. (2000c). At a mean daily temperature of 29°C, the detrimental effects of heat stress on feed intake is less pronounced when the ambient temperature is fluctuating (29 ± 4°C) than when temperature was maintained constant over the day. This result indicate that heat stressed sows are able to consume feed during the fresher periods of the day in attempt to compensate the low feed intake during the hotter periods. However, in this study, the increment of feed intake has no consequence on milk production and BW loss. Under tropical humid conditions, the feeding pattern of the lactating sow is characterized by two peaks (Figure 4). In hot season, more than one half of the total feed intake occurs during the nocturnal period and the time between peaks increases in such way that feed intake tends to happen under the lowest temperature in the evening period. An important practical consequence of these results is that heat stressed lactating sows should be fed ad libitum and nocturnal feed consumption or distribution of feed during the cooler periods of the day when animals are meal fed should be favored (see following section).

3. Nutritional solutions to minimize the effects of heat stress in lactating sows

Several management techniques have been already tested to mitigate the effects of heat stress in lactating sows but only a few ones were found effective and economical in minimizing the impact of heat stress in pig production. These solutions include management strategy to reduce the housing ambient temperature (evaporative cooling system) (Suriyasomboon et al., 2005) and/or to increase animal heat losses (floor cooling, fan system, drip, snout cooling) (McGlone et al., 1988; Silva et al., 2006; Silva et al., 2008a). According to the fact that management strategies are usually expensive, not economically and technically feasible in most cases particularly in many tropical small scale producers, nutritional strategies are alternative techniques that should be recommended to minimize the negative effect of heat stress. Therefore, this review is focusing on the modification of nutritional strategies to alleviate the detrimental effects of heat stress on sow performance.

3.1. Modifications in diet composition

In order to maximize energy intake of sow during heat stress, nutritional solutions can be described according to their ability to reduce dietary heat increment or to increase dietary nutrient density.

Reduction of dietary heat increment

According to the net energy system for pig, heat increment associated to the metabolic utilization of nutrient is higher for crude protein than for starch or ether extract (40 vs. 18 and 10% of the ME content; Noblet et al., 1994). The higher heat increment of digestible crude protein (CP) is partly related to the deamination of amino acids (AA) excess for the urea synthesis. In addition, the increase of CP supply is associated with a higher protein turn over which enhances heat production. According to Le Bellego et al. (2001), a reduction of dietary CP content from 18.9 to 12.3 % in 35-kg pigs results in a reduction of 7% of total heat production attributed to a decrease of the thermic effect of feed (TEF) component of energy expenditure. According to these results, it can be hypothesized that low CP diets should attenuate the reduction of feed intake associated with heat stress. Practically, CP is partially replaced by starch and/or fat and industrial AA are incorporated in the diet to meet the AA requirement for optimal performance. The voluntary feed intake related to maintenance requirement (and TEF) is much higher in lactating sows than in growing pigs in connection with the high requirement for milk production. As a consequence, the potential gain in using low increment diets under hot conditions should be increased in lactating sows. However, few studies are available on the effect of low-CP diets on performance of lactating sows exposed to heat stress (Table 1). The effects of lowering the dietary CP level on sow performance during lactation are not quite clear. The general trend is an increase of energy intake from 3 to 20% of metabolizable energy (ME) with the reduction of dietary CP level. This high variability in response is probably related to factors such as genotype, lactation length, and temperature
range. However, this increase in energy intake in sow fed low CP diet does not enhance litter BW gain. Results obtained for maternal body weight (BW) loss are contradictory: when essential amino acids supply across diets is kept constant, correctly balanced and above requirements for optimal performance, the extra energy intake with low CP diets benefits mainly to the sow and her BW loss is reduced (Table 2). In contrast, Johnston et al. (1999) reported a 25% increase of BW loss in hot season for mixed parity sows fed a low CP diet (13.7 vs. 16.5%). In this study, the increase of sow body reserve mobilization is probably due to an imbalance of some essential AA in low CP diet.

Increase of dietary nutrient density

The increase of the dietary nutrient density in the diet could also be a good alternative for alleviating the depressed feed consumption and performance in pigs maintained in hot conditions. The increase of dietary energy and/or AA contents should compensate the reduced feed intake in pigs reared under hot conditions. Moreover, energy from fat is more efficiently used for production than starch purposes which reduce dietary heat increment and the heat burden of the pig during heat stress. The response to high dietary fat addition-energy diets has been studied in heat stressed lactating sows but under variable conditions. When high-fat diets were used without an increase of CP or essential AA to maintain a constant CP/ME ratio, the BW loss during lactation and the milk yield were not affected by the dietary treatment (McGlone et al., 1988). In contrast, when the diet was correctly balanced for CP or lysine to ME ratio, the increase of nutrient density in heat stressed sows improved litter BW gain via an increase of milk-fat content but did not decrease the body reserves mobilization (Table 3). Similar results with a lower magnitude were reported by Schoenherr et al. (1989) and (Dove and Haydon (1994); these attenuated effects of fat addition in lactation diet are mainly explained by differences in the nature and the rate of dietary fat incorporation.

As shown above, an increase of energy density has positive effect on milk production whereas the use of low CP diet can attenuate the effect of heat stress on BW loss. Technically, it is possible to combine both techniques using low CP plus fat diet. This approach was tested in lactating sows housed at 29°C adding 4% fat to a 14.2% CP diet with well balanced AA supply. Results are summarised in Table 2. The addition of fat in a low CP diet failed to increase milk production. We hypothesized that this result could be related to the low level of fat incorporation.

Some studies were carried out for evaluating the effects of AA complementation in lactating sows raised under high temperature. Increasing dietary lysine content affected neither milk production nor BW loss during lactation in sows reared under tropical climate (Table 4). According to Cheng et al. (2006), the lack of positive effect of high lysine diet on performance could be related to an imbalance between other essential AA and lysine. However, Silva et al. (2008a) provided synthetic AA to maintain a constant ration between essential AA and lysine and did not report any significant improvement of performance in hot season for primiparous sows fed with a diet with 1.34% lysine. In fact, when dietary AA contents are correctly balanced and above requirement, the response of N deposition in milk proteins or in maternal body proteins is energy dependant. In other words, it would be possible to minimize the effect of heat stress on sow performance during lactation by maintaining a correct essential AA to lysine and lysine to energy balance.

Nutrient balance for lactating sows during heat stress

As reported previously, an optimal ratio between digestible lysine and net energy (NE) is required when high energy or low CP diets are used as a nutritional solution to fight against heat stress. In addition, the other essential AA should be then increased when using high energy diets. However, it can be questioned whether values for lysine to energy ratio and essential AA to lysine are similar at thermoneutrality and in elevated temperature conditions.

Using the factorial approach for sows eating enough feed to cover the energy requirement for milk production, a minimal lysine to energy ratio can be calculated to be equal to 0.53 g of
digestible lysine per MJ ME\(^1\). It is stressed that this value corresponds to the minimal requirement for a sow with a 0% energy deficit. Under most practical conditions, lactating sows are unable to consume enough feed to meet their requirement so that they generally lose BW during lactation. This nutritional deficit is accentuated during heat stress in connection with the effect of high temperature on feed intake. Practically, the average daily feed intake is about 4.5-5 kg/d in tropical humid climate (Gourdine et al., 2004). In this case, the energy deficit is about 30% (i.e., only 70% of energy for milk production is provided by diet) and therefore, ratio between digestible lysine and ME in diet must be higher than 0.83 g/MJ ME (> 1.0 % digestible lysine in a diet containing 13 MJ ME/kg).

The requirement of the others essential amino acids is traditionally calculated using the ideal protein calculated from AA profile in milk. According to the fact that the content of some amino acids released from the tissue mobilization is lower than that found in milk (e.g., threonine and leucine), it was suggested that expected levels of AA mobilization are important factors that must be considered in designing diets for lactating sows (Table 5). This concept developed by Kim et al. (2001) would allow to a more precise estimation of ‘true’ AA requirement especially for sows who mobilize a large amount of body reserve during lactation. These authors showed that the order of limiting AA would vary according to the amount of BW loss. For example, threonine would become a critical AA for sows having a low feed intake and a large BW loss (Table 6). Using this concept, the improvement of protein quality might then be an attractive solution to alleviate the effect of heat stress on maternal body reserve mobilization and post weaning reproductive performance especially in primiparous sows.

Using the ideal protein concept based on the AA composition of milk, we assume that AA used for milk are provided mainly by the diet (see previous paragraph) and ignore the possibility that some particular AA can be used by the mammary gland for lactose synthesis, energy production or maintenance function. Using the arterio-venous technique, it was demonstrated that pattern of AA uptake from blood by the mammary gland differed from the AA profile in milk especially for branch chain amino acids (valine, leucine, isoleucine and arginine) (Trottier, 1997; Renaudeau et al., 2003b; Guan et al., 2004). These results would suggest that requirement for some AA should be higher than the requirement estimated from the AA profile in milk. Based on this assumption that requirement for arginine in heat stress sow is inadequate to maximize milk synthesis, Laspiur and Trottier (2001) provided supplemental dietary arginine to sows housed at 29.4 or 20.0°C. It has been shown that when arginine is given at dietary concentration above requirement for N deposition in milk and maternal body reserve, the BW loss was reduced but no benefit was found for milk production.

### 3.2. Modification of feeding management strategy

#### Feeding strategy

In lactating sows, the nycthemeral pattern of feed intake is mainly diurnal with two peaks occurring in the morning and late afternoon (see previous section). The occurrence and the size of these peaks are driven by light and temperature changes. For example, the feed intake tends to happen under the lowest temperatures in early morning and late evening periods (Renaudeau et al., 2005). According to knowledge of diurnal pattern of the feeding behaviour of lactating sows raised under hot conditions, it can be suggested that use of feeding programs would improve the performance under heat stress. These strategies may include a change in the feeding time with feed distributions corresponding to the cooler period of the day or a dual feeding system with a high-protein and an energy-rich diet provided during the cooler and the warmer periods of the days, respectively. In contrast to poultry, these feeding techniques have not yet been investigated and deserve future research.

#### Water management techniques

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\(^1\) Digestible lysine requirement (g/d) = 15.1 + 0.0133 \times \text{Litter BW gain (g/d)} (Dourmad et al., 1998). ME requirement (MJ/d) = 0.460 \times \text{BW}^{0.75} + 0.0206 \times \text{Litter BW gain (g/d)} - 0.376 \times \text{Litter size} (Noblet et al., 1990). Calculations were made for a 28-d lactation and a sow weighing 220 kg nursing 11 piglets with a 2500 g/d BW gain.
Water intake during heat stress is a limiting factor for survival and performance since water has a fundamental role in heat exchange system for temperature regulation and maintenance of hydric balance. High ambient temperatures increase water requirements in pigs. The increased consumption coupled with increased urinary water losses is an effective mechanism by which pigs loose body heat. For example, expressed as L/kg feed intake, the average water consumption of lactating sows is two fold higher at 29°C than at 20°C (4 vs. 8 L/kg; Renaudeau et al., 2001a). A reduction of water availability can accentuate the effect of high temperature on performance. In lactating sows, Leibbrandt et al. (2001) reported that a reduced water intake as a result of a restricted water flow through nipple drinker decreased the voluntary feed intake and increased the BW loss. In addition, in many high temperature regions, drinking water provided to pigs is often warm. Chilled water can provide sufficient cooling to allow the lactating sow to increase their performance under heat stress. According to Jeon et al. (2006), the reduction of water temperature from 22 to 15°C increases feed intake and milk production by about 40 and 20% respectively, in lactating sows during summer. In addition, improved feed intake in lactating sows housed at a high ambient temperature has been reported using a system combining self-feeding and an option for the sow to wet her feed compared to a dry feed hand-fed system (Pettigrew et al., 1985). In conclusion, as water intake increase by 2 times that of normal during heat stress, water management is critical to encourage water and feed consumption and to minimize the effect of elevated temperature on sow performance.

3.3. Other ‘nutritional’ techniques

Provision of supplemental feed or milk substitute in nursing piglets

The growth performance of nursing piglets is directly dependent on the ability of the sow to produce milk. As mentioned above, milk yield is reduced in lactating heat stressed sows. When offered during the last week of lactation, the amount of creep feed consumed before weaning by nursing piglets was higher when sows were kept in hot conditions (Renaudeau et Noblet, 2001b). This higher intake was interpreted as an adaptation to compensate the insufficient milk production of the heat stressed sow. According to these authors, there was a strong relationship between creep feed consumption and daily growth rate of piglets: each gram increase of creep feed intake resulted in a 2-g increase of litter BW gain. In fact, protein to energy ratio was higher in creep feed than in milk. As a result, the high marginal feed efficiency was due to an increase in protein deposition in connection with a higher protein to energy ratio in the feed (milk + creep feed). In addition, Azain et al. (1996) showed that providing litter with milk substitute during the warm season is more effective to improve litter BW gain than during the cool season (+38 vs. +10%). These results suggest that the practice of supplying supplemental feed or milk substitutes can attenuate the reduced growth rate of nursing piglets during heat stress. However, these practices need to be economically evaluated in regard of the relative high cost of these types of substitutes.

Micronutrients complements

The decrease of nutrient intake at high temperatures has also some repercussions on the intake of micronutrients such as vitamins which play an important role in performance and immune function of the pig. The positive effect of vitamins complementation on poultry performance is well known (Lin et al., 2006), but little is published in pigs. Zhao and Guo (2005) showed that selenium and vitamin E complementation improved the resistance of pigs against heat stress. According to the lower density in functional sweat glands in pigs, the excess of heat is dissipated via an increase of respiratory rate. This thermal panting results in a respiratory alkalosis with possible negative consequence on acid/base metabolism. Heat stress increases the urinary excretion of various minerals leading to a reduction of their retention in pigs (Holmes and Grace, 2007). Thus, it can be suggested that more research should be focused on the determination of specifics requirement of vitamins and minerals in pigs reared under heat stress.

4. Conclusion
The lactation period is the most critical period of reproductive cycle because requirement for milk production is often higher that the voluntary feed intake. This energy deficit is compensated by mobilization of body reserves with possible subsequent negative effects on reproductive performance. This situation is accentuated under heat stress in relation with the high susceptibility of lactating sows to hot conditions and may become more and more crucial with the increase of sows productivity. According to the increase of pig production in tropical and subtropical regions, nutritional strategies can limit the lower nutrients intake of pigs under heat stress and improve their performance. The use of low increment diets or high-density diets can mitigate the effect of heat stress only when diets are correctly balanced for AA to energy ratio. Some changes in the feeding management such as changes in feeding time or in water management, and use of feed complements can also be efficient to enhance productivity of pigs in hot conditions. Moreover, optimal pig production under heat stress would also require an appropriate combination of nutritional, management or genetic solutions.

References


Figure 1: Partition of the components of heat production according to the physiological stage (adapted from van Milgen et al., 2000). For the lactating sow, the reported value were calculated for an animal weighing 250 kg and producing 10 kg/d of milk (Noblet et al., 1990). HP act for heat production related to activity, TEF for thermic effect of feed, and FHP, for fasting heat production.
Figure 2: Effect of ambient temperature (T) on respiratory rate (RR, breaths/min, bpm) and rectal temperature (RT, °C) in lactating sows. A broken line relationship was used to predict the RR and RT responses to ambient temperature change: T ≤ 22.0, RR = 27.3 bpm, if T > 22.0, RR=27.3 + 9.2 × (T – 22.8); T ≤ 22.2, RT=39.3°C bpm, if T > 22.2, RT = 39.3 + 0.09 × (T – 22.0).
Figure 3: Literature survey on the effect of high ambient temperature on metabolizable energy intake (ME intake), maternal body weight loss (BW loss) and litter BW gain. The bold
line is the average response. Y = 128 − 2.607 T, Y = -0.37 + 0.048 T, and Y = 3225-47.9 T, for ME intake, BW loss and litter BW gain, respectively.
Figure 4: Effect of season and time of the day on the kinetics of daily feed intake in Large White sows. *x* = hourly feed intake was significantly (*P* < 0.05) affected by season. For daily fluctuation of ambient temperature, dotted line = hot season, solid line = warm season. Adapted from Renaudeau et al. (2005).
Table 1: Effect of reducing dietary crude protein content on performance of lactating sows reared in hot conditions.

<table>
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<tr>
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<tbody>
<tr>
<td>Parity</td>
<td>NC</td>
<td>Mixed</td>
<td>Multiparous</td>
<td>Multiparous</td>
</tr>
<tr>
<td>Nb. of sows/treatment</td>
<td>NC</td>
<td>65</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Lactation length, d</td>
<td>NC</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>28</td>
<td>29.2</td>
<td>29</td>
<td>26¹; 90% RH</td>
</tr>
<tr>
<td>Dietary CP</td>
<td>20 vs.14%</td>
<td>16.7 vs. 13.3%</td>
<td>17.6 vs.14.2%</td>
<td>17.3 vs.14.1%</td>
</tr>
<tr>
<td>AA complementation</td>
<td>NC</td>
<td>Lys</td>
<td>Lys, thr, met, ile, trp, val</td>
<td>Lys, thr, met, ile, trp, val</td>
</tr>
<tr>
<td>Performance, % variation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ME intake</td>
<td>+19%</td>
<td>+3%</td>
<td>+16%</td>
<td>+12%</td>
</tr>
<tr>
<td>NE intake</td>
<td>NC</td>
<td>+7%</td>
<td>+19%</td>
<td>+14%</td>
</tr>
<tr>
<td>BW loss</td>
<td>NC</td>
<td>+25%</td>
<td>-29%</td>
<td>-26%</td>
</tr>
<tr>
<td>Litter BW gain</td>
<td>NC</td>
<td>+4%</td>
<td>+3%</td>
<td>0</td>
</tr>
<tr>
<td>Weaning to estrus</td>
<td>NC</td>
<td>+0.3 d</td>
<td>0</td>
<td>0</td>
</tr>
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</table>

NC not communicated
1 Study performed in tropical humid conditions with an average relative humidity of 85%
Table 2: Effect of lowering dietary crude protein (CP) level on lactating sow performance at 29°C (Adapted from Renaudeau et al., 2001ab)  

<table>
<thead>
<tr>
<th></th>
<th>17.2% CP</th>
<th>14.2% CP</th>
<th>14.2% CP + 4% fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net energy (NE) intake, MJ/d</td>
<td>37.4</td>
<td>42.9</td>
<td>43.3</td>
</tr>
<tr>
<td>BW loss, kg</td>
<td>41</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>Litter BW gain, kg/d</td>
<td>2.15</td>
<td>2.24</td>
<td>2.06</td>
</tr>
</tbody>
</table>

1 data obtained on multiparous LW sows. The three diets supplied the same level of digestible lysine (0.82 g/ MJ NE) and similar amount digestible essential AA relative to lysine.

Table 3: Effect of fat supplemented diet on primiparous sows performance at 26°C (Quiniou et al., 2001)  

<table>
<thead>
<tr>
<th></th>
<th>NE content, MJ/kg</th>
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<tbody>
<tr>
<td></td>
<td>9.7</td>
</tr>
<tr>
<td>No. of sows</td>
<td>49</td>
</tr>
<tr>
<td>NE intake, MJ/d</td>
<td>37.8</td>
</tr>
<tr>
<td>BW loss, kg/d</td>
<td>1.24</td>
</tr>
<tr>
<td>Milk production, kg/d</td>
<td>9.9</td>
</tr>
</tbody>
</table>

1 The increase of net energy (NE) content was obtained increasing the dietary fat content from 3.6 to 6.5%. The two diets supplied the same level of digestible lysine to NE content and levels of digestible essential amino acids relative to lysine were maintained constant.

Table 4: Effect of dietary lysine supplementation on performance of lactating sows during hot season.  

<table>
<thead>
<tr>
<th>Lysine, %</th>
<th>Cheng et al. (2006)</th>
<th>Silva et al. (2008)</th>
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<tr>
<td>ME content, MJ/kg</td>
<td>13.0</td>
<td>14.6</td>
</tr>
<tr>
<td>Feed intake, MJ/d</td>
<td>3.76</td>
<td>4.71</td>
</tr>
<tr>
<td>BW loss, kg/d</td>
<td>0.779</td>
<td>0.580</td>
</tr>
<tr>
<td>Litter BW gain, kg/d</td>
<td>1.44</td>
<td>1.96</td>
</tr>
</tbody>
</table>

49 multiparous crossbred sows (Landrace × Yorkshire) were studied over a 28-d lactation period in Taiwan (average T = 27.8°C).  
30 primiparous sows (synthetic line) studied over a 21-d lactation period in Brazil (average T = 25.5°C).
Table 5: Amino acid patterns relative to lysine from tissue mobilization, milk protein and a corn-soybean based lactation diet (adapted from Kim and Wu, 2005)

<table>
<thead>
<tr>
<th></th>
<th>Tissue mobilization</th>
<th>Milk protein</th>
<th>Dietary source¹</th>
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</thead>
<tbody>
<tr>
<td>Lysine</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Threonine</td>
<td>42</td>
<td>59</td>
<td>70</td>
</tr>
<tr>
<td>Valine</td>
<td>77</td>
<td>77</td>
<td>90</td>
</tr>
<tr>
<td>Leucine</td>
<td>101</td>
<td>114</td>
<td>175</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>59</td>
<td>60</td>
<td>78</td>
</tr>
<tr>
<td>Arginine</td>
<td>124</td>
<td>65</td>
<td>125</td>
</tr>
</tbody>
</table>

¹ Conventional diet with 71.1% corn and 22.8% soybean meal containing 17% CP and 0.87% lysine.

Table 6: Effect of level of tissue mobilization on ideal amino acid pattern (adapted from Kim et al., 2001)

<table>
<thead>
<tr>
<th>Level of mobilization¹</th>
<th>NRC</th>
<th>0 %</th>
<th>25 %</th>
<th>50 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysine</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Threonine</td>
<td>58</td>
<td>59</td>
<td>64</td>
<td>75</td>
</tr>
<tr>
<td>Valine</td>
<td>85</td>
<td>77</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Leucine</td>
<td>115</td>
<td>115</td>
<td>120</td>
<td>128</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>55</td>
<td>59</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>Arginine</td>
<td>66</td>
<td>72</td>
<td>43</td>
<td>22</td>
</tr>
</tbody>
</table>

¹ Percentage of amino acids in milk protein coming from tissue protein mobilization.
² NRC ideal amino acid profile for milk synthesis (NRC, 1998):