THE WEANER PIG
NUTRITION AND MANAGEMENT
The Weaner Pig
Nutrition and Management

Edited by

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Preface

This book is the proceedings of a conference organized by the British Society of Animal Science (as part of their ‘Occasional Meetings’ series) held at the University of Nottingham, UK, in September 2000.

The post-weaned piglet presents a particular challenge both in modern production terms and in the context of the sciences related to production. The systems used in most of the pig-producing countries of the world include weaning at between 16 and 30 days of age using controlled environment housing and highly specialized diets. Whilst early weaning generates significant advantages for annual sow productivity, the system also demands a high level of management skills to make it work successfully.

The principal objective of the meeting was therefore to focus attention on the various disciplines involved in weaner science and production, and to review the research and development carried out recently in these areas. Accordingly the present work includes sections on: growth patterns, nutrition, feeding requirements, gut physiology, enteric health and the environmental requirements of the young post-weaned piglet. The papers were presented by acknowledged experts from around the globe and provide a solid foundation both for future research directions and also as guidelines for managers and consultants looking to improve their systems.

In addition to formal papers, the meeting also had submitted posters, abstracts for which can be found at: www.bsas.org.uk

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Acknowledgements
Growth of the Young Weaned Pig

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The Potential for Growth

Without human intervention, the pig will become nutritionally independent of its dam at 15–20 kg liveweight. Natural weaning will occur at 70 days or so of age. Earlier weaning than this creates a disruption to the growth of the weaned pig that is inversely proportional to pig age. The competence of the digestive system of the suckled pig to handle a non-milk diet begins to develop (aided by challenge/response) between 14 and 28 days of age. Under conditions of gradual diet change from liquid to solid feed, growth is likely to be fully supportable without sucked milk from around 56 days. The presentation of a mixture of milk and externally sourced solid feed to the gut of the young pig is relevant to natural development.

Abrupt weaning at 21 days of age is not conducive to the achievement of normal growth in pigs. Fifty years ago, conventional European practice was to wean at 56 days of age. Advances in nutritional knowledge and the manufacture of specialist housing for young pigs led to a rapid reduction in weaning age. After a number of failed flirtations with 7-day, 10-day and 14-day weaning, the ‘industry standard’ in the UK settled at 21-day weaning. A substantial proportion of successful practitioners nevertheless chose not to wean at ages below 28 days, and in other European countries 35-day weaning remains common. The UK industry standard has, since the 1980s, drifted upward from 21 days towards 28 days, with an apparent advantage in terms of numbers of pigs born per sow per year.

The description of growth following weaning requires at its core a prediction of protein mass and of its incrementation. Description of body composition further requires quantification of lipid mass and an understanding of any relationship that may exist between protein and lipid retention in the course of positive (and, in the case of the weaned pig, negative) growth.

(eds M.A. Varley and J. Wiseman)
Theoretical considerations

There is dissent over the nature of the curve that might best describe protein growth over time and weight. The conventional assumption of a sigmoidal form requires the rejection of the proposition still held by the de Lange school at Guelph (C.F.M. de Lange, personal communication, Guelph, 2000), which follows from the reviews of Kielanowski (1969) and Rerat (1972) and suggests that a single value be used to describe maximum daily potential protein retention rate ($Pr_{max}$) at all times during the active growing life of the pig. That the (single value) potential for growth is not achieved in early life, and particularly after weaning, may be ascribed to a failure on the part of the pig to be able to ingest sufficient feed. In addition to $Pr_{max}$, the original models of Whittemore and Fawcett (1974, 1976), and those that later sprang from them, required a second parameter: that of a minimum ratio between the daily rate of retention of lipid and protein in the gain ($Lr:Pr$). This latter was argued for on the grounds of a physiological imperative, and had the further (beneficial) effect of restraining the simulated daily rate of achieved protein retention ($Pr$) below $Pr_{max}$ in young pigs, when appetite was limiting. The rule effectively enforces partitioning of energy from $Pr$ to $Lr$. The setting of the minimum ratio of lipid to protein in the gain was necessary for the achievement of fit of the ‘single value’ model to recently weaned and young growing pigs, which would otherwise be predicted to perform at extravagant rates of protein growth. The $Lr:Pr$ ratio was subsequently argued against (Whittemore, 1995), on the grounds that it was superfluous to modelling requirement to restrain early protein growth if a sigmoidal (Gompertz) function rather than a single value were used to describe $Pr_{max}$. The Gompertz function had an evident effect of limiting early protein growth potential. In both the original and amended (Whittemore, 1995) eventualities, potential lipid retention ($Lr_{max}$) was unrestrained, and achieved lipid retention ($Lr$) was a function of energy supply. Emmans (1988) proposed that potential lipid retention ($Lr_{max}$) may also be described by the Gompertz function.

Functions other than the Gompertz in the sigmoidal series have been discussed by such as Huxley (1932), Hammond (1940), Brody (1945) and Schinckel (1999). The common characters of the sigmoidal descriptor are: (i) a period of increasing growth rate in early life; (ii) a period of decreasing growth rate in later life; (iii) a point of inflection (linearity) between the two; and (iv) an asymptote, at which point maturity is approached and growth ceases. The weaner pig finds itself in the middle of the phase of increasing growth rate, which in practice it rarely achieves.

The Gompertz (1825) function may be employed with the growing tissue (whole body, protein, or lipid, etc.) on the y axis, and the scale against which growth is to be expressed (time, or a body tissue) on the x axis. The function requires as parameters the asymptote of the y axis (an approximation of maturity for the tissue concerned) and a growth coefficient. Importantly, the y-coordinate of the point of inflection is fixed at $1/e$ of the asymptote. The general equation is:

$$y = A^* \exp\{-\exp[-B(x - x^*)]\}$$

where $A$ is the asymptote for $y$, $x^*$ is the point of inflection measured on the x-axis and $B$ is the growth coefficient.
It is of interest to express growth rate \( (dy/dx) \) as a function of both time and weight, either being potentially useful depending on circumstance.

Differentiation with respect to time of the general equation where \( y = \text{weight} \) and \( x = \text{time} \) leads to the derivative for gain as a function of time \((x)\):

\[
dy/dx = A^*B^* \exp \left\{ -B^*(x - x^o) - \exp \left\{ -B^*(x - x^o) \right\} \right\}
\]

and for gain as a function of weight \((x)\):

\[
dy/dx = y^*B^* \ln(A/y)
\]

where \( dy/dx \) is the gain, and \( A \) is the value for \( y(W) \) when \( dy/dx \) (daily gain) has diminished to zero.

Whittemore (1998) suggested various values for \( B \) and \( A \) according to sex and genotype. These values range from 0.010 and 220 to 0.014 and 330, respectively, where \( A \) is expressed in terms of liveweight. Potential growth rates for pigs of 5 kg, 10 kg and 15 kg are predicted to be 189 g, 309 g and 402 g for the lower values and 293 g, 490 g and 649 g for the higher.

Alternatives to the Gompertz equation have been examined (and largely rejected) by Whittemore et al. (2001a). Amongst these were the functions of Bridges and Richards. The Bridges equation (Bridges et al., 1986) differs from the Gompertz mainly in not having the inflection point fixed at 1/e. The Bridges equation is:

\[
y = y_o/A^* \left\{ 1 - \exp\left\{ -\left( m^*x^b \right) \right\} \right\}
\]

where \( y_o \) is the start point for \( y \) (weight of growing tissue), \( A \) is the weight at maturity, \( m \) is the ‘exponential growth decay constant’, \( x \) is time and \( b \) is the ‘kinetic order constant’.

The Richards equation (Richards, 1959; and described by France and Thornley, 1984) is more generalized and also has a variable inflection point, which gives it the flexibility to describe different pig types with points of inflection at differing proportions of their mature age (or weight). The Richards equation is expressed as:

\[
y = \left( y_o A^* \right) / \left\{ y_o^a + (A^* - y_o^a) \exp\left\{ -\left( k^*x \right) \right\} \right\}^{1/a}
\]

where, if \( y \) would be weight, \( y_o \) is the start weight, \( A \) is the asymptote for \( y \), and \( x \) measures time. Bridges and Richards are of interest as, although by no means as convenient as Gompertz, they can better describe data sets that do indeed have different inflection points. However, Knap (2000) found, rather convincingly, that although the point of inflection (as proportion of mature weight) did vary with data sets differing in their provenance, it did not deviate importantly from the 1/e determined with the Gompertz.

The description of growth through the relationship between a component (such as total protein, \( Pt \)) and the whole (such as live bodyweight, \( W \)) was suggested by Huxley (1932) and has been used with good effect by countless others since. The form used is:

\[
z = a^*y^b
\]
Whittemore et al. (1988) determined allometric relationships (commented upon by Schinckel, 1999) for \( z = \) protein (\( Pt \)), lipid, water and ash mass, and \( y = \) bodyweight. The pattern of daily protein retention rate, \( Pr \), or \( dPt/dx \), with increasing bodyweight was determined as follows. Daily liveweight gain, \( dy/dx \), was first described with the Gompertz function:

\[
dy/dx = B*y^a \ln(A/y).
\]

Subsequently, \( Pt \) was taken as a simple allometric function of weight (\( Pt = a*y^b \)). It follows that:

\[
Pr = [a*b(y)^{b-1}][B*y^a \ln(A/y)].
\]

As pointed out by Schinckel and de Lange (1996), the simple \( z = ay^b \) allometric is potentially faulted in the assumption that the body component changes according to whole bodyweight in a uniform way.

### Early growth as a special case

Being born with a body-fat content of perhaps 10–20 g kg\(^{-1}\), the suckling pig partitions nutrients in favour of lipid deposition to reach 150–160 g kg\(^{-1}\) at the time of weaning, the ratio of lipid to protein in the body being around 1:1 at this time. The modern meat pig, slaughtered at less than 120 kg liveweight, is unlikely ever to be as fat again. Post-weaning feed intake inadequacies together with stress and disease challenge ensure a rapid loss of body lipid in support of maintenance (and protein synthesis). Whittemore et al. (1978) found no liveweight gain for 7 days in pigs weaned at 14 days of age. At 21 days of age, the body composition of these pigs comprised 150 g protein kg\(^{-1}\) and 76 g lipid kg\(^{-1}\), compared with 146 g protein kg\(^{-1}\) and 148 g lipid kg\(^{-1}\) in unweaned 21-day-old pigs. In the case of both groups of weaned pigs (14- and 21-day weaned), the gains that occurred subsequent to post-weaning weight stasis and lipid loss were made in favour of protein (and not any recovery of body lipid). Lipid and protein gains after weaning were made in approximately equal proportion. Thus, by 50 days of age the composition of the body was little changed, with some 60–70 g lipid kg\(^{-1}\) and 150–180 g protein kg\(^{-1}\). These authors noted that lipid losses had taken place commensurate with weight stasis (not weight loss), and concluded that water enhancement had compensated for the removal of lipid. This proposition was put to a more severe test by Whittemore et al. (1981), who found that zero daily weight change was associated with 56 g of lipid loss and 53 g of water gain. Only when the daily weight gain exceeded 193 g did lipid gains begin to become positive.

- Water gain (g day\(^{-1}\)) = 0.56 empty bodyweight gain + 53
- Lipid gain (g day\(^{-1}\)) = 0.29 empty bodyweight gain − 56
- Protein gain (g day\(^{-1}\)) = 0.15 empty bodyweight gain − 4

Between zero and 200 g daily liveweight gain, it would appear that the pigs catalyzed body lipid in favour of the anabolism of body protein. Not until the rather
appreciable rate of gain of some 60% of what would normally be expected at this
time did the pigs return to lipid retention. Whittemore et al. (1978) also noted the
relative intransigence of the body proportion made up of protein and the stability
of protein content in the face of perturbations in feed intake.

Whittemore (1998) pointed out that, given appropriate conditions, weaned pigs
will grow at rates substantially above the commercial norm (Table 1.1). Healthy pigs of
little more than 5 kg have the potential, given unrestrained feed intake, to grow at 500 g
daily, and $B$ coefficients for the Gompertz function as high as 0.020 have been mea-
sured at Edinburgh. It would seem, therefore, that the negative consequences of
post-weaning growth suspension are in part, or in whole, avoidable.

Given the propensity of contemporary pig-keeping systems to predispose
weaned pigs to a period of slow, zero or negative growth, it is natural that great
interest is shown in the possibility of compensatory growth. By such means may
nature gratuitously make amends for the inadequacies of husbandry. That animals
will grow faster when feed is plentiful, and make provision for times when feed is
scarce, is undeniable. It is also undeniable that lipid losses in support of tissue accre-
tions is physiologically normal (as, for example, in lactation). The seminal question
in the case of the weaned pig, however, is whether or not supra-normal gains follow-
ing a period of deprivation can make good the earlier growth losses and whether, in
addition, these gains can be achieved at supra-normal efficiency. This, of course,
makes 'normal' a begged definition.

Tullis and Whittemore (1986) conducted a carefully constructed trial, some of
the findings of which are given in Table 1.2. Pigs on restricted feeding from 25 to
55 days expressed reduced liveweight gains and little or no lipid gains, but achieved
no greater liveweight gains on realimentation, nor gains of differing composition,
than unrestricted pigs. Compensatory gains were not in evidence. Kyriazakis and
his group at Edinburgh have put forward the concept of the young pig having a
preferred ratio of lipid to protein in the body. Post-weaning feed restriction will
move the pig away from that preferred ratio through the catabolism of lipid, and
there will be a natural predisposition to readjust the balance. It should not be
assumed, however, that the lipid content of the body at weaning is necessarily
expressive of a preferred ratio; the storage of lipid in excess of this ratio (in case of
hard times to come) would be a normal expectation. Were compensatory growth to
be found, its benefaction would lie in the recovery of protein mass by an enhance-
ment in the rate of protein deposition. The difficulty with the test is in proving that
the ‘control’ group was maximizing in the first place. Animals may readily show

<table>
<thead>
<tr>
<th>Liveweight at start (kg)</th>
<th>Liveweight at finish (kg)</th>
<th>Days</th>
<th>Daily feed intake (g)</th>
<th>Daily liveweight gain (g)</th>
</tr>
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<tr>
<td>6</td>
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<td>760</td>
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</tbody>
</table>
enhancement of appetite and growth above that achieved under previous restriction, and no ‘compensatory’ benefit could be claimed. Further, over the total period under review (restriction followed by compensation) there is no likelihood of any recovery of the efficiency lost in the former period. As a management tool of convenience, compensatory growth must therefore be rejected, however attractive its acceptance might be to those espousing less than adequate husbandry techniques. This is not to deny the propensity of the pig to make the most of growth opportunities. In a classical experiment Kyriazakis et al. (1991) fed young pigs to achieve luxury levels of lipid deposition, and then presented the pigs with a diet of exceptionally high protein content. The pigs used body stores of lipid to augment ingested energy levels (limited by the constraints of gut capacity) and achieved remarkable rates of protein retention and liveweight gain. Whether the 925 g of daily liveweight gain attained at a live bodyweight of 13 kg should be considered as indicative of a potential normally available or of compensatory gains remains conjecture.

It may be concluded that, in the case of the young weaned pig, the driver for growth is feed intake and that this inevitably constrains growth to a level that is below potential.

**Feed Intake**

Although gut capacity is dependent on body size, Parks (1982) states the inevitable truth that in the actively growing animal it is the (increasing) bodyweight that is dependent on feed intake:

\[ W = (A - W_o) \cdot (1 - \exp[-(AB/F)A]) + W_o \]

where \( W \) is liveweight (accumulated gain), \( A \) is the liveweight at maturity, \( W_o \) is the initial liveweight, \( B \) is the efficiency coefficient and \( F \) is the accumulated feed intake. Whittemore et al. (1978) showed that a 1 g increment in the intake of digestible crude protein was associated with 2.5 g bodyweight gain, 0.49 g protein gain and 0.28 g lipid gain. An increment of 1 MJ in digestible energy (DE) intake was associated with 22 g bodyweight gain, 3.3 g protein gain and 8.2 g lipid gain. These functions emphasize that it is feed intake that regulates growth in the weaner pig, and growth is invariably curtailed below the potential through the adverse modulation of a constrained appetite.
For a few days immediately after weaning, feed intake may be strictly rationed. This is usually in the interests of actual or presumed enteric disease limitation. Where disease susceptibility is low, or the threat presumed to be passed, weaned pigs may optimize their growth by maximizing their voluntary feed intake. The *ad libitum* appetite may be indicative of the potential appetite prevailing for a given pig type and its nutrient requirement (conventionally the sum of the requirements for maintenance, protein retention, lipid retention and cold thermogenesis). However, appetite in weaner pigs is far more likely to be indicative of the circumstances of feed type, management quality, herd health and housing environment, including: (i) living space, feeder space, and peer competition; (ii) health and individual assertiveness of the animal; (iii) environmental temperature; (iv) pig size; and (v) gut capacity (volume, but usually expressed as feed weight).

It is not evident to what extent the type of pig, and selection pressure upon the type, might affect voluntary feed intake of weaner pigs. It is clear, however, that in the case of growing pigs certain breeds (such as the Chinese types) may have a superior capacity for fibrous feeds, whilst halothane-positive pigs eat some 15–20% less than negative types (Henry, 1985; Kalm, 1986; Webb, 1989). Schinckel and de Lange (1996) observed a 30% difference between genotypes of pigs fed under similar conditions. Unimproved genotypes have appetites up to one-third greater than those selected for leanness (Meat and Livestock Commission, 1982; Cole and Chad, 1989; Webb, 1989).

**Feed intake capacity**

Despite all of the above together with the assumption that little or no feed is eaten in the first day, NRC (1998) presented the following alternative empirical expressions to describe feed intake in young pigs of 5–15 kg:

\[
\text{Energy intake (MJ DE day}^{-1}\text{)} = -6.40 + 1.93W - 0.0407W^2
\]

\[
\text{Energy intake (MJ DE day}^{-1}\text{)} = -0.556 + 1.05W - 0.00413W^2,
\]

using the latter in their model. NRC (1987) risked the suggestion of a single equation for the liveweight range 4.5–117 kg:

\[
\text{Energy intake (MJ DE day}^{-1}\text{)} = 55 (1 - e^{-0.0176W}).
\]

The form \(y = y_0 + ax^b\), where \(y = \text{feed intake (kg) per day, has been found useful to deliver a curvilinear response fitting much of the data for older growing pigs. Cole et al. (1967) proposed:}

\[
\text{Energy intake (MJ DE day}^{-1}\text{)} = 2.4W^{0.68}
\]

and Whittemore (1983) suggested:

\[
\text{Feed intake (kg day}^{-1}\text{)} = 0.12W^{0.75}
\]

as descriptive of practical feed intakes from *ad libitum* dry-feed hoppers. These latter two may also be reasonable for some circumstances of weaned pigs of less than 20 kg.
Fowler and Gill (1989) pointed out that to maintain a pre-weaning growth rate of some 280 g daily, a 6 kg weaned pig would need to eat 475 g of a diet of high energy concentration (16.5 MJ DE kg\(^{-1}\)). Weaned pigs may eat less than their maintenance requirement for some 3 days or more after weaning, and a feed intake commensurate with pre-weaning growth rates is only likely to be achieved between the second and third week after weaning in the case of pigs weaned at 21 days of age. Fowler and Gill (1989) gave the guidance as presented in Table 1.3. Whittemore (1998) suggested a rather similar outlook (Table 1.4).

Whittemore et al. (1995) pointed out that in considering the prediction of feed intake, bodyweight is reflective only of maintenance, a minor component of feed usage in the growing pig. Pigs of similar weight may ingest nutrients and grow at widely dissimilar rates of growth and body composition. Kyriazakis and Emmans (1999) put forward the logic also favoured by Black et al. (1986) that feed intake will equal that which is desired to fulfil the metabolic requirements of the day in question. These requirements are a function of pig weight (maintenance) and tissue weight gains:

\[
\text{Daily feed intake} = \left(\frac{1}{\text{feed energy content}}\right) \times \left(\frac{E_m + E_{Pr}/k_{Pr} + E_{Lr}/k_{Lr}}{H_{11002}}\right)
\]

where \(E_m\) is the energy for maintenance, and \(E_{Pr}\) and \(E_{Lr}\) are the daily rates of energy retention in protein and lipid, together with their respective energy cost factors \((k)\). In cold environments an energy cost for cold thermogenesis may also be added: 0.016 MJ \(W^{0.75}\) for each °C of cold \((T_c - T_e)\) (ARC, 1981).

Observed feed intakes in weaned pigs fail to differentiate between limits imposed by satisfaction of nutritional desire and those imposed by the capacity of the gut and other environmental constraints. The concept of the young weaned pig eating to its energy requirement is therefore likely to be redundant.

In the early stages of growth, young pigs show characteristics that are indicative of gut capacity limiting intake below that desired. These include rapid increase in feed intake commensurate with rapid increase in bodyweight and immediate positive growth response to increasing diet nutrient concentration (Cole and Chadd, 1989). The capacity of the gut is a function of its size or volume, the extent of habituation to low nutrient concentration diet, and the rate of throughput of digesta (diet digestibility). There is likely to be a genetic component to gut capacity (Fowler and Gill, 1989), but it remains largely unquantified. Black et al. (1986) reviewed data showing that the ability of pigs to increase their voluntary intake in the face of decreasing nutrient concentration is strongly related to pig size. Thus there is little or no accommodation possible for pigs of less than 50 kg whose capacity for growth appears in excess of their capacity for feed at any nutrient concentration. Tybirk (1989) presented curves suggesting that, at 20 kg liveweight, pigs will be able to eat to 70% of their ‘energy capacity’ when fed a diet of 11 MJ ME kg\(^{-1}\), 85% when fed a diet of 12 MJ ME kg\(^{-1}\), and 95% when fed a diet of 13 MJ ME kg\(^{-1}\). These values need to be appropriately proportioned for pigs of lesser weight. Fowler and Gill (1989) presumed a DE concentration of 15.5 MJ for 6 kg weaners, and it would appear likely that concentrations below this cannot be accommodated by young weaned pigs of less than 15 kg. Such pigs will therefore invariably eat below
their requirement unless offered diets of high nutrient concentration and digestibility. NRC (1987) pointed to minimum DE concentration of around 14 MJ, and a reduction of intake of some 1.5 MJ daily for each dietary DE concentration decrease of 1 MJ kg\(^{-1}\). Black \textit{et al.} (1986) set a maximum (gut capacity) feed intake limit of:

\[
\text{Feed intake (kg day}^{-1}) = 0.111 W^{0.803}
\]

where the feed is of 900 g dry matter (DM) kg\(^{-1}\).

Whittemore (1993) explored the influence of diet digestibility, through the medium of the equation:

\[
\text{Feed intake (kg day}^{-1}) = 0.013 W (1 - \text{digestibility coefficient}).
\]

The term 0.013W emanates from an estimate of faecal organic matter dry matter output by pigs. This equation suggests, for weaned pigs of 5, 10 and 15 kg liveweight, physical limits of 325 g, 650 g and 980 g, respectively, if a digestibility of 0.80 is used. Ferguson \textit{et al.} (1994) proposed that feed intake be constrained by:

\[
\text{Feed intake (kg day}^{-1}) = 0.090 (P_t/BULKDN)
\]

where \(P_t\) is the protein mass of the pig and BULKDN is the estimated indigestible organic matter content of the feed and therefore rather similar to \((1 - \text{digestibility coefficient})\); and as \(P_t\) is usually around 0.16W, 0.09\(P_t\) is rather similar to 0.013W.

Tsaras \textit{et al.} (1998) proposed that water-holding capacity (WHC) can adequately describe the 'bulkiness' of fibrous feeds. Thus an experiment using differing levels of inclusion of feed ingredients of differing fibrosity and WHC (measured by centrifugation) yielded:

\[
\text{Feed intake (g DM kg}^{-1} \text{W daily}) = 207 (1/\text{WHC})
\]

where WHC was measured in g water per g feed and ranged from 5.1 to 8.5 (the control value was 3.9). Expressed in this way, the equation is presumptive upon a

**Table 1.3.** Feed intake of weaned piglets.

<table>
<thead>
<tr>
<th>Pig weight (kg)</th>
<th>Feed intake (g day(^{-1}))</th>
<th>Energy intake (MJ DE day(^{-1}))</th>
<th>Daily liveweight gain (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First day</td>
<td>6.50</td>
<td>26</td>
<td>0.385</td>
</tr>
<tr>
<td>First week</td>
<td>6.00</td>
<td>210</td>
<td>2.72</td>
</tr>
<tr>
<td>Second week</td>
<td>7.10</td>
<td>410</td>
<td>5.29</td>
</tr>
<tr>
<td>Third week</td>
<td>9.34</td>
<td>630</td>
<td>8.15</td>
</tr>
</tbody>
</table>

**Table 1.4.** Feed intake of weaned piglets.

<table>
<thead>
<tr>
<th>Pig liveweight (kg)</th>
<th>Nutrient need</th>
<th>Gut capacity</th>
<th>Good commercial practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>375</td>
<td>350</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>10</td>
<td>750</td>
<td>700</td>
<td>400</td>
</tr>
<tr>
<td>15</td>
<td>1000</td>
<td>800</td>
<td>800</td>
</tr>
</tbody>
</table>
‘base-line’ feed intake of around 50 g feed kg\(^{-1}\) liveweight. The experiment of Tsaras et al. (1998) would suggest that a unit (g g\(^{-1}\)) increase in the WHC value of a feed is associated with a decrease in feed intake of some 6 g feed DM kg\(^{-1}\) liveweight. An earlier experiment (Kyriazakis and Emmans, 1995) also indicated that one unit (g g\(^{-1}\)) increase in WHC was associated with a decrease in feed intake of around 6 g feed DM kg\(^{-1}\) liveweight.

It has been proposed that gut constraints may become plastic when animals are in frank nutrient deficit through being given bulky feeds (an effective definition of the weaned pig transferring from milk to a solid cereal-based diet). This means that the influence of feed bulk upon feed intake can be overridden (Tolkamp and Ketelaars, 1992). If this proposition were to hold for young weaned pigs, then any model of feed intake would need to accommodate the concept of eating to optimize the efficiency of the metabolic processes as expressed by the ratio of net energy consumption to oxygen utilization rate (Tolkamp and Ketelaars, 1992). However, a recent series of carefully constructed experiments (Whittemore et al., 2001a,b) has shown that the balance of evidence is in favour of the assumption that, even when nutritionally embarrassed by being presented with a diet of lower nutrient concentration than preferred, the young pig cannot readily override the constraint of gut capacity. The pigs appeared limited at around 50 g daily feed intake kg\(^{-1}\) W (Whittemore et al., 2000). It would appear safe to assume that on all but the highest DE concentration diets (those in excess of 15 MJ ME kg\(^{-1}\)), the feed intake of the recently weaned pig is constrained by the limitations of its gut capacity.

Influence of environmental temperature and stocking density

Pigs at first eat more, and then less, in a quadratic response of feed intake to environmental temperature (Close, 1989; Whittemore, 1998). Effective temperatures (\(T_e\)) below that required for the metabolic comfort of the pig will increase energy demand for cold thermogenesis. To calculate effective temperature, Whittemore (1983, 1998) followed the ARC lead by developing the findings of the Cambridge School (Mount and colleagues) to give:

\[
T_e = T_a \times V_e \times V_l
\]

where \(T_a\) is the ambient temperature and \(V_e\) and \(V_l\) are described with a series of coefficients ranging from 0.7 to 1.4, depending upon rate of air movement, draught and lying conditions. The energy cost of cold thermogenesis (MJ) when the effective temperature (\(T_e\)) is below the animal comfort temperature (\(T_c\)) is probably between 0.011 and 0.016 per degree difference between effective (\(T_e\)) and comfort (\(T_c\)) temperatures per kg \(W^{0.75}\) (Verstegen et al., 1973). Whittemore and Fawcett (1976) give:

\[
\text{Energy cost of cold thermogenesis} = 0.016W^{0.75}(T_c - T_e).
\]

Appetite will therefore increase as the ambient temperature is reduced.