Integrated management systems for livestock
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Nutrition management of growing pigs

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Abstract
Nutritional management of pigs to optimise growth demands pig-specific, time-specific and place-specific determination and provision of nutritional requirement. These elements need to be incorporated into response prediction models that operate in a real-time (not retrospective) closed-loop control environment. This implies appropriate means for the on-line measurement of response to change in nutrient provision, and the simultaneous means for manipulation of feeding level and feed quality. The paper describes how response prediction modelling and response measurement may now be achieved. Optimisation may be pursued with mixed objectives, including those of production efficiency and environmental protection.

Introduction; managing the nutritional environment
The potential benefits of optimising pig response to nutrients by the targeting of specific production objectives rather than the satisfaction of generalised 'nutrient requirements' were proposed by Whittemore and Elsley (1974), and recently reaffirmed by Jean dit Bailleul et al., (2000). Both reports differentiate between biological and economic performance, and place the understanding of nutrient dispositioning at the centre of any ability to optimise production response.

Present considerations are as much directed to the management of the environment as of production performance. It may be calculated that some 5 kg of excreta are voided daily by pigs. For each pig place on a farrow-to-finish production unit, the annual output of N, P and K respectively is about 7.5 kg, 3 kg and 4.5 kg. This may be considered as a potential organic fertiliser or a potential pollutant (Whittemore, 1995). Losses are usually in the order of greater than 30 % for N, and around 10 % for P and K.

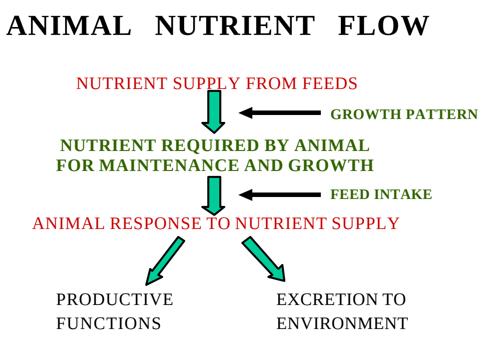


Figure 1 Components of nutrition management in the growing pig

As indicated in Figure 1, the prediction of nutrient response needs knowledge at three levels. First, the yield of nutrients from dietary substrates: feed evaluation. Second, the uses to which the nutrients will be put. Third, the way these two levels interact to produce output in terms of retentions and excretions; that is, model algorithms and structures. Nutrition management also needs further knowledge of the value of the response in the market place, and the means to balance monetary with non-monetary value.

Explicit in nutrition management is the means to accurately measure and control inputs, and to accurately measure and timeously respond to outputs. Optimisation necessitates control responses within the time period of the production process itself. Retrospective determination of inefficiency is inefficient in itself, and past history is no certain guide to future events in the production of pigs. The growth of the pig requires therefore to be managed toward the optimum end point throughout its growth course by an Integrated Management System (IMS). Real time measurement of response to nutrient supply, the comparison of that response with the predicted expectation, and the immediate on-line adjustment of nutrient supply are all seminal to management. This is the 'closed-loop' paradigm. In this respect the rules are no different to other dynamic management cycles of Design, Implement, Measure, Emend… Emendation to meet target outputs can only result from measurement of response. In the context of the production of pigs, both measurement and design emendation have till now been unavoidably retrospective.

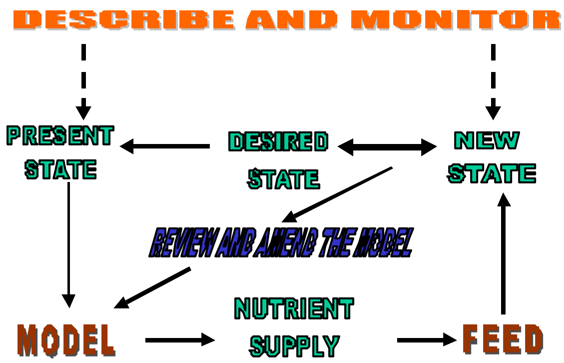


Figure 2 The tools required for closed loop management of pig nutrition

The tool kit for nutrition management (Figure 2) thus comprises

A response prediction model
An on-line measuring device for growth response
A communication mechanism between measuring device and model
A feeding system controlling both the quantity and quality of nutrient supply

Integrating pig growth models into the production management and control system enables an advanced control engineering approach to be applied. This involves measuring process output (in the present case of the IMS PIGS programme, by video imaging), and feeding this into a process controller which calculates the difference between actual (measured) and optimal (calculated from a model) growth. This then allows the feed input to be altered to closely meet the requirement. When controlling diet, the main inputs will be the level and balance of dietary energy and amino acid. An IMS approach will take direct control of these inputs on a daily basis, and deliver instructions to control mechanisms to manage the nutrient supply.

That possession of these tools enables real time steering of the production process and efficiency gains have been ably demonstrated at Silsoe Research Institute by the pilot trial of Milne et al., (submitted). Gill (1998) found that three-step phase feeding achieved a saving of 7 % on feed costs. It can be estimated from the Silsoe trials that day-step phase feeding will double that benefit. In addition, fitting dietary protein supply to ensure avoidance of over feeding can reduce the rate of nitrogen excretion into the environment by up to 40% (Kay and Lee, 1995; Lee et al., 1995; Kay and Lee, 1996). Dourmad et al., (1999) estimate that two-thirds of the nitrogen consumed by pigs in the European economy is excreted in faeces and urine. This is both a measure of nutritional shortcomings and an embarrassment to the target maximum application rate of 170 kg/ha, and the control of ammonia emissions into the atmosphere. More than 25% of these losses may be attributed to a failure to maximise production and to optimise efficiency by the correct matching of dietary protein quantity and quality to that required by the pig as it grows.

Response prediction modelling

The quantity and composition of pig daily live weight gain is a result of the amount of feed eaten, the nutritive value of the feed, the purposes to which the feed nutrients are put, and the limits to the retention rates of tissues. All of these are interdependent. A description of any one characteristic in the absence of knowledge of others is nonsensical.

Models initialising nutrition management systems must make estimations of feed intakes, nutritive values and pig responses, but given the diversity and dynamic of the production process they will be in error to a greater or lesser extent. The closed-loop paradigm however allows continuous learning as the process of pig growth unfolds. Thus the net value of nutrients consumed, and the limits to tissue retentions, may be evidenced from the measured (rather than presumed) output. It has yet to be determined whether empirical iteration and trial and error learning will become sufficient to model the process adequately for its optimisation. Presently, we suspect (a) that diagnosis of causes of change in response and (b) that the need to accommodate step changes in management practice will both require analysis and interpretation exterior to the process. This is likely to be best managed through the medium of intelligent and deductive models, rather than dumb responders.

Recent excellent reviews relating to the scientific bases of model construction can be found in Moughan et al., (1995), Kyriazakis (1999), and McNamara et al., (2000). Whittemore et al., (2001a,b,c) have completed technical reviews of the energy and protein requirements of growing pigs for feed intake, energy, and protein respectively.

Feed intake

Whittemore et al. (2001a) propose that daily feed intake is either that which is prescriptively allocated to the pig on the basis of live weight or age, or the feed that the pig is able to obtain when fed ad libitum within the constraints of physical elements such as the environment, feeder space, and peer competition. In both cases the feed ingested will be modulated by; the health and demeanor of the animal; the effective environmental temperature; the size of the pig; the capacity of the gut of the pig; the nutrient requirement of the pig for the day in question; and the type of the pig. These authors concluded, pessimistically, that the variable nature of feed intake measured over different production circumstances had the consequence that it was unrealistic to expect from the scientific literature any reasonable prediction of the ad libitum feed intake of any particular group of pigs. More optimistically, the authors also concluded that general principles may be drawn from the literature to derive; (a) the likely forms (but not the parameter values) of intake functions relating feed intake to pig live weight, and (b) the likely factors involved in the modulation of feed intake at any given live weight. Using these principles two methods for determining on-farm feed intake from the use of simple and available records were proposed. One required knowledge of start and final weight, the time elapsed and total feed intake, and involved the determination of a suitable growth curve and the fitting of a suitable feed intake curve. The other method required spot measurements through the growth period and the testing of different functions for best fit. An example is shown in Table 1.

Table 1 *Estimated parameters for various equations to describe the voluntary daily feed intake (DFI) of pigs fed to appetite by Tullis (1982), (from Whittemore et al. 2001a). The measured data were three plots each at three stages in the growth period (n = 9).*

Equation	a	b	r^2	SE of estimate
$DFI = a \cdot W^b$	0.159	0.693	0.95	0.262
$DFI = a + b(W – W_0)$	1.37	0.0312	0.93	0.319
$DFI = b \cdot (1 – \exp(-a \cdot W))$	0.0113	5.72	0.97	0.198

Models for feed intake predictions that quantify modulating factors may have functionality as diagnostic tools.

Energy requirement

Energy requirement may be expressed as the sum of its components, maintenance, protein retention and lipid retention; together with their respective efficiencies. The review of Whittemore et al. (2001b) found however that these components were not simply additive in nature as is commonly assumed. Expressions of maintenance requirement found in the literature were unconvincing in their variety of expression of coefficients and exponents and difficult to accommodate within the known framework of the interdependence of estimates of the efficiencies of maintenance (E_M) and of protein retention (k_{Pr}). The review concluded that maintenance in the growing pig should relate to protein metabolic activity. It is likely that maintenance costs will also be farm-specific, not least because of the requirements for activity and disease, both of which are presently difficult to quantify in practical circumstances. The energy cost of cold thermogenesis at low ambient temperatures and the reduction in energy intake at high ambient temperatures can now be rather closely quantified. However the effective temperatures and environmental circumstances at which these costs become active are less well described.

The review concluded that a single value for the energy cost of lipid retention (k_{Lr}) was inappropriate as the retention of lipid by direct incorporation was high and may comprise the usage of a substantial proportion of the dietary lipid supply. The lower efficiency relating to the utilisation of metabolisable energy from carbohydrate for lipid retention appeared to be constant.

For protein retention, most workers now assume the linear-plateau response. The reviewers confirmed the undependability of estimates for the efficiency of utilisation of metabolisable energy for protein retention (k_{Pr}). This was found to be consistently variable, and associated with high error statistics. It would appear that k_{Pr} will depend upon, inter alia; the nutrient supply and the rate and mass of total protein tissue turnover (which are dependent upon the maturity and the type of pig concerned).

The present authors interpret the findings of the Whittemore et al. (2001b) review as suggesting that whilst the general forms and structures for energy requirement may be elucidated, parameterisation is complex. Many algorithms are likely to be specific to circumstance and not general in their nature. There is a significant element of unquantifiable inefficiency in the system due to disease and other farm specific circumstance, and this can only be dealt with by some sort of 'taring-off' mechanism. All of this calls for iterative and continuous feedback into the model. Only then can a model be expected to predict response and guide nutrition management within the context in which it finds itself.

Protein requirement

The maintenance requirement for absorbed amino acids serves to replace endogenous losses and skin and hair, and support a minimum rate of protein turnover such as might occur when protein retention is zero. The amino acid requirement for growth is directly linked to the level and composition of the daily rate of protein retention, for which the linear-plateau response to energy supply now appears almost universally accepted (Black et al., 1986).

For description of the maximum rate of protein retention (Pr_{max}), the Gompertz function $Pr_{max} = Pt \cdot B_p \cdot \ln(A_p / Pt)$ is found to be useful. Values for B_p (the growth coefficient), A_p (the mature weight of protein tissue (Pt_{max}) in the whole live body), and $B_p \cdot A_p / e$ (the highest value for Pr_{max} which occurs at 0.37 of mature protein weight), have been suggested by Whittemore (1998) for meat pigs. However, the use of a single value throughout the 20 – 120 kg growth period may be just as appropriate (Kielanowski, 1969). The parameters of the growth function are, of course, specific to pig type.

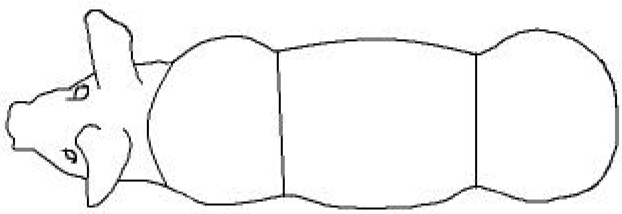
An important conclusion to the review of Whittemore et al. (2001c) was that the inefficiency of use of presumably optimally supplied ileal digested ideal protein was an expression of protein losses occurring as a result of protein turn over. A requirement for the satisfaction of the losses from protein turnover consequential upon protein retention, and therefore additional to the requirements for maintenance, has thus been identified. Quantification of this novel algorithm has now been achieved with sufficient success to warrant its inclusion into models of requirement estimation. This approach not only deals with a previously inadequately explained inefficiency of protein use, but it also allows both energy and protein elements to be conceptualised within a single coherent modelling framework, which readily accommodates protein / energy interactions. This will substantially facilitate the operation of closed-loop management systems.

Measurement by visual image analysis

Schofield, Marchant and their co-workers at the Silsoe Research Institute have developed, together with Osborne (Europe) Ltd., machine vision systems to measure, specifically at present, the aerial view of the back plan area of pigs as they stand eating or drinking. The system affords continuous monitoring of changes in size and shape, as measured from the outline of the pig image, as the pig grows. Whittemore and Schofield (2000) point out the numerous benefits of measuring size and shape directly, as this is in many cases the primary measurement of interest; weight only being the measure of common usage as it was so much easier to determine. In instances such as post-weaning, and during the reproductive cycle, shape (condition) change is a better indicator of metabolic activity than weight change. Maintenance is expressed as a function of mass scaled to size (by use of an exponent of 0.60-0.75). Carcass value is better expressed in terms of the size and shape of cuts for sale, and of the joints from which they arose. Bastianelli and Sauvant (1997) state "Growth has sometimes been defined as the rate of change in body weight……but the development of the animal, e.g. change in body composition, or in the relative importance of the different parts of the body, also needs to be included in the definition". It is specific muscle volume that gives a better prediction of carcass value than lean tissue weight.

Notwithstanding the possibilities of direct interpretation of response through the medium of change in size and shape, the initial interest in visual image analysis systems (VIA), has been as a means of measuring the weight of pigs from a remote point. Dismay at the difficulties inherent in providing a reliable stream of information from weighing mechanisms incorporated into feeding stations (Ramaekers, 1996; Henderson, personal communication) would suggest that visual imaging systems may be a more reliable route to the determination of pig mass than the in-pen weigh station. Recent work at Silsoe (Marchant et al., 1999) has shown that the change in plan surface area as measured from an overhead visual image of a growing pig (Figure 3) is closely correlated to the simultaneous change in body weight (Figure 4).

Figure 3 Overhead plan view of the pig as monitored by the imaging system. The A4 plan area includes the three body



segments, and excludes the head.

Thus,

$W = a + bX$

where W is live weight and X is the plan surface area, and where the s.e. of a is 0.63, that for b is 3.5, and that for the prediction less than 0.5 kg. The difference between VIA predicted weight and mechanically determined weight was less than 3 %; that is, no different from the expected difference between two determined weights, given the influences of change in intestinal and bladder content, and the accuracy of mechanical weighing systems. The first effective use of 'VIA derived weight' to optimise production is reported by Milne et al., (submitted). These authors present a graph with manually measured weight (conventional weigh crate), and VIA derived weight (from A4) on the y axis, and day of trial on the x axis. The two lines are effectively indistinguishable (Figure 5).

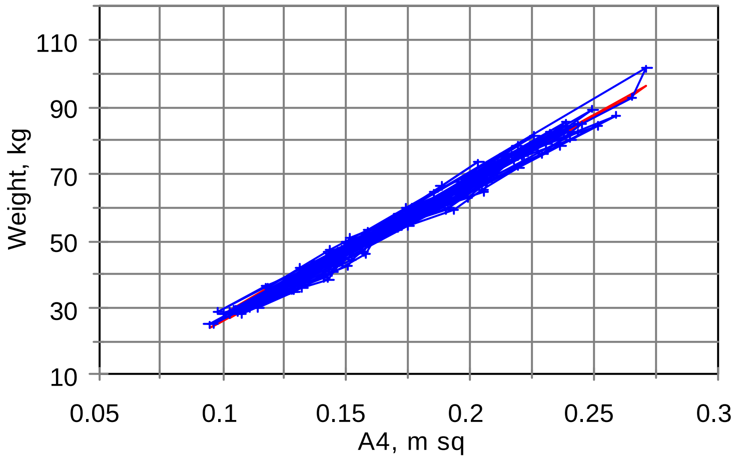


Figure 4 Pig live weight as a function of the A4 plan area measured by the VIA system

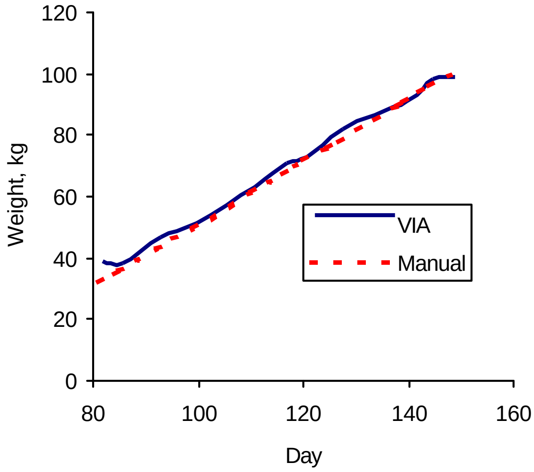


Figure 5 Pig live weight in relation to day on test by manual mechanical manual weigher, and by visual image analysis (VIA). (From Milne et al.)

In a more recent experiment (Henderson, M. and Schofield, C.P., unpublished) a pilot set of 59 pigs was weighed frequently over a period of one month to give same-day comparisons of 851 weighings from the platform (load cell) weigher (W) and those predicted from the VIA A4 data stream (VIAW). From this data set 3 pigs (with 15, 7, and 8 associated weighings) were removed on grounds of aberrant data, and a further 14 individual measurements were removed as the differences between values for the two systems exceeded 10 kg. The data set thus comprised 56 pigs and 807 comparative values. Pigs averaged 35.1 (SD 7.34) kg for this trial, ranging from 13 to 56 kg. Regression of VIAW on W (standard errors for the coefficients, the constants and the overall equation are in brackets) gave,

VIAW (kg) = 0.959 (0.0122) W + 1.42 (0.439) (2.55) n=807

Both the coefficient and the constant were significant ($P<0.01$). The more close to zero the constant and the more close to unity the coefficient; the more similar the VIAW and W measurements of weight may be considered to be. In the case of difference (which is a result of errors in both systems), it is not possible to ascertain which, if either, of the weights was the indicator of true pig mass. In any event, the regression equation for values of W yielded estimates that might be considered as within expectation of that for two weighings undertaken for a single pig with the same machine at two different times of day. However, the presence of a systematic error may be interpreted from a significant constant, although the constant was relatively small in absolute terms. As is commonly the case, it was also apparent that many of the cases of differences between VIAW and W related to the early days of the experimental period due to the high degree of oscillation in pig live weight at this time. Under normal experimental conditions, in the absence of a methodology for the continuous monitoring of live weight, it is naively assumed that the weight at entry to the experimental pen is a true reflection of ‘start weight’, which it may well not be.

As has already been discussed, the ability to measure and act upon changes in pig parameters relating to shape (composition) is likely to be more significant than the conventionally monitored change in weight, when used as a control input for managing the nutrition of growing pigs. Figure 6 demonstrates how the
VIA measurement system can provide weight-related information by processing plan view images of individually identified pigs within a production pen.

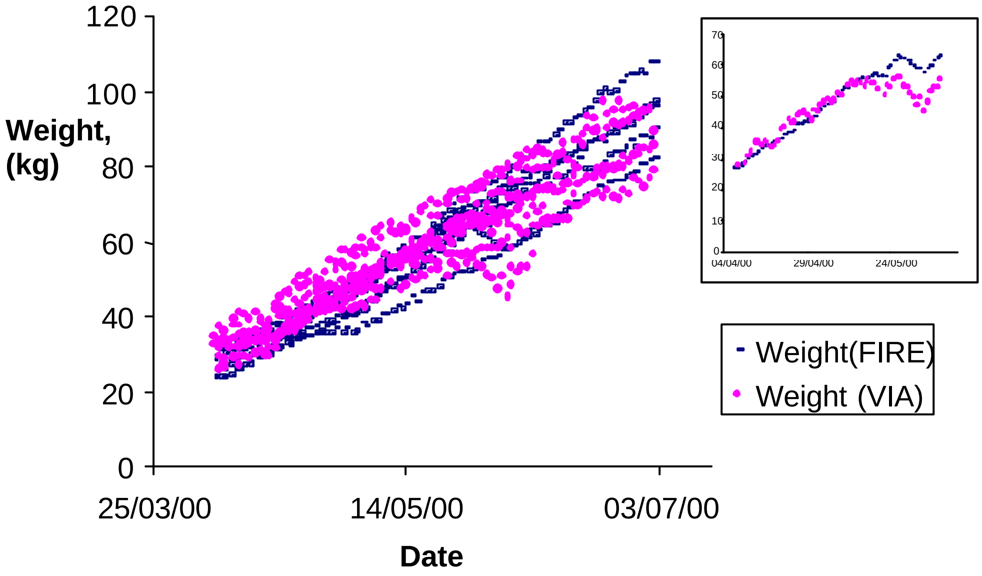


Figure 6 Changes in VIA-predicted weight (from A4, coloured points) and conventionally measured weight over time for 8 pigs. Inset demonstrates recorded drop in weights for a pig with a leg infection.

The overall relationship between VIA-derived and conventionally measured weight for the whole pen data set is satisfactory when a typical weight-to-area algorithm of W = 0.052*A4 -32 is applied, yet there are extremes which suggest that a more accurate algorithm could be derived. The inset graph separates one pig's data from the group, and clearly demonstrates that the VIA derived weight matches, and indeed emphasises the weight loss recorded using the conventional weigher. It is reasonable to conclude from this, that the relationship between that pig's condition and its area A4 is stronger than with its weight, corroborating the proposal that dimensional measurements are more valuable than weight when monitoring pig condition.

Conclusion

Optimisation of nutrient provision to pigs through integration of the management of the feeding system requires dynamic methodologies both to determine requirement and to measure response. The former is
satisfied through response prediction modelling, and the latter, until now unavailable, we believe will be provided through VIA.

Acknowledgements

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