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Contents

Omega-3 and omega-6 polyunsaturated fatty acids and fertility in female ruminants Kevin Sinclair, Karen Wonnacott and Phil Garnsworthy	1
Environmental and genetic influences on successful heifer rearing D.C. Wathes, A. Clemson and J.S. Brickell	3
Reducing dietary phosphorus inputs within grass-based dairy systems C.P. Ferris	6
Practical aspects of feeding grass to dairy cows Pat Dillon	8
Methods to reduce mycotoxins in animal feeds Giuseppina Avantaggiato	11
Practical considerations of feed evaluation systems for dairy cows Jonathan Blake	14
Adapting livestock production systems to climate change CJ Stokes, SM Howden and AJ Ash	17
Legislation affecting animal production systems Mike Brade and John Chambers	20
The effect of nutrition on stress and immunity T. A. Niewold	24
Potential applications of GM technology Greg Tucker	25
Influence of feed processing technology on pig performance L.A. den Hartog and S.R. Sijtsma	28
Piglet starter feeding: in a changing business climate Dr Mike Varley	31
Organic acids in pig diets Kirsi Partanen, Jarkko Niemi, and Timo Karhula	33
Amino acid requirements in piglets with special emphasis on tryptophan and valine Etienne Corrent, Aude Simongiovanni, Jaap van Milgen, Nathalie Le Floc'h	37
Factors affecting pork quality Jeff Wood	40

Omega-3 and omega-6 polyunsaturated fatty acids and fertility in female ruminants

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Dietary polyunsaturated fatty acids (PUFA) are known to mediate a broad range of actions on reproductive tissues, influencing processes such as ovarian follicle development, ovulation, corpus luteum function, pregnancy establishment and embryo survival. These actions in turn are mediated by effects of PUFA on a number of physiological processes including alterations to membrane fluidity and composition, intracellular cell-signalling cascades and susceptibility of cells, including embryonic cells, to oxidative injury. Central to the current thesis are the reported differential effects of omega-3 (n-3) and omega-6 (n-6) PUFA on reproductive tissues where interest to date in ruminants has primarily concerned the differential action of these two families of PUFA on ovarian, endometrial and placental synthesis of prostaglandins, with implications for ovulation, embryo survival and the onset of labour.

Attention in recent years at Nottingham has turned to the uptake and metabolism of fatty acids, including PUFA, by the ovary, and to the effects that this can have on egg and early embryo development. Working with lactating and non-lactating cattle and sheep, ongoing studies are revealing that cells within the ovarian follicle preferentially select and/or synthesise saturated fatty acids (FA) at the expense of PUFA, thereby minimising effects of dietary induced differences in plasma PUFA on the developing oocyte. As a consequence of this, and in the absence of differences in circulating metabolic hormone concentrations, diets contrasting in vegetable sources of n-3 and n-6 PUFA had negligible effect on the post-fertilisation developmental potential of oocytes recovered by ovum pick-up from lactating Holstein cows. In sheep, animal studies are being extended to include high- and low-density lipoproteins, fractionated from sera of ewes offered contrasting n-3 and n-6 PUFA diets, in ovarian follicular-cell and embryo culture media. Results to date indicate that granulosa cells can acquire fatty acids from HDL, but that there are no differential effects of n-3 and n-6 PUFA HDL on granulosa cell proliferation, steroidogenesis and expression of genes involved in fatty acid uptake and

metabolism. In contrast, n-6 PUFA HDL reduced embryo development during culture relative to the non-supplemented Control and the n-3 PUFA HDL treatment groups. These findings, together with some of the underlying mechanisms, are discussed in this paper in the context of their implications for embryo survival and female ruminant fertility.

Environmental and genetic influences on successful heifer rearing

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Dairy heifers represent the future of the herd. The aim should be to rear healthy, well grown individuals with excellent fertility that are well equipped to join the herd at first calving. Such animals are then able to fulfil their genetic potential by leading a long and productive life. Many farms do not, however, devote sufficient resources to their replacement heifers. Overall, on UK farms at the present time around 8% of calves are born dead and 15% of liveborn heifer calves do not survive until first calving.

Extent and timing of heifer losses

Heifer rearing covers a number of phases, each with very different demands in terms of management. The overall UK perinatal mortality rate (including birth and the first 24 h of life) is about 8% with a higher rate in first calving heifers. The other main risk factors are twinning and dystocia, with evidence that an increasing proportion of perinatal deaths are associated with smaller, weaker calves born unassisted particularly to first calving heifers. A further 6-7% of dairy calves on UK farms die in their first 6 months, mainly from gastrointestinal and respiratory diseases. Losses due to death or culling during the period from 6-15 months averaged 3.5% across farms and were mainly attributable to accidents. Even if calves survive an initial infection, affected animals are more likely to die or be culled before calving and age at first calving is likely to be delayed. Low weights and circulating IGF-I concentrations at 1 month are both risk factors for calf mortality. Some exposure to disease is inevitable, but the risk of infection can be minimised by ensuring an adequate colostrum intake, cleanliness in the preparation of milk feeds together with good hygiene in the calving pens and calf housing. Dairy heifers are normally bred for the first time at around 14-15 months of age to calve at or shortly before 24 months. On average about 4% of heifers reaching breeding age are culled during this period, primarily due to poor fertility. Conception rates to first service are consistently better in heifers than in lactating cows and generally exceed 60%. Nevertheless not all animals conceive readily and some heifers receive multiple inseminations over an extended time period before eventually either conceiving or being culled. Late embryo mortality or abortion have a low incidence of about 2-5%, but when they do occur they cause significant delays in age at first calving. Considerable variations in the mortality rates at different ages between farms suggest that improvements are possible if best practice is consistently adopted during the rearing process. Conversely, a brief period of inattention during the 2 year rearing period can have major consequences in

reducing the supply of replacement heifers, with some farms losing over a quarter of all live calves born.

Growth and nutritional management

Targets should be set for each phase of development to ensure that heifers reach first calving with a large, lean frame having experienced good skeletal growth without becoming too fat (BCS <3). At service animals should have achieved about 55-60% of their mature body weight and this should have increased to 85-90% by first calving. Studies in both the UK and USA show that calving at 22-24 months minimises the rearing costs by reducing the period before the animal becomes productive. This does not have any adverse consequences providing the animals are well grown when bred. Indeed, well grown animals which calve relatively young go on to perform well within the herd. In contrast, poorly grown or over fat heifers have an increased risk of dystocia, even if they are older at calving. In order to calve by 24 months it is necessary to achieve an average growth rate of around 0.7 kg/d throughout the rearing period. Growth rates of 0.7 kg/d before puberty and 0.8 kg/d after puberty are often recommended. In practice we found extreme variability in growth rates between cohorts of calves on different UK farms, which ranged from 0.5-1.0 kg/d between 1-6 months of age. Although management factors on any one farm should have been consistent, we also found much variation in the growth rates for animals on the same farm. Many heifers were therefore below the target weight of 350-380 kg recommended for Holsteins at breeding. The first vitally important goal in nutritional management is to ensure that all calves receive an adequate supply of good quality colostrum so that they rapidly acquire passive immunity to the pathogens to which they will immediately be exposed. There is extreme variation in colostrum quality between dams. Failure to achieve a minimum level of passive transfer (defined as a serum IgG levels >10 g/L within 48 h of birth) occurs in 20-50% of calves. In order to maintain good growth rates calves should then be fed either good quality whole milk or (preferably) milk replacer with a protein content of >25% dry matter. Some concentrates should be provided well before weaning to avoid making the transition too abrupt and either hay or good quality straw must be available to the calf to promote rumen development. Careful management around weaning will reduce any check to growth. Sub-optimal nutrition at any point during the rearing period delays the age at first calving, so having significant cost implications.

Possibilities for genetic selection

Currently the phenotypic measurements used in selection indices are all based on the milking cow, so require the animal to reach that stage in life before they can be assessed. Traits such as heifer sizes (weight, height, girth, crown rump length) at particular ages, growth rates and heifer fertility could in future be included into traditional breeding indices, as

they are all correlated with later performance. Some studies also suggest that measurements of metabolic parameters in growing heifers may be informative. Recent developments in genomics offer the promise of basing selection decisions on an analysis of the DNA of an individual cow or bull, which can be performed at birth. Single nucleotide polymorphisms (SNPs) are variations in the DNA sequence which may be linked with particular traits.

Designing a management strategy for optimum heifer rearing

In summary, in order to produce well grown, healthy heifers for an acceptable economic outlay it is first necessary for dairy units to draw up a comprehensive management strategy to suit their individual circumstances. This should set targets for survival and growth at different stages which can subsequently be checked through good monitoring. This should avoid delays for animals in joining the milking herd associated with poor prospects for adult performance.

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Reducing dietary phosphorus inputs within grass-based dairy systems

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Phosphorus (P) inputs to agricultural systems (mainly in inorganic fertilisers and concentrate feedstuffs) are derived from phosphate rock, a finite resource. However, in many agricultural regions, and at an individual farm level, there is a significant imbalance between P inputs and P outputs. Although most surplus P accumulates within clay type soils, part of this P is at risk of being lost to the environment. In addition to representing a loss of a valuable nutrient from agricultural systems, this may also lead to eutrophication of waterways (the process of nutrient enrichment, whereby a body of water changes from a nutrient poor (oligotrophic) to a nutrient rich (eutrophic) state), with negative effects on water quality and amenity value. However, European Union legislation dictates that the trophic status of waterways is improved, a particular challenge in some member states and regions, including Northern Ireland.

Dairy systems have been implicated as an important source of P pollution. Although improved manure management practices can reduce P losses, reducing the quantity of P purchased onto farms is the first important step in addressing the problem. One option by which this can be achieved involves feeding concentrates with a lower P level. However, reducing P levels in dairy cow diets will clearly be unacceptable if animal performance, health and fertility are compromised.

During the last four decades a number of studies have examined the effect of dietary P level on dairy cow performance. However, most of these studies were of a relatively short term nature (less than two years), which is of concern as cows have the ability to deplete phosphorus reserves for milk production over a number of lactations, and as such deficiency symptoms may not arise in the short term. In addition, most of these studies involved non-grass/grass silage based diets. Recognising the limitations of many early studies, and that many aspects of P nutrition and metabolism are not well understood, the current UK rationing system (AFRC, 1991) includes a recommendation that dairy cow P requirements should be validated in long term feeding trials using roughage-based diets. This recommendation was addressed recently in a four-year experiment which was conducted within a predominantly grassland-based system at Hillsborough in Northern Ireland. Within this study dietary P levels were reduced to approximately 3.6 g/kg DM, resulting in P intakes

of approximately 0.8 (proportionally) of AFRC (1991) requirements. This was achieved without adverse effects on cow performance, health, fertility or bone P reserves. These results confirm that there is an opportunity to reduce the P content of dairy cow rations to levels lower than those recommended within AFRC (1991), in agreement with recent recommendations from a number of other countries.

However, accurate ration formulation with regards to P requires that the P concentration of both the concentrate and forage components of the ration be known. Although P content of concentrates can normally be calculated with a high degree of accuracy, P content of forages is rarely known in practice, and can be extremely variable. Thus, when advocating adoption of reduced P concentrates, it is important that concentrate P levels are adequate for silages of different P contents over a range of concentrate feed levels. For example, a lower concentrate P content could be adopted when a forage with a high P content is supplemented with a high level of concentrates, compared to when a forage with a low P content is supplemented with a low level of concentrates.

Offering diets containing reduced P levels can substantially reduce farm P surpluses, a key requirement of Northern Ireland legislation which applies to farms requiring a derogation of the European Union Nitrates Directive. In addition, it has been demonstrated that offering reduced P diets will reduce faecal P excretion in dairy cows (from 103 to 72 g/day when the P content of dairy cow diets was reduced from 5.2 to 3.7 g/kg DM). Reducing the P content of dairy cow rations will also reduce the solubility of P excreted in manure by up to 90%, a fact which can be attributed to reduction in the soluble orthophosphate fraction. These latter two factors, when combined with improved manure management systems, have the potential to substantially reduce P loss from dairy systems.

Practical aspects of feeding grass to dairy cows

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Grassland area has been significantly reduced in Europe during the last thirty years (by approximately 15 M ha) in favour of the production of fodder maize and other annual crops. One of the major advantages of grass-based systems of milk production is its low cost per unit of production. It is envisaged that the cost of both concentrate feed and grass silage will continue to increase over the coming years. Concentrate feeds due increased world demand and lower supplies and conserved grass silage due to increases in contractor charges associated with inflation in labour, energy and machinery costs. Recent research has shown that milk produced from cows fed grass diets is superior in milk composition to that produced from cows fed indoor concentrate/conserved forage based diets due to being higher in unsaturated fats; especially omega-3 and ruminic acid. Similarly there are advantages to grass-based systems of milk production in terms of animal welfare, conservation of biodiversity, regulation of physical and chemical fluxes in ecosystems and the mitigation of pollution.

Daily grass DM intake will be maximised by adhering to important sward characteristics such as maintaining a high proportion of green leaf within the grazing horizon while allocating an adequate allowance of daily herbage. Increasing the green leaf proportion at the base of the sward through appropriate grazing management in spring will play an important role in increasing herbage intake and making grazing management easier. This requires knowledge of the carryover effect of early season grazing management on mid-season pasture quality and its implication for milk output per hectare. Recent advancements in grazing management have shown opportunities to extend the grazing season in early spring and late autumn as well as increase animal performance during the main grazing season. This can be achieved by grazing management, cultivar selection and N fertilizer application strategy. Both high grass DM intakes while at the same time low residual post-grazing heights can be achieved simultaneously to facilitate the availability of high quality herbage over a long grazing season. Increases in the grazing season length will have profound effect on the overall system through reducing the quantity of slurry to be stored, reduction in the quantities of silage required for winter feeding, reductions in the energy associated with silage harvesting and slurry spreading.

Traditionally, plant breeding objectives were mostly focused on increasing DM yield and pest and disease resistance, with little emphasis on factors that affect animal performance under grazing plus characteristics of animal produce. There is a clear requirement for an increased

selection emphasis on characteristics that influence animal performance, i.e., herbage intake. This can be best achieved by adopting an interdisciplinary approach with plant physiologists, nutritionists, breeders and evaluators sharing knowledge and resources. Animal production from grazed pasture could be improved through increased use of herbage species or varieties with increased intake and digestibility potential. Digestibility is a heritable characteristic and some improvement has resulted from conventional breeding, with further increases likely to result from biotechnological modification. The development of plants with elevated concentration of ruminal undegradable dietary protein and high-energy yielding compounds, such as starch or triacylglycerides. Another major objective of grass breeding should be to select cultivars with better seasonality of production i.e. greater DM production in spring and autumn/winter.

In the future, cow genotype must be compatible with the system of milk production, and prediction of the phenotypic performance of dairy cattle must be based on knowledge of the cows' genotype as well as the environment in which they are managed. Besides appropriate grassland management, successful grazing systems require animal breeds or strains that are adapted to achieving large intake of herbage relative to their potential yield, are fertile and healthy, have good conformation to walk long distances and high survivability. Recent studies have shown large differences in performance (especially in relation to fertility and survival) and overall farm profitability between divergent breeds or strains of dairy cows when fed on a grass-based system. Grass-based systems of milk production require a cow that produces between 400 and 500 kg of milk solids from grazed grass, calve compactly every 365 days and survive for up to 5 lactations within a large herd scenario. Recent studies in both New Zealand and Ireland have demonstrated large variation in productivity, health and ultimately profitability between divergent strains of Holstein-Friesian dairy cows, differing in genetic potential for milk production and reproductive performance. The results demonstrated that the most profitable strain of Holstein-Friesian was one that was selected within grass-based systems using an index that results in increase farm profitability, e.g. Economic Breeding Index in Ireland and Breeding Worth in New Zealand. In grass-based systems, crossing the Holstein-Friesian with an alternative dairy breed (e.g. Jersey) can provide farmers with an alternative to increase overall animal performance by increasing herd health, fertility and milk value through hybrid vigour.

Recent advancements in grassland technology have the potential to significantly increase farm profitability through an extended grazing season and higher performance from grazed pasture. Applying this technology at farm level will depend on monitoring and budgeting of grass supply. Feed budgeting will be required at farm level for short term rationing at paddock level, for medium term budgeting on a weekly/biweekly basis and long term on a

yearly basis. The development of reliable, easy to use decision support tools that facilitate increased reliance on grazed grass, to be used by farmers and extension services, will contribute to optimise animal performance from grazed pasture. In recent years there has been substantial development of decision support tools to help dairy farmers to increase animal performance from grazed grass. The grazing season is divided into three periods: spring, mid-season and autumn. The Spring Grazing Rotation Planner is used from turnout until grass growth equates herd demand (late January until early April). The Pasture Wedge is used during the main grazing season (early-April until end of August) to control grass supply taking into account herd demand, rotation length and post-grazing residual. The objective of autumn grazing management is to maximise the amount of grass utilized while at the same time finish the grazing season in late-November/early-December with the desired farm grass cover so as to set up the farm for an adequate amount of grass for the following spring.

Methods to reduce mycotoxins in animal feeds

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Mycotoxins are secondary metabolites produced by a wide array of diverse fungal species, mostly belonging to the three genera *Aspergillus*, *Penicillium* and *Fusarium*. They can be produced in the growing crop and during storage. Mycotoxin-contaminated feeds impair farm operations as well as feed production in various ways: mycotoxins are invisible, odourless and cannot be detected by smell or taste, but can reduce performance in animal production significantly. All species of livestock are affected by mycotoxins. Monogastrics (swine, horses) are most sensitive, followed by poultry and ruminants. In general, young stock and animals under environmental, nutritional and production stresses are most sensitive. Direct effects of mycotoxins include acute diseases, where severe conditions of altered health may exist prior to death as a result of exposure to the toxin. These conditions are more likely following exposure to high levels of a mycotoxin. Other, more insidious or occult conditions (e.g. growth retardation, reproduction troubles, impaired immunity, decreased disease resistance, decreased milk or egg production) or more chronic disease manifestations (e.g. tumour formation) may result from prolonged exposure to small quantities of a toxin. Mycotoxins display a diversity of chemical structures, accounting for their different biological effects. Depending on their structure, these toxins can be carcinogenic, teratogenic, mutagenic, immunosuppressive, tremorigenic, hemorrhagic, hepatotoxic, nephrotoxic, and neurotoxic. Diagnosis of mycotoxicoses in animals is difficult as they may be similar to diseases with other causes. This is even more difficult in cases where more than one mycotoxin is involved because the toxins can produce additive, and sometimes synergistic, effects in animals. In addition, the possible presence of toxic residues in animal product such as milk, meat and eggs may have some detrimental effects on human health. Considerable economic losses are attributed to reduced crop yields and grain quality following fungal contamination, to downgrading of cereals from human food grade to animal feed, and to decreased animal performance and increased incidence of disease in livestock consuming mycotoxin contaminated grain. Due to the modern methods and to a growing interest in this field of research more than 300 mycotoxins have been differentiated to date. Mycotoxins commonly found in animal feed include aflatoxins (EFSA, 2004a), ochratoxin A (EFSA, 2004b), zearalenone (EFSA, 2004c), trichothecenes (e.g. deoxynivalenol) (EFSA, 2004d), fumonisins (EFSA, 2005), which differ in their toxic effects and their prevalence across regions. Aflatoxins cause liver damage and impaired immune function. Trichothecenes

reduce feed intake and weight gain and, at higher concentrations, cause emesis and complete feed refusal. Fumonisin B₁ is a carcinogen that is associated with equine leucoencephalomalacia, porcine pulmonary oedema, and spiking mortality in poultry. Zearalenone is an oestrogen that causes reproductive problems. Ochratoxin A is a nephrotoxin. Safe levels of mycotoxins in feed, below which there is no effect on animal health or production, are not well established. Regulatory officials worldwide are very concerned about the presence of mycotoxins in food and animal feed. In the EU, two mycotoxins (aflatoxin B₁ and rye ergot) are regulated (EC Regulation, 2002) under strict limits, while deoxynivalenol, zearalenone, ochratoxin A, T-2/HT-2, and fumonisins are subject to recommend guidance values (EC Recommendation, 2006). Use of feedingstuffs with levels above the maximum permitted is not allowed in the EU, neither is the mixing of contaminated feed with non contaminated feed in order to reduce the concentration of mycotoxins. Controlling mould growth and mycotoxin production is very important to feed manufacturers and livestock producers. Although desirable, prevention of mycotoxin contamination of grain in the field is currently impossible. Destruction of contaminated products or diversion to non-animal uses are not always practical, and could seriously compromise feed supply. Control of mould growth in feeds can be accomplished by keeping moisture low, feed fresh, equipment clean and using mould inhibitors. Mycotoxin decontamination refers to methods by which mycotoxins are removed or neutralised from the contaminated feed while detoxification refers to methods by which the toxic properties of mycotoxins are removed. Feed processing may involve physical and/or chemical decontamination and can destroy or redistribute mycotoxins. Physical procedures like sorting, thermal inactivation, irradiation or extraction of contaminated products have been attempted with different levels of success. Chemical procedures like treatment with acid/base solutions or other chemicals, ammoniation, ozonation, and reaction with food grade additives such as sodium bisulphite have been shown to be effective in degrading and detoxifying aflatoxin contaminated feedstuffs. Biological methods primarily involving toxin degradation by microorganisms are receiving increasing interest and have shown promising results. Dietary supplementation with large neutral amino acids, antioxidants, and omega-3 polyunsaturated fatty acids as well as the inclusion of mycotoxin-sequestering agents can ameliorate the harmful effects of mycotoxins in contaminated feeds. Guidelines for evaluating mycotoxin detoxification and decontamination procedures have been established by the Food and Agriculture Organization (FAO) and the U.S. Food and Drug Administration (FDA) (Park et al, 1988). The process should be able to (1) inactivate, destroy, or remove the mycotoxin; (2) avoid the formation of toxic substances, metabolites, or by-products in the feed; (3) retain nutrient value and feed acceptability of the product or commodity; (4) avoid significant alterations of the product's technological properties; and if possible, (5) destroy

fungal spores. In addition to these criteria, the process(es) should be readily available, easily utilized, and inexpensive. Although a variety of decontamination/detoxification methods show potential for commercial application, large-scale, practical, and cost-effective methods for a complete mycotoxin decontamination are currently not available. Moreover, no single decontamination method that is equally effective against the variety of naturally occurring mycotoxins has been developed.

An overview of strategies to control and reduce the major mycotoxins (aflatoxins, trichothecenes, fumonisins, zearalenone, ochratoxins) occurring in animal feeds will be presented.

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Practical considerations of feed evaluation systems for dairy cows

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Introduction

Describing feeds in the 21st century has become a combination of chemical and biological terms. Dairy rations in the UK are described using both historical and new terms required for the Feed into Milk system (FiM, 2004). Many of the terms are predicted by near infrared reflectance spectroscopy (NIRS) techniques providing values quickly and cheaply. Inevitably there are errors within any prediction system, not only from requirement equations, but feed analysis variation due to sampling, wet chemistry or equation error.

The perfect feeding model would be based on nutrients and not rely on all encompassing terms such as Metabolised Energy (ME). Although an improvement on gross energy, ME can only be considered as a total term as describes neither the form of the energy within the feed (starch, protein, fibre, etc.) or the fate of the energy within the animal. The Holy Grail for animal feeding systems is the mechanistic model where biochemistry defines the yields of metabolites, and the yield of metabolites defines animal performance. Despite considerable philosophical and scientific efforts, there is no published mechanistic rumen model that has successfully predicts fermentation acid production.

Feed characterisation and measurement

As animal models developed, so did the number of feed characterisation terms. Each new animal model required new methods to analyse and describe feeds. The FiM model specifies 11 animal descriptors and 32 feed terms. Of the 32 feed terms, 22 are chemical and 10 biological.

Chemical methods are often considered as the 'gold standard' and there is a tendency to forget that chemical methods are subject to sampling, method and laboratory variability. For some of the more difficult techniques such as NDF and starch determination, variation can be large, particularly in heterogeneous feeds such as forages. For example, starch determination requires forage material to be pulverised to a fine powder by ball milling to ensure the efficient release of sugars by amyloglucosidase.

Published UK ruminant feed values have stagnated since the last major database review by the FiM group in 2001. There may be analyses carried out by feed suppliers and manufacturers, but these are used to commercial advantage and are not widely available.

The lack of a dynamic feed database encourages the over and under feeding of nutrients leading to unexpected performance, inefficient use of resources and increased environmental pollution. In addition, there is no public domain system to evaluate new feeds such as biofuels co-products, leaving the nutritionist either to rely on the supplier of the feed or to make educated guesses on their likely nutrient content. Although considered unexciting, it is an essential area of science which perhaps needs European commitment.

The only freely available and routine feed analysis is for forage and more particularly silage. Forage is the most variable feed component and generally represents a high proportion of the diet, so an accurate analysis is essential for meaningful ration formulation. Drying forages may change their nutritional quality and, combined with the requirement for rapid turnaround and low cost, has led to the widespread use of NIRS for wet forages. First introduced during the late 1980s and developed independently by commercial laboratories, it became clear that repeatability between silage laboratories was unacceptable. To reduce variation between laboratories and to provide methods to measure the new feed terms for the FiM model, led to the formation in 2000 of the Forage Analytical Assurance (FAA) group. Its aims were to introduce industry agreed quality control procedures ensuring that forage results were accurate, reliable and repeatable. The quality control protocols developed by the group identified that wet NIRS scanning requires more technical expertise than dry scanning due to interference of the spectra by the large water peak.

As for chemical parameters, most biological feed values have been fixed since the publication of the FiM database from data collated in 2001. Some further work has been completed by the FAA group to improve the prediction of DOMD for high DM grass silages and for development of NIRS prediction equations for whole crop silages. There has been no further animal work on PAL (used in the rumen stability model) or degradability characteristics of silages. Currently there is no agreed energy prediction method for maize silage, and no PAL and degradability values NIRS predictions for maize and whole crop silages.

Rumen stability and fibre terms

Fibre supply and its description is a complex area of ruminant nutrition. It is particularly important in high performance animals where energy dense diets can challenge the animal's ability to maintain a stable rumen environment. This has led to a number of different terms to estimate its rumen stability potential. The FiM rumen stability system uses the principle that rumen pH is regulated by salivation, which is stimulated by chewing, set against the effect of feeds which lower rumen pH. Industry feedback indicates that the FiM RSV system reflects animal performance although it does not perform well with highly digestible NDF

forages such as spring grass. Modification of the system based on forage NDF degradability better predicts farm observations.

Silage sampling

On farm sampling of forages is a major source of concern for silage laboratories. Advisors are quick to criticise forage results as inaccurate without always considering variations that exist within any large volume of biological material. Care must be taken in preparing a representative sub sample of silage clamps.

Conclusions

Dairy models have developed over time and are a mixture of chemical and biological terms. Ideally models should be based on biochemical and mechanistic approaches, but such models seem out of reach in the current economic environment. For dairy feeding systems to be used successfully, both nutrient requirements and supply must be based on reliable science. Animal inputs need to be measured carefully, and feeds (particularly forages) must be carefully sub sampled before being sent for analysis.

There is no public domain system to evaluate existing or new feeds, leaving nutritionists to make educated guesses of nutrient content. The lack of a dynamic feed database encourages over or under feeding leading to unexpected performance, inefficient use of resources and increased environmental pollution. Silages are the only feeds routinely analysed. Nutrient measurement is largely based on wet NIRS techniques with the FAA group ensuring reliable and reproducible analysis in the UK. However, NIRS predictions are based on chemical procedures which are themselves variable. Estimation of silage degradability characteristics is difficult and further animal work would be required to improve predictions. The description of fibre within the FIM system predicting rumen stability works well in practice, apart from forages containing highly degradable fibre. Inclusion of a measure of the effectiveness of the fibre better reflects farm observations when these forages form a major part of the diet.

Adapting livestock production systems to climate change

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Livestock production is the world's dominant land use, covering about 45% of the earth's land surface, much of it in harsh and variable environments that are unsuitable for other uses. The risks of climate change are now adding to existing climate challenges and there is growing evidence that humans are contributing significantly to these changes through increased emissions of greenhouse gases (GHG). Climate change could impact the amount and quality of produce, reliability of production and the natural resource base on which agriculture depends. In order to continue to thrive in the future, livestock industries need to anticipate these changes, be prepared for uncertainty, and develop adaptation strategies now. We look at some of the specific impacts and opportunities climate change may bring to livestock industries and what some of the options could be to adapt to them.

Although climate change will have some direct effects on livestock, the dominant influences will be through changes in plant growth and the timing, quantity and quality of forage availability. Climate change will involve a complex mix of responses to (1) rising atmospheric carbon dioxide (CO₂) levels, (2) rising temperatures, (3) changes in rainfall and other weather factors, and (4) broader issues related to how people collectively and individually respond to these changes (Table 1). We consider how each of these influences will affect livestock production systems.

The ultimate impacts of climate change are likely to be strongly modified (potentially for both better and worse) by the way in which people, individually and collectively, respond to these challenges. Vulnerability to climate change can be reduced by preparing, evaluating and implementing adaptation strategies that limit the risks of negative impacts while taking advantage of new opportunities. Building adaptive capacity will require (1) availability of effective adaptation options, (2) capability of enterprise managers to implement these options and (3) a policy and institutional environment that promotes development, evaluation and adoption of effective adaptation strategies.

In the short-term, many adaptation options are likely to correspond strongly with efforts to promote existing 'best practices' that are both economically and environmentally sustainable.

These would include practices such as managing diet quality (using fertilizer, legumes, choice of planted pasture species and diet supplements), matching stocking rates to pasture production, adjusting herd management to altered seasonal patterns of forage production, using fire to control woody thickening, and monitoring the spread of pests, weeds and diseases. Enhancing such practices should be an initial priority because they provide an immediate benefit, irrespective of whether climate change occurs. A broad array of adaptation options will be needed to deal with geographic differences in grazing resources, culture, institutions, economies and impacts of climate change. A wider variety of options is likely to be viable in high-input, productive managed pastures than for more extensively managed rangelands. In more arid environments, where coping with climate variability is already a management priority, building capacity to cope with climate variability can serve as a strong starting foundation in preparing for climate change. Over the longer term, it will also be necessary to develop new management options that are better suited to emerging novel climate conditions.

Table 1: Summary of key influences of climate change on livestock production

Plants & Natural Resources	Livestock
<i>CO₂</i>	
Enhanced pasture resource use efficiency	No direct effects
Reduced forage quality (protein and digestibility)	
Prolonged moisture availability from water savings	
Shifts in vegetation composition	
<i>Temperature</i>	
Reduced water use efficiency, increased evaporation	Greater effects of heat stress and water demand
Decreased forage quality (digestibility)	Livestock concentrate around water points
Poleward expansion of pests, weeds, native species and suitable ranges of planted pasture	Poleward expansion of tropical pests and diseases
<i>Rainfall, sea level rise and other changes in climate</i>	
Changes in forage production magnify percentage changes in rainfall	Changes affect availability of feed and water for livestock
Changes in seasonality of forage availability	
More variable forage supplies and soil erosion	
Saltwater intrusion and increase risks of flooding	
Broader context and other issues	
Potential shifts in land use and competition between land uses	
Delayed action exacerbates impacts	
Changes in regional and international competition	
Changing demand for livestock products and availability/price of feed supplements	
Indirect (and direct) costs of GHG reduction measures	
Conflicts and synergies with other public and private policies and initiatives	

Creating conditions that encourage climate adaptation will require: effective communication of climate science to provide confidence that climate change projections are real; acceptance that these changes will have practical impacts on livestock production enterprises; demonstrating the practical benefits of adaptation options in reducing potential impacts; protecting early adopters against establishment failure in implementing adaptation strategies; altered transport and market infrastructure that supports adapted livestock production systems; and evaluation and monitoring systems that track changes in climate and management practices to allow iterative learning and improvement of adaptation strategies over time. Climate adaptation should become a routine consideration in policy-making to reduce conflicts, particularly in areas relating to drought, greenhouse gas emissions, and natural resource management. An inevitable aspect of climate adaptation will be to accept that uncertainty is unavoidable and that decisions made on the best available, imperfect knowledge may, in retrospect, turn out to be suboptimal. It will therefore be equally important to collectively learn from such experiences and incorporate this and other new knowledge in iteratively improving adaptive responses over time.

Legislation affecting animal production systems

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The main areas where legislation is impacting most on animal production are in pollution and welfare. Nowhere is this more pointed than in the effect of the European Directive 2008/1/EC on 'intensive' pig & poultry farms. This directive, known as the IPPC directive, applies to any business with more than 750 sows or 2000 pig places for 'production' pigs over 30kg or 40000 birds.

Pollution

IPPC stands for Integrated Pollution Prevention and Control and it is the word Integrated which characterises the main features of the directive and its consequent legislation in member states. In the UK permit applications for existing farms had to be submitted by the end of January 2007. Permits were issued throughout the year and the inspection regime started. In 2008 the England and Wales Pollution Prevention and Control Regulations were incorporated into the Environmental Permitting Regulations and IPPC permits have now been transposed into EPR Permits. Although the detail remains unchanged, the EA have changed their forms and guidance, the most significant being the application form is now common across a range of regulatory regimes including waste.

The legislation tries to take a comprehensive approach to each aspect it covers – hence the word “integrated” in its title. If we look at ammonia emissions as an example – one of the main target areas for the pig sector - the principles would be:-

- minimising the emissions from the pigs – match protein levels in feed to the class of stock and keep the pigs clean
- house in “low emission” buildings
- remove slurry from the building as soon as possible
- store slurry in a covered tank
- spread onto land at prescribed rates using “low emission” equipment
- spread in conditions unlikely to cause run-off
- incorporate the manure quickly after spreading

IPPC introduces the concept of Best Available Technique – BAT – to the production process. A simple interpretation of this is “the most effective means to achieve the objectives of IPPC

at an affordable cost” – bearing in mind that affordability changes with time, as does what is deemed “best practice”.

Other Directives impinge onto IPPC, for example the Habitats Directive places further demands on farms close to protected Habitats sites, for example Sites of Special Scientific Interest (SSSI).

As an example, when looking at the impact of the legislation on future pig housing designs a significant problem for producers is that the most common type of specialist housing developed over the last 20 - 30 years – fully slatted floors with several months’ slurry storage below slat - is the base system over which the European legislators have decreed we need to improve.

The suggested design principles are largely based on two ideas:-

- i) Reducing the exposed surface area of slurry.
- ii) Removing slurry frequently.

One problem associated with rapid removal of slurry from buildings is the consequent need for additional (covered) slurry storage outside. The problem is not simply additional cost, for example, a planning application for a new finishing house might need to include a new slurry store with the consequential additional planning concerns.

Other techniques can be considered to reduce the need for external slurry storage which reduce the emissions at source or remove the ammonia from the exhaust air before it is released to the atmosphere. The list of designs to do this is not exclusive but the onus is on the producer to persuade the EA that non listed techniques will provide at least equivalent reductions in ammonia emissions.

The extra costs are difficult to predict, but simple, part slatted systems might add 5 to 10% to costs whereas more complex exhaust treatment systems might add up to 20% more with additional running costs as well.

It needs to be noted that straw based systems produce a similar level of ammonia to the fully slatted system so reverting to these more traditional types of housing is not an option for reducing ammonia emissions.

Slurry storage capacities must now increase to 26 weeks capacity at least to comply with the new changes to the Nitrate Vulnerable Zone (NVZ) Action Programme rules and Minimum nitrogen efficiency factors have to be used when calculating the contribution of nitrogen to crops and manure nitrogen content has to be assessed following prescribed methods. If this

extra storage requirement is combined with the loss of storage currently under the slats within the building, a large amount of new covered storage will be required with all the planning implications that will bring.

When a permit is issued, a range of conditions are presented. Some of these are 'fixed' conditions for all units whilst others are specific to that unit or installation. There is an ominous requirement that most units are required to prepare 'Improvement Plans' (IPs) and although this is intended to be implemented in stages by agreement, as anticipated, some IPs have been the subject of much discussion with disparity between the expectations of the two sides!

The big change under IPPC is the expectation of a high level of recording. Under the heading 'General Management', records relating to areas like maintenance schedules are required along with details of any incident under the heading "accident management". Accident management plans need to be reviewed at least every 4 years. Energy records are required and again need to be reviewed along with the use of raw materials; medicines, biocides, pesticides and water use. Any complaints from sensitive receptors – odour, noise etc – need to be recorded along with whatever action was taken. Details of the number of animal places and animal movements are required, plus records of all slurry and FYM spreading under the unit's Manure Management plan. Where slurry and FYM are exported from the unit, details of dates, amounts, destination and land area available for spreading are required. All waste exported from the site must be recorded.

In addition to the recent consultation on the Nitrates Directive, there is a further consultation looking at Diffuse Sources in England. The likely outcome of this is the introduction of designated Water Protection Zones with further possible controls on activities such as manure spreading and also on outdoor pig keeping.

Welfare

There appears to be some conflict between the requirements of IPPC to limit ammonia emissions by encouraging part slatted systems and the welfare legislation which 'encourages' the use of straw: - "all pigs must have permanent access to a sufficient quantity of material such as straw". This will test the ingenuity of building designers to come up with low emission buildings while still offering compliance with welfare regulations.

For many years the farrowing crate has been under discussion on the basis that it does not offer good welfare conditions for the sow, an argument countered by the fact that it does offer high welfare for the piglets by preventing them being overlaid. We arrived at using the farrowing crate after years of research moving from pens with rails round the outside through

pens with a crate in half of it, from which the sow can be released after a few days, to a maternity 'crate', followed by multiple suckling, but ending up with the farrowing crate for the whole lactation. As Gerry Brent points out so succinctly in his article in April 2009 'Pig World', the farrowing crate was tested against all the other systems over many years at the NAC Pig Demonstration Unit and gave the best results for piglet losses, piglet observation and the safety of personnel.

Since the introduction of the farrowing crate for the whole lactation, weaning age has increased from 21 days to at least 28 days and often more. We need to look again at the design of pens with crates in them as we cannot really justify keeping the sow confined over the whole lactation length on the basis of piglet welfare when all the research shows that the majority of such problems occur in the first week after farrowing. German designs are showing promising results giving good piglet protection, easy access to the litter and safety for the stockperson.

The effect of nutrition on stress and immunity

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Each meal provokes a host of physiological responses. The most well-known response is of course the start of the process of digestion and absorption of nutrients. Much less known is the postprandial (low-grade) inflammatory response in the intestines, which is also referred to as a metabolic inflammation. The degree of this inflammation is related to the caloric value, the glyceamic index and specific constituents such as fatty acids and others. This shows the very close relationship between nutrition and the immune system. The immune system is also highly integrated with other physiological systems. The nervous, endocrine, and immune systems communicate through neuropeptides, hormones, and cytokines, thus linking stress with disease resistance. Chronic stress brings the body into an inflammatory state. Behavioural responses activate neuroendocrine and autonomic pathways, which affect the immune system thereby possibly modulating susceptibility to a variety of diseases. The immune system and the other systems are also influenced by the nutritional state of the individual, by nutrients or metabolites, and by the hormones involved in regulation of feeding behaviour. Disease itself leads in turn to behavioural changes (sickness behaviour), indicating discomfort and diminished welfare, accompanied by symptoms such as inappetite. This leads to an ever increasing complexity which may hamper research; on the other hand, it also means that health and stress as modulators of immunological reaction are in principle open to nutritional intervention. In this context, it is important to note that in contrast to the often suggested need to enhance intestinal defences, the organism rather benefits from down regulation of the intestinal inflammatory responses.

In the present paper, the current knowledge on the interaction between nutrients and the immune system is reviewed.

Potential applications of GM technology

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Products from genetically modified (GM) organisms, and indeed the organisms themselves, have been used commercially for several decades as processing aids within the food industry. The first genetically modified organisms, given regulatory approval for inclusion in the food chain, were introduced into commercial trade in the 1990s. These were a tomato modified for better shelf life and processing qualities and soybean that had been modified for resistance to the herbicide glyphosate, closely followed by the introduction of maize which had been modified for insect resistance. Since then GM technology has been the subject of intense controversy, with a significant consumer backlash, especially within the EU countries. This has not however, prevented the widespread introduction of these crops in many countries worldwide. Whilst the acreage of GM crops continues to grow year on year, the number of applications for which this technology has been targeted has remained relatively small, with the vast majority of crops having been modified for either herbicide or insect resistance, this despite the fact that fundamental scientific research has in the meantime established a multitude of additional potential applications. With the UK moratorium on new GM organisms being lifted, now is a good time to consider the drivers for the potential introduction of this technology – food security, sustainability, healthy diet – and also the potential timeline for the introduction of these novel GM organisms. The vast majority of these will be new GM crops, although micro organisms and perhaps even applications in animals may be included. It is also relevant to note that most if not all of the currently approved GM organisms within the EU are approved for use as animal feeds. This is likely to be the case for new introductions as well, at least in the near future.

One way to attempt to predict the more short term (5 year) trend in the application of GM within agriculture is to examine the list of GM products that are currently under consideration by the EC for approval under regulation (EC) No 1829/2003. This list currently contains 78 relevant applications for approval of new GM products. Not surprisingly the majority of these are for new “events” within maize (43), cotton (13), soybean (9), Oil seed rape (2) and sugar beet (2). Thus the first obvious thing to note is that the range of crops subject to this GM technology is unlikely to expand significantly in the near future. The remaining applications involved six for GM bacteria for inclusion in animal feed and modifications to potato (2) and Arabidopsis (1). The second thing to note is that the vast majority of these applications are for herbicide and insect resistance and as such the range of applications is also unlikely to

change considerably. In many cases the new introductions relate to “stacked” genes in which herbicide and insect resistance have been combined and where insect resistance is being maintained by “stacking” several different genes for resistance. It is interesting however, to note that the applications also include modifications to the composition of the crop. This is particularly the case in the less common species for instance starch modification in potato. Compositional modification is likely to be a significant application in the longer term as shall be discussed later.

It is more difficult to predict the long term applications of GM technology. Perhaps a good way to assess this would be to examine applications related to recent field trials carried out within the EU countries. Again the major proportion of these trials are targeted towards traits likely to impact on agricultural productivity; thus herbicide (47%), insect (16%), fungal (4%) and viral (5%) resistance traits dominate this group. It is interesting though that 17% of the trials involved compositional modifications.

The use of GM to enhance the nutritional value of a food is not a new concept. Indeed at the laboratory level GM plants with modified nutritional characteristics have been available for several years. The obvious best known example of this is the “Golden rice”. This has been modified for enhanced levels of beta-carotene a precursor for the formation of vitamin A in the diet. Other examples are enhanced vitamin C in tomatoes, vitamin E in corn, folate in tomato, flavonols in tomato and iron in rice. More recently these nutritional traits have also been “stacked” within maize to provide enhanced levels of beta-carotene, vitamin C and folate within a single plant. These nutritionally enhanced crops, whilst providing potential health benefits for the human consumer, may also benefit animals if they were incorporated in crops to be utilised as animal feed.

Other potentially relevant compositional changes that could be addressed by GM and which would be of more immediate impact on the livestock production would include modifications to the amino acid composition, in particular enhancement of lysine and methionine and a reduction in phytase within animal feed. These modifications can, and have been, achieved without recourse to GM but often have associated problems with yield. The application of GM may provide a more effective means to attain these ends.

Thus in conclusion it is clear that use of GM worldwide is going to continue to increase in the future. This technology has the potential, along with many other technologies, to help us meet the growing challenges of food security, climate change and healthy diets.

One requirement for this is to enhance agricultural productivity and the major GM crops currently under cultivation address this by being targeted at herbicide and insect resistance.

The number of GM crops exploited commercially is very small compared to the number that can be modified. Similarly the number of traits that have been modified to date is also very small. The short term extension of GM technology is likely to be targeted at increased exploitation of the current traits in a wider but still limited range of crop plants. The targeted traits and range of crops are both however, likely to be extended in the longer term, although this will depend on consumer perception and the perceived profitability of these products. The new traits to be targeted are likely to include those that will further enhance productivity such as drought, cold or salt tolerance along with the ability to better utilise resources such as nitrogen. Another potentially significant application may be in modification of the composition of the crops. These modifications may make subsequent processing of the crop, into for example oils, more efficient or may be targeted at improving the nutritional value of the crop for human and potentially animal diets.

Influence of feed processing technology on pig performance

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Crucial in the development of modern pig production is the concept of *sustainable precision livestock farming*. This concept aims to optimize productivity and efficiency by an integrated approach taking into account as much relevant factors dealing with feed, animal, microbiota, farm and their interactions, as well as customer, consumer and societal demands. Several indicators demonstrate that optimising productivity and efficiency in pig production is still potentially possible. The genetic potential is only partially utilized, the utilization of most nutrients appears to be low and there is a huge variation in performance among farms and within farms among pigs.

As feed usually contributes to more than 60% of total costs, it has received most attention. In particular nutrition in terms of nutrient requirements and nutrient supply has been given a high priority in many research groups. However, feed processing technology does play an important role in improving productivity and efficiency as well, not only with respect to minimizing feed production costs but also optimizing pig performance. Feed processing technology is therefore essential in the concept of *sustainable precision livestock farming*.

An overview of some of the aspects is presented with the aim to identify new opportunities from the perspective of improving pig performance. The focus is on feed manufacturing rather than processing of feed ingredients, both on an industrial and farm level.

Particle size reduction has shown to be of importance and results in more consistent effects than particle size uniformity. Nevertheless, the best strategy remains difficult to prescribe as the results indicate an optimum between 600 and 900 µm, depending on several other factors involved. It could be hypothesized that protein sources require a finer grinding than carbohydrate sources in order to maximize the digestion of amino acids. In particular fibre-rich protein sources such as rapeseed and sunflower meal may benefit from this approach. However, gains in pig performance must outweigh production costs. The latter usually increase when feed ingredients need to be ground separately using different screens. Moreover, grinding to particle sizes less than 600 µm sharply increase costs due to higher energy consumption and lower feed mill capacity. In addition, fine grinding without pelleting may result in increased dustiness of feed, as well as bridging problems in bulk bins and feeders.

Correct mixing is also of importance but does not seem to be a critical factor in practice. At least this appears to be the case for fattening pigs and sows, because of the relatively high amount of feed consumed per day and the fact that a single batch will usually be consumed in a short period of time.

Further processing of meal into pellets has proven to increase growth rate by 6% and feed efficiency by 6-7% on average under controlled pelleting conditions. However, the mechanism of action is still not fully resolved and processing conditions used in practice are usually based on experience of the feed mill operator. This might result in suboptimal processing conditions, in particular when taking into account the instability of certain specialty protein sources and micro-ingredients. Moreover, pelleting may abolish the preventive effect of coarse grinding on gastric mucosal alterations and could even be a risk factor for colonization of the gut with *Salmonella*. The impact of other pellet characteristics, such as the quality in terms of hardness, durability and pellet diameter on pig performance is often unclear. The presence of fines in the pelletized feed has proven to be undesirable. However, with respect to the effects of pellet diameter, a parameter often highlighted in sales, there is hardly any scientific basis. As a consequence, optimization of the feed form and required thermal processing conditions should receive some more attention and may still offer opportunities in optimizing productivity and efficiency.

All processing technologies discussed so far apply to dry feed and feed ingredients. However, the use of moisture-rich co-products from the food and biofuel industry offers a lot of opportunities and such ingredients can easily be fed when making use of automated liquid feeding systems. Moisture-rich co-products are usually price competitive as they do not require expensive drying and can be fed directly at the farm without interference of a feed compounder. Moreover, they may be abundantly available in the neighbourhood of pig farms. Liquid feeding has proven to result in excellent pig performance, provided the circumstances are well controlled. In particular estimation of the nutrient content of the moisture-rich co-products, the final diet formulation and hygiene conditions are important. Inclusion of liquid co-products from the food and biofuel industry in animal diets also avoids wasteful disposal and, as a result, can decrease the environmental burden.

Liquid feeding also offers the opportunity for fermentation. The concept of fermented liquid feed (FLF) seems to be promising and several studies have shown beneficial effects in animals fed FLF compared to those fed with dry or liquid feed, such as improved gastrointestinal health and growth performance, and reduced mortality and morbidity in both piglets and fattening pigs. These benefits appear to be the result of enhanced nutrient availability, and reduced growth and shedding of pathogenic bacteria due to the formation of

organic acids resulting in low pH and the presence of bioactive, often antimicrobial substances. Therefore FLF could be an alternative strategy for reduction of the use of antibiotics in pig production. However, various studies have shown that the effect of FLF on pig performance can be inconsistent. Palatability, health and nutrition value could be affected by uncontrolled fermentation. In particular the prevention of free lysine degradation has received much attention. Nevertheless, FLF seems to be manageable and large scale implementation may follow soon.

In conclusion, feed processing technology is indeed important in the concept of *sustainable precision livestock farming* and certainly offers new opportunities in pig production. However, more research is necessary for optimization of existing and developing of new technologies. A potential bottleneck for innovation is the fact that implementation in practice often requires relatively large investments. Therefore, it is necessary to have better estimates and more quantitative data of the effects of feed processing technology on pig performance.

Piglet starter feeding: in a changing business climate

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BPEX

One of the most significant management decisions for a swine producing business is the average weaning age or the average lactation length for the sows. This not only determines building requirements, but also has a bearing on the feed inputs and health status of the weaned piglets and even growth rates to slaughter. Many industries around the world have targeted 21-day weaning as an optimal operating value and this is normally based on the fact that physical productivity of the sow is maximized for a 3-week weaning system. This was also based on research done many years ago and mostly in Europe.

Once the decision to wean at a set target age has been made, this then automatically dictates building requirements. A later weaning herd will need far more farrowing crates than a very early weaning herd because the former sows spend more time in crates before weaning takes place. This will also alter the number of dry sow places required, which is the cheaper accommodation, and there may also be implications for both weaner piglet places and for growing / finishing pig places.

There are also implications for the sow feeding programme. Prolonged weaning ages tend to put more sows into acute negative energy balance and therefore they will require increased feed inputs over a longer lactation. The lactation feeds are also more expensive and hence there are overall feed cost considerations. Shorter weaning ages put less drain on the sow's backfat reserves and can reduce feed inputs per cycle for each sow.

In terms of inputs for piglets, there are also important issues to consider. A herd weaning at 18-22 days, for example, will probably need high cost, high quality nursery units with a significant energy input for heating and ventilation and this will require very high levels of management and stockmanship. At the other extreme, herds weaning at around 5 – 6 weeks will only need very basic semi-intensive large-group systems and this can include cheap straw yards and naturally ventilated units. This is applied in countries like Sweden, Switzerland and Denmark where very late weaning systems are popular.

Feed inputs for the piglets will also vary depending on the weaning age. A piglet weaned at 18-21 days will require a very high quality nutrition programme that has a high inclusion of milk powders, and cooked cereals and specialized ingredients to sustain gut health. A piglet weaned later at 30 days of age can be weaned straight on to a starter feed much lower in nutrient density

Gut health management, always problematic with weaned pigs at any age, is also perhaps easier for the later weaned piglet with better immune and enzyme systems to cope with the changed environment.

One of the principal reasons back in the 1970s for producers moving to 3 week weaning was to derive improved sow output. The simple mathematics involved show that a 1000 sow herd weaning at 30 days of age has a farrowing index of around 2.1 and if we assume 11 piglets born alive per litter this is 23,100 piglets produced per year. If the herd moved to 20 day weaning then with an improved farrowing index of 2.3 the herd will produce 25,300 pigs

per year for costs that may well be similar. This is a big incentive to wean earlier. Much work in this area was carried out in the UK in the 1970s and much of it was from the University of Nottingham.

The number of piglets born alive per litter is one of the biggest determinants of profitability for any pig breeding operation and this is also profoundly affected by weaning age as can be seen in figure 3. The evidence from all the work in the 1970s showed that in the range 21-25 days through to 35 days and above, there is little effect of weaning age on litter size; for weaning ages below 21 –25 days there is a precipitous drop in litter size and the magnitude of this effect is quite large. In my view therefore the early North American integrators that set up businesses based on 14 – 18 days weaning were probably doomed to failure because of this effect. They had established high cost systems but the performance just was not there to justify the costs.

The data presented in the paper show that far from optimizing at 3 weeks, under the UK conditions of 2007, with very high cereal and other feed prices and poor pig prices, the optimum weaning age was probably between 30 and 35 days. It is also interesting to note that whatever producers did in terms of weaning age they could not get into a profit situation at all in 2007. Weaning earlier however made matters worse because of the extra costs and no increased revenue to compensate.

The lesson from this exercise is that we should never see weaning age as a fixed parameter. It cannot obviously be changed in short term business planning but over medium and long terms it could be managed to change. The main driver is the ratio between pig prices and general feed costs. Back in the 1970s in Europe, it was a situation of very low feed costs in real terms and healthy pig prices. It was probably true at that time that the maximum physical productivity curve concurred precisely with the financial productivity curve and hence weaning at 3 weeks of age was correct. In today's economic climate we have moved to a situation where weaning ages need to be higher to maximize profitability (or minimize losses!).

From this analysis we have learnt that every industry around the world, and also every different swine producing business, has a different cost / price structure. The author has therefore been able to compare and contrast 3 separate industries as they existed in 2007 and this analysis is presented in the paper.

The analysis has also shown that very definitely, maximum physical productivity does not concur with maximum financial margin and the calculations for large swine businesses need computing very carefully in order to maximize margins.

Organic acids in pig diets

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Introduction

Organic acids have been much investigated as growth- and health-promoting feed additives to find effective ways to compensate the former use of in-feed antibiotics in pig production, which has been banned in the EU. Data on the effects of different organic acid and salt additions to pig feed have accumulated over the years, and many reviews have been published summarising the growth-promoting effects of acidifiers on pigs of different ages, and to discussing their possible modes of action. The aim of this paper is to look into some recent developments in the field of feed acidifiers and the main focus is on formic-acid-based acidifiers and benzoic acid. An economic evaluation of the potential benefits of using acidifiers in sow diets is also presented.

Impact of organic acids and salts on pig performance

Different organic acids and salts have different impacts on the performance of weaned piglets and fattening pigs. The variable performance responses are evident since the acidifiers influence the performance of pigs indirectly via gastro-intestinal microflora, and different organic acids and their doses have distinct differences in their antimicrobial activity. According to Partanen (2003), growth rate of the average weaned piglet in the treatment group where feeds were supplemented with formic acid, fumaric acid, citric acid, or potassium diformate exceeded that of 71, 60, 62, and 73% of the pigs in the negative control group, respectively. The average pig in the treatment group used less feed per kg of weight gain than 80, 77, 82, and 83% of the pigs in the control group, respectively. Similarly, the response of fattening pigs to different acidifiers was positive, and formic acid and potassium diformate were the most efficient acidifiers. The shape of the response curve of pigs to increased acidifier additions is of great interest, and this information is needed to optimise the response of pigs in relation to the cost of using the acidifier. Unfortunately, the number of dose-response studies with several incremental acidifier additions is limited, and it is not yet possible to estimate the shape of response curve for most acidifiers when combining the results of several studies.

Formic acid and formates as feed additives

Formic acid is an approved feed additive in the EU for preservation of feedstuffs for all animal categories, whereas potassium diformate is approved performance enhancer for weaned piglets, fattening pigs, and sows. In pig feeding, formic acid is used in liquid by-products and feed mixtures in order to prevent suboptimal fermentation. Addition of formic-acid-based preservatives to fermented liquid feed has positive effects on the microbial quality of the feed and can improve pigs' performance (Canibe *et al.*, 2008). Formic acid has a strong antibacterial effect, but is highly corrosive. However, new ammoniation techniques of formic acid and the use of carriers and coatings have reduced the corrosiveness and volatilisation of formic acid considerably. The carrier seems to have variable impacts on the response of pigs to different acidifiers. Attempts to improve the efficacy of formic acid have focused on mixing it with other organic acids or salts. In acidic conditions, small sorbate and benzoate additions have antimicrobial effects in small amounts and have boosted the efficacy of formic acid as growth promoter (Partanen *et al.*, 2002; 2007). Addition of combinations of formic acid and lactic acid have also given promising results (Partanen *et al.*, 2006).

Benzoic acid as a feed additive

Benzoic acid is widely used in the preservation of acidic foods in the form of sodium benzoate. In the EU, sodium benzoate is a permitted preservative in silages only, whereas benzoic acid is approved as an acidifying agent, and it can be used in fattening pig feeds (5–10 g/kg feed). In the pig, ingested benzoic acid is eliminated from the body by conjugation with glycine, and the product hippuric acid is excreted in urine. Hippuric acid is responsible for the pH decrease observed in the urine of pigs fed diets containing benzoic acid or benzoates. Lower urinary pH is advantageous from the environmental point of view since it depresses pH of slurry and consequently reduces ammonia emission from slurry. Benzoic acid is an antimicrobial influencing growth of micro-organisms in the gastro-intestinal tract of the pig, and thus it has the ability to influence the growth performance of pigs also (e.g. Kluge *et al.*, 2006).

Modes of action of feed acidifiers

The exact mechanisms behind the growth-promoting effect of organic acids are not yet clear (e.g. Partanen, 2003). As antimicrobials, organic acids can improve feed hygiene. Generally, they are claimed to reduce gastric pH which increases pepsin activity in the stomach and consequently improves protein digestibility. However, lowering of gastric pH or increased pepsin activity has been difficult to show. There is considerable microbial activity in the stomach and the small intestine of growing pigs and bacterial nitrogen can represent 40–60% of ileal nitrogen. It is likely that increased pepsin activity is not the sole cause of the

improved apparent protein digestibility. It could also be due to a reduced amount of bacterial protein in the digesta (Partanen *et al.*, 2007). When bacterial growth is restricted by organic acids, more amino acids are absorbed rather than being incorporated into bacterial protein. Organic acids have also improved fat and mineral digestibility. Acidic gastric conditions are considered essential for prevention of the survival of ingested pathogens in the stomach so that they do not gain access to the small intestine. Feeding organic acids to weaned piglets enhances the biological barrier function against pathogenic bacteria in the stomach. However, the effectiveness of organic acids against pathogens differs. Organic acids not only act on pathogens, but also modify beneficial flora. Reduced microbial fermentation means that more fermentable carbohydrates are available to the animal.

Economic evaluation of the possible benefits of using feed acidifiers in sow feeds

The effects adding acidifiers to sow feeds have been investigated scarcely (Øverland *et al.*, 2009). Therefore, a preliminary economic evaluation was carried out to estimate possible benefits of using acidifiers in sow feeds using a static farm model of piglet production (Karhula and Leppälä, 2006) and a dynamic programming model that maximises returns per sow place (Niemi, 2008). The feed acidifiers were expected to influence piglet mortality at birth and during the suckling and post-weaning periods, and the growth rate, feed conversion ratio medication of weaned piglets. Sows receiving acidifiers were assumed to lose less weight during lactation than sows not receiving them, and this could decrease the number of non-productive days. The results of economic evaluation suggest that piglet producers have good reason to start using feed acidifiers if any performance improvement scenario considered in this study can be achieved at an acidifier cost of €6 per 1000 kg of lactation feed and other traits remain unchanged. If the performance of sows or their piglets can be improved, the most significant effects are expected in reduced piglet mortality before weaning and improved feed conversion ratio of weaners. Although pig performance improvements reduce the per piglet production costs and increase the net return per sow place, annual production costs per sow can even increase.

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Amino acid requirements in piglets with special emphasis on tryptophan and valine

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In growing animals, the term “requirement” is usually associated with maximization of growth. Dose-response trials are frequently used to determine amino acid requirements, but reported results can be quite variable due to experimental conditions and modes of expressing the requirement. In the ideal protein concept, amino acid requirements are expressed relative to Lys, which is typically the first-limiting amino acid for growth in piglets. This mode of expression is useful in practical nutrition. The Lys requirement varies during growth, but the ideal protein profile is supposed to remain constant. To estimate the requirement of an amino acid relative to Lys, Lys must be the second-limiting amino acid in the diet, after the one that is studied. If Lys is not the second-limiting nutrient, another unknown factor may become limiting, and the resulting requirement expressed as a ratio to Lys will be underestimated. In that case, the amino acid requirement should be expressed relative to the second-limiting factor and not relative to Lys.

Tryptophan requirement in piglets

Objectives and method. Tryptophan is an indispensable amino acid and the fourth-limiting amino acid in piglet diets in Europe. There appears to be no general consensus concerning the Trp requirement and difference in recommendations can be found between Europe and North America. In the present study, we compiled and analysed experimental results on the Trp requirement in piglets (7 to 25 kg LW) using a meta-analysis (Sauvant *et al.*, 2008). A database of 130 trials on the Trp requirement in piglets was created. Trials had to test at least two levels of Trp to be considered in the database. Composition of the diets was recalculated using a feed table of nutritional values (Sauvant *et al.*, 2004). Among the 130 trials, 58% originated from Europe, 33% from USA and 9% from other countries. European trials were more recent than American trials and feed efficiency of piglets increased with date of publication. To verify if Lys was sublimiting in the experimental diets, the contents of standardized ileal digestible (SID) Lys and other essential amino acids were compared with the recommendations from NRC (1998) and Whittemore *et al.* (2003). As a result, 89 trials were eliminated because they either used an insufficient number of Trp levels, or factors other than Lys were second-limiting for performance. A total of 41 trials (31.5%) were kept for the meta-analysis.

Non-linear models such as linear-plateau, curvilinear-plateau and asymptotic models were tested on this dataset. Since a meta-analysis regroups data from different experiments, we made the assumption that the plateau-value was different for each trial, whereas the other model parameters were assumed to be common across the selected trials. This analysis allowed estimation of the SID Trp:Lys requirement for average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F).

Results and discussion. The requirement values estimated by the three models are shown in Table 1. The requirement for ADG was 21.6% SID Trp:Lys with the curvilinear-plateau model, but this value was 5 percentage points lower when estimated with the linear-plateau model. This illustrates the importance of choice of model when estimating nutritional requirements.

Table 1: Standardized ileal digestible (SID) Trp:Lys requirement in piglets estimated by different statistical models (meta-analysis of 41 trials).

Response criterion	Linear-plateau ¹	Curvilinear-plateau ¹	Asymptotic ²
Average daily gain	16.7 (0.3)	21.6 (0.8)	26.7 (2.9)
Average daily feed intake	/	22.1 (1.1)	24.7 (3.5)
Gain to feed	16.2 (0.4)	20.3 (0.9)	20.7 (2.2)

¹. The minimum SID Trp:Lys level required to reach the plateau

². The SID Trp:Lys level required to reach 95% of the plateau

The models differ in their biological interpretation. Although the linear-plateau model assumes a constant marginal efficiency of Trp utilization before the breakpoint (i.e., requirement), the curvilinear-plateau model describes a linear decline in marginal efficiency. The linear-plateau model is often associated with the response of individual animals, while the response of a population is better described by the curvilinear-plateau model. Taking account of a safety margin, the curvilinear-plateau model is more adapted for economic optimization (Pesti *et al.*, 2008).

This statistical analysis also indicated that the Trp requirement for ADG estimated by the curvilinear-plateau model was not affected by geographical origin (North America vs Europe). The linear-plateau model is more often used in North American studies, and this may have contributed to the debate on differences in Trp requirement.

Valine requirement in piglets

Valine, like Ile and Leu, is a branched-chain amino acid (BCAA). With the decrease in dietary crude protein levels, Val appears as a limiting amino acid for piglets. Since relatively few studies on the Val requirement have been carried out (12 since 1970), it is difficult to perform a meta-analysis. As for Trp, the compilation required a further selection to express the Val requirement relative to Lys. In most of the selected trials, ADFI, ADG, and G:F were maximum between 70 and 75% SID Val:Lys. In studies where the SID Val:Lys appeared to be lower, Lys was often not the second-limiting amino acid. Requirement estimates depend on the model and the response criterion used (averaging 72, 74 and 71 % SID Val:Lys for ADG, ADFI and G:F, respectively). It is concluded that 70% SID Val:Lys is a minimum for 7-25 kg piglets.

Due to a common catabolic pathway between the three BCAA, supply of one may interfere with metabolism of the two other BCAA. For example, Barea *et al.* (2009) observed that an excess of Leu amplified the negative effect of a Val deficiency in piglets. The interaction between BCAA was also apparent in the study of Wiltafsky *et al.* (2009).

Conclusion. The availability of five crystalline amino acids allows for a further reduction in protein content of the diet and to formulate diets with a more balanced amino acid profile. The risk of providing diets with insufficient amino acid supply is also greater, and may require the use of security margins.

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Factors affecting pork quality

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This paper is a review of the factors affecting pork quality, with updates in current areas of interest. The most important characteristics of quality are muscle colour and wateriness, which are important at retail and eating quality, especially tenderness and flavour. All of these characteristics show variation because of the many factors that influence them, some operating during production and some after slaughter during processing.

Colour and water retention

Muscle pH is a key quality indicator. Its rate of fall after slaughter and its absolute level 24hr later at butchery determine how strongly water is retained during the rest of the period before retail. An increase in 'ultimate' pH above the normal value of 5.5 enables more water to be retained in the intra-fibre spaces and results in greater tenderness. The use of marinades also increases the amount of water retained and increases juiciness and tenderness. A gradual rather than a rapid fall of pH after slaughter ensures that pale, soft, exudative (PSE) muscle is not produced. Good handling protects against PSE and dark, firm and dry (DFD) pork.

A recent comparison of the 'new' genotypes comprising Pietrain and Hampshire breeds by BPEX involved meat quality tests. These breeds were notable for having high proportions of the halothane and Rendement Napoule genes respectively which have deleterious effects on pork colour and water retention. However the genotypes currently being used in Britain showed good meat quality. Loins from Pietrains had deeper 'eye' muscles than Hampshire and Large White and similar pH and colour characteristics. Hampshires had the highest scores from the taste panel for eating quality.

Tenderness

Tenderness is the most important characteristic of pork. A recent study commissioned by BPEX at the Universities of Leeds and Bristol showed that in Large White x Landrace pigs, growth rate above 600 g/d between 40 and 100kg live weight resulted in more tender pork than in pigs growing at a slower rate or in those whose growth had been interrupted.

Marbling fat is believed to be an important indicator of eating quality in many countries. However the correlations between marbling fat and eating quality scores are often very low. Actual values are lower in Britain than US where the pigs are fatter. The use of low protein diets unbalanced in terms of amino acids increases marbling fat and improves tenderness and juiciness. However it reduces growth rate and feed conversion. We have recently tried to produce low protein diets which are efficiently utilised but still have the marbling fat and eating quality advantages and this is difficult. The industry is encouraged to feed lower protein levels to reduce N emissions from pig units. An advantage for product quality would be a bonus.

Ageing (conditioning) meat for a period at about 1°C after slaughter is a good way to increase tenderness. Pork tenderises faster than beef, around 80% of the total effect being achieved in 5 days compared with 10 days in beef. But the extra 20% of tenderness is worth obtaining, especially for premium products. Results show that pork which is inherently tough

tenderises more during ageing. Recent research shows that ageing causes degradation of key structures in the filamentous protein structure of muscle under the influence of calpains. This weakens the fibres which break down more easily in the mouth. The removal of some key internal structures also creates more space for water and, as we have seen, this also results in greater tenderness after cooking.

Boar taint

This is not a major issue in Britain but is in the rest of EU with the impending ban on surgical castration with no anaesthetic.

The Pfizer product Improvac is effective in reducing the concentrations of skatole and androstenone in pork from entire males. After 2 doses of the vaccine, pork from entire males is similar to that of castrates in levels of boar taint compounds and flavour. The effectiveness of the vaccine shows the importance of androstenone in controlling the level of skatole. Normally, clearance of skatole from the circulation and the tissues is inhibited by high levels of androstenone.

Two recent studies have shown that the Large White breed has low levels of skatole and androstenone in fat tissues. In the first, Large Whites had lower concentrations than Durocs when both breeds were fed similar diets between 40 and 120 kg live weight. Only 3% of Large Whites exceeded 'threshold' levels of both compounds, compared with 14% of Durocs. The second study, funded by BPEX, examined boar taint in Large White cross pigs growing rapidly or slowly. Actual levels of boar taint compounds were low compared with the 'thresholds'. Levels of both compounds were higher in faster-growing than in slower-growing pigs.

Skatole is probably the more odorous of the 2 boar taint compounds and, because it is produced during digestion, there is the possibility that boar taint can be controlled by diet. Adding fibrous ingredients such as sugar beet pulp and chicory to the diet has been successful in reducing skatole production and deposition. A recent study commissioned by BPEX has examined the effects of different proportions of dried chicory fed for short periods before slaughter on boar taint compounds and pork eating quality.

Conclusions

Pork meat quality is variable because so many factors affect it. Muscle colour, water retention in the meat, tenderness and flavour can all be modified by combining production and processing inputs in a controlled way. Premium pork products taste better than standard ones and are more likely to encourage people to eat more pork.

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