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FAO ANIMAL PRODUCTION AND HEALTH

report

IMPACT OF ANIMAL NUTRITION ON ANIMAL WELFARE

Expert Consultation
26–30 September 2011
FAO Headquarters, Rome, Italy

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Executive Summary

An expert meeting was held to review the impact of animal nutrition on animal welfare. During the meeting, three major tasks were undertaken for both ruminant and monogastric species:

1) Identify feeding options for different livestock production systems (extensive, mixed crop-livestock, and intensive) that improve animal welfare while increasing profitability of the livestock producers and ensuring safety and quality through the food chain.
2) Identify challenges and opportunities to enhance animal welfare through animal feeding approaches.
3) Draft guidelines and policy options promoting sustainable animal feeding that enhance animal welfare, animal productivity, animal product quality and profitability.

Animal welfare includes the combination of both physical and mental well-being. A properly balanced diet and water supplied in adequate amounts will avoid physical and psychological suffering from hunger and thirst; furthermore correct nutrition is crucial for optimal performance and to sustain optimal fitness.

In *Extensive production systems*, the major challenge is the supply of adequate nutrients year-round despite climatic variation. In *Mixed-crop production systems* the challenge is to better integrate the nutrient management of crop and animal production enterprises within the system, to be relatively self-sufficient and reduce dependence on external inputs. In *Intensive production systems*, the highly specialized genotypes and diet formulation approaches, and the large scale of operation, mean that the nutritional welfare of the animals is best safeguarded when expert nutritionists are involved in diet formulation. Feeding to sustain high production levels can lead to metabolic disorders in ruminants, whilst breeding animals of monogastric species which are restrict-fed to optimise health and production may suffer from chronic hunger.

A number of Opportunities and challenges to enhance animal welfare through animal feeding approaches were identified. In ruminant species, *welfare assessment* could be improved by development of better integrated and more robust welfare measures. *Preventing undesirable competitive behavior* requires appropriate group composition and facility design. *Maintaining appropriate nutrient balance* involves avoiding excessive mobilization of body reserves for high production, preventing rumen acidosis by appropriate diet formulation, and providing mineral as well as protein supplements to remedy imbalances in extensive conditions. Correct nutrition can reduce *infectious afflictions* by enhancing cell-tissue integrity and optimising defence mechanisms of the immune system. *Toxicity issues* associated with ingested herbage can be reduced by better management of grazing lands, training animals to avoid poisonous plants and use of medicines in supplements to counteract their negative effects. *Parasite control* can utilize plants containing antiparasitic agents and be aided by appropriate host nutrition, particularly adequate metabolisable protein nutrition, and regular use of anti-parasitic drugs. To reduce *morbidity and mortality in young stock*, adequate provision of colostrum at birth and adequate supply of milk replacer until weaning age is essential to ensure proper immune protection.

In monogastric species, the greatest challenge involves *understanding and dealing with chronic hunger*, which can arise from the absence of sufficient feed in subsistence systems, the deliberate restriction of feed for breeding animals in intensive systems, and the possibility of nutrient specific hungers arising from imbalances between the diet supplied and the metabolic needs of the animal. There is also scope for *better matching of diets to nutritional needs* through improved knowledge of the nutrient requirements of animals in different situations, and particularly of local breeds of livestock used in more extensive systems. In improved breeds, there are nutritional opportunities to mitigate the effects of problems associated with genetically induced fast growth and the partitioning of nutrients to production functions. The *development of more sustainable nutritional strategies* requires consideration of the use of nutritional approaches to address other societal goals including the supply of food which is both safe and nutritious to humans whilst generating low environmental impact from production systems. Furthermore, there is a challenge in *implementing knowledge and socio-economically applicable solutions* in the field by promoting effective dissemination and motivating uptake of good practice.

In terms of policy, it is important to emphasize that welfare recommendations need to go hand-in-hand with profitability. Some proposed practices aimed at improving welfare might reduce levels of profitability. On the other hand, some interventions will increase the profitability, and these should be given priority.

In addressing the opportunities and challenges to promote welfare of animals through better nutrition, there is a need for integrated activity from governments, inter-government organizations, professional bodies, scientists, extension workers and industries to support the implementation of good practice by the farmers themselves. In many cases, although not all, nutritional approaches which improve animal welfare will also improve productivity, product quality and hence profitability. Most importantly, there should be a concerted effort of scientists, politicians, farmers and food-chain industry to develop and validate indicators, in order to allow an international endorsement of specific acceptable minimum welfare standards related to nutrition. Social knowledge about responsible farming practices that consider longevity, long-term performance, and overall life-cycle should be improved. Showing and promoting the positive relationship between animal welfare and production with respect to good nutritional programmes should be fostered through farm programmes and extension services.

Introduction

In assessing the impact of nutrition on animal welfare, there are clearly different considerations for the various farmed livestock species because of their differences in evolutionary history and ecological niche, and hence feeding behavior and digestive processes.

EVOLUTIONARY HISTORY OF FARMED RUMINANT SPECIES

Cattle and sheep were first domesticated approximately 9 000 years ago and were unique amongst domesticated livestock in their ability to produce both milk and meat for human consumption, as well as being used for work in some instances. The ruminant digestive system includes a large first chamber, the rumen, for the processing of coarse fiber and other feeds by the resident microorganisms. This digestive modification enables cattle and sheep to survive on low quality fodder, but generates substantial heat and renders the animals more susceptible to excess heat than cold. Their use for sustained milk production required a regular and plentiful supply of nutrients, hence dairying developed mainly in regions able to produce good quality feed. However, beef cattle, and dual-purpose cattle and sheep are kept in some of the world's less hospitable regions to produce meat and milk, including drought-prone regions and areas with extreme high and low temperatures. Even in regions better endowed climatically, there are usually times of the year when pasture production can be limited or, in some instances, non-existent due to inadequacy of soil moisture, soil temperature or sunlight. In all such regions, animals will experience a reduction in plane of nutrition that may range from slight to severe. Droughts, floods and extreme temperatures regularly challenge meat-producing and dual-purpose livestock, but they often survive due to their ability to metabolize their body fat to sustain them through these difficult periods. Through domestication, humans have augmented this survival capacity by breeding ruminants with concentrated fat depots, e.g. the fat tail of sheep and the hump in *Bos indicus* cattle.

Despite its ubiquity as a food for man, milk is produced under many different farming systems throughout the world. Many smallholder herds have fewer than 5 cows (or buffalos), each producing low to modest amounts of milk, yet collectively they account for a significant proportion of the world's milk supply. In countries that consistently grow high yields of forage suitable for grazing, seasonal milk production is commonplace, with cows utilizing extensive amounts of pasture and producing average milk yields, and some herds milking over 500 cows. Other systems are more suited to all-year round milk production, with cows housed and fed conserved forages either as silage or hay. Herd sizes as well as average milk yields vary, with some farms achieving annual milk yields above 10 000 liters.

EVOLUTIONARY HISTORY OF FARMED MONOGASTRIC SPECIES

Monogastric animals, pigs and poultry, have also had a close association with humans for centuries. As scavenging omnivorous animals, they provided humans with great flexibility in circumstances in which they could be kept. Whilst they could potentially compete with humans for the same feedstuffs, their early role was to utilize natural feeds and human farm and kitchen wastes, and to turn these into nutritious animal protein.

Domestication of the pig is thought to have occurred in Neolithic times by capture and taming of wild pigs scavenging on crops. In contrast to ruminants, they had two major advantages as meat producing animals. One was their prolificacy, producing several offspring at each breeding and with the potential to breed more than once in a year. The other was their ability to utilise diverse food sources to deposit large stores of body fat in seasons when food was plentiful. To achieve this, they could either be herded as groups to use natural resources such as mast, berries and roots, allowed to scavenge around human habitation, or be kept as household animals to utilize kitchen wastes. Intensification of production in developed countries was initially often linked to locations where by-product feeds were produced, such as dairy or brewing wastes. However, in the last centuries, growing demand for animal protein has led to development of larger and more specialized farms where animals are fattened more efficiently on cereal based diets. Because of their adaptability, farmed pigs are found in almost all regions of the world, although consumption of their meat is restricted in some regions by taboos for those of the Moslem and Jewish religions. Over the world as a whole, almost 1000 million pigs are kept, with two-thirds in developed countries and one-third in developing countries. They constitute the most important source of meat, providing about 40% of total world meat consumption.

There are a variety of different farmed poultry species, including geese, ducks and turkeys, but it is the chicken which predominates. The ancestor of the modern chicken was the jungle fowl and the keeping of poultry also goes far back in time, with records of domestic fowl in early Egyptian, Roman and Chinese societies. As a low value, low maintenance species, they were able to subsist in conditions of food scarcity where larger mammalian species could not, scavenging on food scraps, seeds and invertebrates. They could also provide both eggs and meat for human consumption. Initially chickens were dual purpose, with the male birds and older female birds at end of lay being used for meat. It is only in relatively recent times in developed countries that specialization into laying and meat strains by selective breeding has been exploited. Highly selected laying hens can now maintain peak egg output above 90% per day for up to 40 weeks, whilst meat chickens can grow to final weight in 5–6 weeks and convert cereal diets to meat with an efficiency of less than 2:1. Chickens therefore have the greatest efficiency of all farmed species in converting cereals into animal protein and are the ideal animal to exploit resources in regions where climate and soil are suitable for growing crops surplus to human needs. Thus, between 1970 and 2005 global egg production tripled to almost 60 000 tonnes whilst approximately 50 000 million meat chickens are produced annually. Whilst poultry are found worldwide, the principal regions for large scale production have changed from Europe and North America to Asia.

DEFINING ANIMAL WELFARE

Animal welfare has been defined in several different ways, but most of them consider animal welfare as a combination of both physical and mental well-being. Therefore, in order to achieve optimal welfare, physical and mental discomfort and suffering must be prevented. A properly balanced diet and water supplied in adequate amounts would avoid physical and psychological suffering from hunger and thirst; furthermore correct nutrition is crucial for optimal performance and also to sustain optimal fitness (i.e. welfare). Undue restrictions of feed and water are recognized as important adverse influences on animal welfare (Ewing *et al.*, 1999). Malnutrition arises when an animal is given access to a food that is not adequately balanced to meet its physiological needs such that it impairs normal functionality. Nutritional wellbeing and behavior are interrelated in ways that are not obvious when scientists or managers focus strictly on nutrition or behavior. Feeding behavior can be described simply as the link between feed and feed intake. It constitutes a number of aspects, including finding the feed, choosing the feed, gaining and maintaining access to the feed, as well as the amount of feed eaten in any one meal and the rate of ingestion (feeding rate). Measures of feeding behavior can be used as a tool with which to gauge how an animal perceives the diet offered. However, animals in a farm environment often feed in a social group, which involves competition between group members for access to the feed. Feed intake may also depend on the presentation of the feed, the previous experience of the animal with a given feed, and to what extent other, competing motivations affect the behavior of the animal. Differences between animals may therefore indicate stressors associated with feeding (Nielsen, 1999a, b, 2004), and changes within an animal over time may reflect alterations in health status. Nutrition is not only the availability of the correct quantity of feed ("gut filling"). Malnutrition from imbalanced feed can result in a number of conditions including ill health, nausea, depression and negative affective states, all of which can cause pain and suffering and hence lower welfare. Interestingly, the reverse is also true: a status of illness, particularly in case of depression and anorexic conditions, means a lower dry matter intake, often associated with reduced feed digestibility, with some risks for future health (extended period of time under energy deficiency, protein, mineral and vitamin depletion). This implies that not only lack of feed or water, and not only nutrient deficiency, but all the causes of tissue damage and/or disease (i.e. feed quality, nutrient excesses causing obesity or digestive disorders), can result in pain and suffering leading to compromised welfare.

Monogastric animals face different welfare challenges in comparison with ruminants. As scavengers rather than grazers, they have a very highly developed exploratory motivation and have evolved a finely tuned ability to balance the nutrients in their diet through selection amongst different available feedstuffs (Rose and Kyriazakis, 1991; Kyriazakis, 1994). When provided with insufficient feed, or with feeds that do not provide a correct nutrient balance, foraging motivation is increased. In more intensive housing conditions, where this motivation cannot be adequately expressed as normal foraging behaviour, this can lead to the development of abnormal and stereotyped behaviours (Lawrence and Terlouw, 1993). Furthermore, because of their omnivorous habit, they are equipped with teeth/beaks capable of dealing with a range of feed types, such as breaking open fruits and seeds, and catching and killing invertebrates. This also gives them the ability to inflict serious injury on each other if competing for scarce resources. To minimize risk that this will occur, they evolved to live in stable groups with well-defined hierarchies, such that priority of access can be decided without overt aggression. When encountering unfamiliar individuals, they therefore fight to determine relative dominance, and this can cause welfare problems when they are kept in ways that cause social instability (Arey and Edwards, 1998).

For all the above, it is argued that the disciplines of nutrition and animal behavior need to be integrated in order to more fully consider the implications of feeding behavior and nutrition on animal wellbeing.

TASKS FOR THE EXPERT MEETING

During the meeting, three major tasks were undertaken:

1) Identify feeding options for different livestock production systems (extensive, mixed crop-livestock, and intensive) that improve animal welfare while increasing profitability of the livestock producers and ensuring safety and quality through the food chain.
2) Identify challenges and opportunities to enhance animal welfare through animal feeding approaches.
3) Draft guidelines and policy options promoting sustainable animal feeding that enhance animal welfare, animal productivity, animal product quality and profitability.

Nutrition and welfare under different livestock production systems

Three different types of production system in which animals might be kept were considered: extensive, mixed-crop and intensive systems. For each system, typical practices for the different livestock species were reviewed, the main food sources identified, and the welfare challenges relating either directly or indirectly to nutrition were highlighted, using as a framework the "Five Freedoms":

- Freedom from hunger and thirst
- Freedom from thermal and physical discomfort
- Freedom from pain injury and disease
- Freedom from fear and stress
- Freedom to express normal behaviour

EXTENSIVE PRODUCTION SYSTEMS: RUMINANTS

Extensive production systems for ruminants are mainly for meat production. Animals raised under these systems must satisfy their nutritional needs through the existing vegetation. In spite of enjoying a certain freedom, the animals often face difficulties such as nutritional deficiencies that may put their welfare at risk. Depending on climatic conditions and stocking density, the amount of nutrients available can, for significant periods of time, be less than the amount of nutrients required by the animal. Thus, undernourishment is a potential threat to animal welfare in extensive production systems. When the availability of nutrients is below the animal's needs, body reserves will be used in an attempt by the animal to maintain quasi-normal body function. Malnutrition, and the associated lack of nutrients essential for the integrity of cells, can cause impairment of the immune system which can increase the risk of infectious diseases, resulting in an inflammatory response with associated pain and suffering (i.e. poor welfare). Furthermore, other physiological functions, such as reproduction, can be compromised as a consequence of nutrient shortages. Undernourished sheep approaching lambing may suffer pregnancy toxemia as a consequence of a marked mobilization of body reserves and hepatic inability to metabolize these. The incidence of this phenomenon, which may result in mortality along with poor welfare and reduced economic returns, can be minimized by providing energy supplementation before lambing and/or grouping ewes based on lamb load and feeding the groups accordingly.

Reducing the welfare impact of climatic variables on ruminant nutrition requires action to be taken sufficiently early, usually by balancing stocking density with existing natural resources (present and forecast), purchasing additional feed, moving stock to areas with better feed supplies or reducing total stock numbers. Much can be done to prepare cattle and sheep stations to withstand drought, such as adopting moderate stocking rates, planting drought-resistant crops and conserving excess forage as hay or silage. Animal distribution or allocation to land is key for sustaining natural resources, and for maintaining the wellbeing of animals. It is acknowledged that the efficiency of use of the dietary supplements depends on several factors, including: the type of supplement, the conditions in which supplementation is offered, the supply and quality of the available forage, the animals' previous experience with the supplement, social interactions, fear of animals for humans and supplement management. Also, low-stress techniques for moving animals are key in rotational grazing systems, improving wellbeing and productivity. Knowledge on how to manage animals in extensive systems as a function of the resources available should entail adequate monitoring, proper training and close involvement of extension services.

A second potential welfare threat of extensive production systems is the presence of toxic compounds and anti-nutritional factors in the vegetation consumed by livestock. Poisonous plants can impose serious health and productivity issues, not only by the incidence of deaths but also through productivity loses, emaciation, negative and chronic impacts on cells, tissues and organs. The increased spread of weed species in many pastures around the world is leading to their colonization in novel regions, thus posing new threats to grazing livestock (Hogan and Phillips, 2011). Frequent overgrazing and climatic extremes allow increased weed colonization of existing grazing lands, added to which industrial pollution can cause grazing lands for livestock to become contaminated, which especially poses problems in drought periods when the animals may consume significant quantities of soil. Other secondary-compound containing plants do not necessarily cause acute toxicity, but can lead to chronic effects that may be sub-clinical. In turn, these may impact nutrient utilization, or liver and kidney function without overt signs. Use of appropriate supplements that block or attenuate the effects of toxins is a possible approach to avoiding animal health or welfare issues. An appropriate plane of nutrition will also improve the animal's ability to detoxify certain secondary compounds, thus reducing their potential negative impacts on the animal. Some soils have high salinity to the point that may challenge both the vegetation and the ruminants reared on them. The welfare and productivity of animals reared on such soil types can be improved with the use of sodium-tolerant animal breeds and plants, the removal of all sodium provision in the mineral premixes, and the use of alley cropping.

Another common problem in extensive production systems is the use of inadequate mineral supplements. For instance, a mineral supplement formulated for cattle should not be fed to sheep, as it is likely to provide copper levels considered excessive for sheep to the point of inducing toxicity. Conversely, a copper secondary deficiency can be caused by an excess of sulfur and molybdenum resulting in anemia, bone disorders, neonatal ataxia, cardiovascular disorders, diarrhea, and increased susceptibility to infections (Underwood and Suttle, 1999). Similarly, an excess of potassium (and NH_3) may impair Mg absorption and lead to a specific secondary deficiency followed by a metabolic disease (grass tetany).

Gastrointestinal parasitism is a major challenge for the health and welfare of grazing farm animals. Parasites (especially helminthes) impair health by causing anorexia, diarrhea, anaemia and, in severe cases, death. In addition, parasitism impairs productivity with compromised growth and reproductive performance, as shown by Coop *et al.* who noted a 70% reduction in body weight gain within a few weeks of infection (Coop *et al.*, 1982). Although animals eventually acquire immunity to the parasites and successfully regulate them, their immunity may be compromised during certain stages of their development (e.g. in the peri-parturient period). In general, young growing animals that encounter parasites for the first time would be expected to prioritize allocation of scarce nutrients to the acquisition of immunity over growth, to avoid succumbing to the negative effects of parasitism before reaching reproductive maturity. However, in reproducing animals that have acquired immunity against nematodes, the nutrient demands of reproduction may be so high that the expression of immunity to parasites suffers when nutrient resources are scarce (Coop and Kyriazakis, 1999). Under protein-limiting conditions (common in extensive production systems), an increased supply of amino acids is likely to improve host resistance to gastrointestinal parasites (Athanasiadou *et al.*, 2008). Alternatively, the use of browses and forbs containing tannins and saponins has been shown to be effective in the control of parasitism. Plants with anti-parasitic properties, indigenous to many parts of the world, have been reported by several authors (Sori *et al.*, 2004; Githiori *et al.*, 2006; Hoste *et al.*, 2006).

Finally, under extensive production systems, animals are openly exposed to prevailing climate conditions. Ruminants are, in general, relatively tolerant to cold but more sensitive to hot conditions. Under hot climates, it is important to select appropriate breeds (i.e., *Bos indicus* is less sensitive to heat stress than cross breeds or *Bos taurus* breeds). Alternatively (or additionally) silvopastoral systems, with plantations of tree cover for shade, or provision of shade cloth can offer some protection for the animals. In contrast, ruminant livestock can frequently experience extreme cold conditions in several areas of the world. Comfort and survivability of animals under extreme cold conditions can be improved by achieving adequate body condition (or body energy reserves) before the cold weather arrives. It is also important to recognise that animals subjected to extreme cold conditions can to some extent compensate by lowering basal metabolic rate.

Overall, it is clear that improving welfare diminishes morbidity and mortality, but a challenge for improving animal welfare in extensive production systems is that in some situations, producers perceive the cost associated with avoiding mortality or improving animal welfare to be uneconomical. It is important that all improved welfare recommendations take full account of the need for ruminant livestock production to be profitable.

EXTENSIVE PRODUCTION SYSTEMS: MONOGASTRICS

Extensive production systems for monogastrics are defined here as scavenging systems, in which the animals are required to find their own food from natural resources and/or utilize waste feedstuffs from human households. These differ from systems in which animals are kept extensively, in fields or in simple housing, but fed as intensive animals on pre-prepared concentrate diets.

The greatest potential welfare threat related to nutrition for animals in extensive systems is that of hunger. Where the animals are scavenging under free-living conditions, and therefore self-sufficient, the food availability in the environment may be scarce and subject to seasonal variation. In some regions this scarcity may extend to availability of water, which can be considered as the most essential nutrient for life for all animals, and thirst consequently poses an even greater welfare threat than hunger. The potential risks to welfare are greater where animals are housed and fed by humans, i.e. where it is the owner that does the scavenging and the animal has no possibility to look for food itself. Lack of feed resources, combined with poor storage conditions for perishable feeds over periods of food scarcity, can result in limited nutrient supply. Even if feeds are available, lack of industry by the owner may result in them not being gathered and presented to the animals. Inadequate dietary energy because of food shortage can result in animals also being more subject to cold stress, since heat arising from the digestion and utilization of food is a significant component of thermoregulation (Verstegen and Close, 1994). This is particularly the case for pigs, which have no insulating coat of fur, wool or feathers to buffer climatic extremes, and for smaller animals which have a higher surface area to volume ratio.

Even where feeds are available, the nature of the materials, and particularly the waste products, means that deficiencies in specific nutrients can easily occur. In scavenging situations, the owner has no knowledge of the intake of the animal, making it difficult to plan for correction of nutrient deficiencies. Where animals are fed on waste products, humans will use the more nutritious components of feedstuffs for themselves, leaving less nutritious residues for the animals. Such residues are likely to be biased towards energy rather than protein content, and may be high in indigestible fibres or anti-nutritional compounds. Unlike ruminants, pigs and poultry are unable to effectively utilize dietary fibre and will in most cases obtain little value from such feedstuffs (Noblet and Le Goff, 2001). Small variations in feed composition and short term deficiencies in specific nutrients may not pose a major welfare problem for monogastrics, which are adapted to deal with a varied diet, although it may impair their productive performance. More extreme deficiencies, however, may lead to clinical consequences, with compromised health and associated malaise. Nutritionally induced immune impairment, in combination with greater health challenge from parasitic infestation and wildlife infection pools, poses a significantly greater welfare risk in free living animals than experienced by animals kept in more segregated conditions.

Subclinical nutrient deficiencies can also be a welfare issue under some conditions, since they too can induce states of hunger even if plentiful, but inappropriate, food is available. There is good experimental evidence that animals can detect such deficiencies and that they seek to remedy them (Jensen *et al.*, 1993). Under free-living conditions, they have some possibilities to alleviate nutrient deficiencies through their own foraging behaviour, for example by catching invertebrates for protein or obtaining minerals from soil (Edwards, 2003; Walker and Gordon, 2003). However, if confined to household enclosures and fed wastes, the possibility to utilize this natural behaviour will be very limited, and animals will thus experience impaired welfare if deficiencies persist in the longer term. Free-living scavenging animals do, however, experience other welfare risks to which enclosed animals are not subject, notably the risk of predation from both wild carnivores and from other humans in the community who are seeking diet supplementation or additional income from illicit activity. This may be associated with increased fear and distress for the animals, and with increased pain and injury if predation attempts occur unsuccessfully.

The keeping of animals in extensive systems also has important implications for the health and welfare of the human population. The lives of the animal and human species are closely intertwined, with both spatial and dietary overlap. As well as eating human waste food, free-living animals may also forage in and consume human excretory products, and transmit bacterial (e.g. salmonella), viral (e.g. influenza) and parasitic (e.g. tapeworm) zoonotic agents to the human population.

Animals kept in these extensive systems are of great economic importance for families living under subsistence conditions. Since they require almost no financial input, being housed not at all or in very simple structures and living off scavenged feeds which are not suitable for human use, the products which they deliver are essentially free and the proceeds from any sales are essentially all profit. In many societies such animals, particularly pigs, can be considered as a type of banking system, in which small contributions to rearing costs over an extended period of time can be realized in significant sale value at a time when major capital expenditure is required.

MIXED CROP-LIVESTOCK PRODUCTION SYSTEMS: RUMINANTS

A large proportion of ruminants (both for meat and dairy) are kept and raised under mixed-crop conditions in peri-urban areas. These production systems typically involve small herd sizes, with animals either confined in limited spaces or free-roaming. Animals under these systems are fed on different feeds as they become available throughout the year and, as such, the quality of the diet will fluctuate throughout the year. This type of production system can be significantly affected by poor feed budgeting, and inadequate nutrient supply is the most significant threat to animal welfare (and productivity). Malnourishment is often a problem consequence of inadequate nutrient supply leading to deficiencies of specific nutrients. In addition, free-roaming animals risk the consumption of foreign bodies that may compromise gut function. The level of animal welfare associated with nutrition under such production scenarios can be improved by the implementation of forage preservation (silages and hays) at times of fodder surplus, improved and more open declaration of purchased energy and protein rich supplements and the provision of balanced rations to optimize rumen function, which in turn improves feed intake and feed conversion efficiency. Such initiatives will have an improved chance of success if suitable technical support is provided by qualified professional individuals.

MIXED CROP-LIVESTOCK PRODUCTION SYSTEMS: MONOGASTRICS

In these systems, animals are enclosed and subject to controlled feeding, primarily using crops and crop residues produced on the farm. The animals may be housed, with all feed harvested and carried to the building, or enclosed in paddocks where animals have the possibility for some controlled foraging but where the primary source of feed is usually supplied as a complete ration by the owner. Where animals are housed, the availability of straws from the crop production system means that bedding can be provided to still allow the animals a foraging substrate. These systems therefore differ from extensive systems by the fact that crops are grown specifically for use as animal feed, and in the level of control of dietary inputs which the owner exerts. They can range from relatively small scale family operations, using home-grown crops to produce animal protein for family or community needs, to much larger operations in regions where crop growing conditions are good and significant yields surplus to human requirement can be used to feed animals, which can then be sold to urban consumers. At the extreme, such systems take on the characteristics of intensive systems, but are differentiated by their complete integration of the crop and livestock enterprises within the farm, both through primary reliance on home-grown raw materials for animal feeding and, conversely, by primary reliance on animals manures for crop fertilization.

Animals within these systems will typically be less at risk of accidental hunger than those in extensive systems, since feed supply can be better planned and monitored. However, they are still at the mercy of climatic extremes or pest infestations which might unexpectedly affect crop yields on the farm and hence feed availability. Since many of the crops are seasonal, feed storage and annual planning is very important to ensure an even nutrient supply throughout the year between harvests. Poor storage can lead to loss of feed through activities of wildlife pests (e.g. birds, rodents and insects), from sprouting or fermentation in warm, damp conditions, or through deterioration resulting from mould and bacterial growth. Where such deterioration occurs, an additional risk is the generation of toxins in the feed, such as mycotoxins, which have deleterious effects on animal health, appetite, growth and reproduction (D'Mello *et al.*, 1999).

Since the animals typically receive complete diets formulated by the owner, some nutritional understanding of the needs of the animal and the value of the different available ingredients is required in this process. Not all owners have the necessary knowledge to perform this function well, and animals may experience specific nutrient deficiencies as a result. Even if the animals' needs are correctly understood, estimation of nutrient supply may still be problematic. Crops can vary in composition according to variety, and to the growing conditions in any season or year. It is therefore easy to incorrectly assume nutrient content if no laboratory analyses are available. These analyses, once considered expensive, are nowadays more affordable from a cost-benefit point of view and the results can be made available in a short time. Where animals are harvesting the crops directly from the ground, by being enclosed on fields at the appropriate time of year, intakes may also not be precisely known and hence the composition required for supplementary feeds is uncertain.

INTENSIVE PRODUCTION SYSTEMS: RUMINANTS

Intensive production systems are, in general, professionalized, using high levels of resources but also yielding high volumes of meat and milk (thus efficiency is high). These production systems typically rely on animals which have been specifically selected through careful breeding programmes for increased growth rate or milk yield potential. Inevitably such animals have increased nutritional demands.

In countries with favorable environmental conditions for growing considerable amounts of pasture over an extended period of the year, milk production systems based on extensive use of fresh grass with minimal use of supplementary feed dominate. New Zealand provides an example of such systems, as does the Republic of Ireland which also places considerable reliance on the use of pasture. However, as fresh pasture contains as much as 75–85% moisture (i.e. 15–25% dry matter), cows on such systems are faced daily with consuming vast quantities of fresh forage in order to achieve reasonable levels of dry matter intake, with as much as 100 kg fresh pasture required for a total dry matter intake of 18 kg/d. It follows that annual levels of milk production achieved by cows on such systems are relatively low, with 5 000 L considered acceptable. Such systems are often referred to as low input/low output, where the input term refers more to the quantity of feed consumed than the quality of that feed. Given such constraints, to achieve satisfactory total annual levels of milk production by the herd most farms operating this system will increase cow numbers.

In all dairy cows, the imbalance between nutrient supply and nutrient demand can be quite evident in early lactation, with milk production sustained, in part, through mobilization of body tissues due to the cow's inability to consume sufficient dry matter to satisfy her nutritional needs. As a consequence, cows after calving may incur different metabolic problems (typically ketosis and fatty liver). This situation can be controlled by limiting the dry period to 50–60 d, as longer periods often render cows excessively fat which will limit their intake after calving and increase their susceptibility to both of the above conditions, and by feeding low energy diets to maximize intake before calving whilst controlling/maintaining body condition. A further consequence of high milk yields is the need for lactation rations to be formulated to contain high levels of metabolizable energy, which is typically achieved by feeding increased levels of non-fiber carbohydrates (starch and sugar). These carbohydrates ferment rapidly in the rumen and can lead to an accumulation of ruminal acids that can eventually result in rumen acidosis. Ruminal acidosis, thought to be the most common digestive disorder in dairy cows, occurs as a result an accumulation of fermentation end-products, mainly volatile fatty acids (VFA) and lactic acid, in the rumen due to either an excessively rapid fermentation that results in the production of large amount of VFA, or inadequate removal of these acids from the rumen via absorption through the rumen wall, passage from the rumen to the intestines or inadequate neutralization with salivary buffers. Rumen acidosis has been associated with increased inflammatory response and laminitis. Laminitis, not only causes pain, but also compromises milk production (Warnick *et al.*, 2001; Green *et al.*, 2002; Bach *et al.*, 2006). Reduced rumen pH is associated with an accumulation of lipolysaccharide in the rumen (Andersen *et al.*, 1994; Gozho *et al.*, 2005) due to the lysis of Gram negative bacteria, which will elicit an inflammatory response. However, although this inflammation mechanism could play a role in laminitis, it is likely that there are other mechanisms by which ruminal acidosis more specifically causes laminitis, such as hypoperfusion resulting in ischemia in the digit as a consequence of endotoxins released in the rumen that reach the blood stream (Nocek, 1997).

It is important to recognize that rumen acidosis also occurs in intensive grazing systems. Research has indicated that cows consuming copious amounts of fresh pasture, containing high levels of soluble sugar, can have rumen pH values below 5.5 for significant periods during each day. Whilst this condition differs from classic lactic acidosis as seen in high concentrate feeding, it nonetheless can cause serious distress to the animal, over and above the general observations of fluctuating milk yields and composition. Post-mortem examinations of cows grazing high quality fresh pasture have confirmed the occurrence of extensive rumen wall damage in a significant number of animals.

The extensive use of pasture in some dairy systems has already been referred to above, where lower achieved levels of feed intake result in relatively low yields of milk and milk solids per cow. However such systems of production are attractive due to the lower cost of pasture compared with other feeds, especially in areas with good grass growing conditions. In New Zealand, the annual yield of milk solids per hectare of land is considered more important than yield per cow and, under such conditions, those farmers seeking to increase annual margins generally do so by increasing herd size. Such systems use little if any supplementary feed and many do not actively conserve forage for those periods of the year when reduced grass availability is an issue. Consequently many of these cows live outside 365 days per year, with the added cost saving of no requirement to house stock in winter. However, at times of grass shortage welfare issues can start to arise. As grass supply fails, cows may be dried off prematurely; this inevitably leads to an extended dry period, which can result in over conditioned cows at calving if suitable management practices are not in place. In contrast, as grass supply fails, and sometimes this may be before drying off, cows are given daily grass allocations according to grass availability with no regard to the cows' nutritional needs. This can result in under-conditioned cows at calving, with associated infertility issues thereafter. These animals, following earlier periods of luxurious pasture availability, may be confronted with extended periods of under-nutrition. This has serious performance as well as welfare implications, added to which cows grazing rain soaked pasture in mid winter, with no cover from the elements, will portray a rather dismal picture of intensive dairy production systems based on extensive use of pasture. Alternatives should be found to manage these cows better and to avoid the under-nutrition and welfare issues that they often experience.

Beef cattle reared under intensive conditions are equally exposed to rumen acidosis with similar consequences on laminitis as for dairy cows. These animals are typically fed rations high in non-fiber carbohydrates to promote high daily weight gains. Problems are especially common during transition from the growing phase, usually with large proportions of roughage in the ration, to the fattening phase when the amount of roughage being offered is often limited.

Prevention of ruminal acidosis requires a minimum of total fiber and physically effective fiber to be provided in the ration. Traditionally, feeding forages of small particle size has been correlated with decreased chewing activity (and saliva secretion), low rumen pH, and low milk fat percentages (Cassida and Stokes, 1986). However, traditional studies have been conducted in cows kept in tie-stalls. Nowadays, most dairy cows are kept in free-stalls or bedded yards, and Leonardi and Armentano (2007) reported that ration sorting activity was greater in cows fed as a group in free-stalls than cows fed individually in tie-stalls. Thus, in practice, offering rations with long fiber can promote selection against the fiber-containing particles, and thus this type of ration may actually increase the risk of rumen acidosis compared with rations formulated with forages and fiber-containing particles of small size. Therefore, improving the balance between fiber and non-fiber carbohydrates in the ration and avoiding selection against long particles in high-concentrate rations by achieving a homogenous ration particle size distribution are pivotal in avoiding sub-acute rumen acidosis and the risk of laminitis and subsequent lameness.

Dairy and beef cattle under intensive systems are usually confined, and the design of the feed barrier may result in serious neck lesions. Stocking density may limit free access to feed due to insufficient feedbunk space, which may cause stress to the cow and compromise welfare and productivity. At least 25 cm of feedbunk space should be available for each animal. The surface of the feedbunk should be smooth to facilitate regular cleaning and the avoidance of microbial growth. Finally it is important to ensure all animals have available feed whenever they visit the feedbunk, which will require regular pushing up of the feed towards the cows.

A rather surprising (but common) problem in intensive systems is the high morbidity, and on occasions mortality, observed in calves. Mortality of dairy replacement calves ranges between 0.8 to more than 10% (Bach *et al.*, 2008), with morbidity from bovine respiratory disease (BRD) usually around 15% (Stanton *et al.*, 2010; Bach *et al.*, 2011). Intensive producers are often too focused on the lactating cows, and on many occasions calves receive less than adequate attention in respect to feeding, housing and general management. This may also be an issue for dry cows. The first nutrients calves receive after birth should be provided by colostrum, which also provides important growth factors and antibodies while the calf's own immune system is developing (Chase *et al.*, 2008). Traditionally, dairy calves are separated from the cow at birth and fed between 1 and 4 L of colostrum (often from a different cow), either by bottle-feeding or esophageal tubing. The rate of increase of immunoglobulin G concentration following colostrum feeding has been reported to be the same between these two methods (Adams *et al.*, 1985) and greater than that obtained when calves are allowed to directly suckle the dam (Besser *et al.*, 1991). Following colostrum feeding, which can range between one single dose to two doses daily for three days, calves are fed either whole milk, waste milk, or milk replacer at different regimes. Traditionally, there has been much pressure to limit the amount of milk (liquid) feeding offered to calves to stimulate consumption of solid feed intake and reduce costs. The most common feeding regime consists of offering 4 L/d of milk or milk replacer (providing about 500 g/d of solids) until the age of 42–49 d, when the amount of milk offered is reduced to 2 L/d until weaning time at 7–14 d later. However, calves are able to consume much greater amounts of milk (Jasper and Weary, 2002) and grow at much greater rates (Díaz *et al.*, 2001; Terré *et al.*, 2007) than often seen in artificially reared calves. Calves offered just 4 L/d of milk often experience some degree of hunger, as indicated by increased vocalization (Thomas *et al.*, 2001) and standing times (De Paula Vieira *et al.*, 2008) compared to calves receiving 8 L milk/d or more. Hunger will enhance sucking motivation in calves (de Passillé and Rushen, 1997), and Roth *et al.* (2008) demonstrated that if calves were weaned based on individual consumption of solid feed (by progressively reducing milk offered when DM intake was above 700 g/d and complete weaning when solid feed consumption was above 2000 g/d), cross-sucking was effectively reduced. Furthermore, calves take longer to consume milk via a teat than from a bucket (Jung and Lidfors, 2001), thus it is advisable that where calves are fed only 2 or 3 times per day they should receive milk from a teat. However, when feeding large amounts of milk, solid feed intake is usually reduced, and this may potentially blunt most of the gain differences after weaning between animals receiving high vs low milk regimes (Terré *et al.*, 2007; Morrison *et al.*, 2009; Sweeney *et al.*, 2010). This decrease in performance can be avoided by weaning based on concentrate consumption (Roth *et al.*, 2009) or progressively decreasing milk allowance (Khan *et al.*, 2007; Sweeney *et al.*, 2010), but ideally these two methods require the use of automatic feeders. Furthermore, despite the time needed to manage calves housed individually is more than 10 times greater than the time needed to manage calves on automatic milk feeders (Kung *et al.*, 1997). This latter approach increases the risk that calves may be left unattended for increasing periods of time and diseases may be detected only when at an advanced stage, thereby contributing to increased morbidity and severity of the disease. It is important to emphasize that producers using automatic feeders need to spend time examining the animals and analyzing the records of feed intake, as these will help identify any underlying potential health issue. Another alternative to minimize the decrease in nutrient intake around weaning is grouping the calves before the milk offer is reduced. Bach *et al.* (2010) showed that grouping at pre-weaning when milk allowance was halved, stimulated intake of solid feed and diminished relapses of BRD in calves that were kept individually until that time. Group composition when mixing is also important, as grouping animals based on their history of respiratory disease will minimize subsequent incidence of the disease (Bach *et al.*, 2011).

Water supply to calves is also important and in too many instances may be inadequate or nonexistent. Although providing water to milk-fed calves is often recommended, there is little experimental data on water intakes by calves (Drackley, 2008). Milk-fed calves drink minimal water until weaning, at which time their intake increases markedly (Hepola *et al.*, 2008) and follows the intake of solid food (Kertz *et al.*, 1984). Terré *et al.* (2006) reported that calves may consume between 4 and 6 L of water per kg of dry matter consumed, with calves on enhanced-feeding programmes (large volumes of milk) consuming more water per unit of dry matter than calves on milk-restricted programmes. Thus, it is important to provide water to calves if solid feed intake is to be maximized.

INTENSIVE PRODUCTION SYSTEMS: MONOGASTRICS

Intensive production systems for monogastrics involve total control of all inputs, and focus on high levels of technical efficiency. Whilst they can be owned by a family business, it is increasingly common for them to be owned or controlled by larger corporate organizations with vertical and horizontal integration at a national or even multi-national level. The animals are intensively selected for production traits, often by international breeding companies, with specialized genetic lines for different functions and circumstances. The feeds are largely based on purchased raw materials, with cereals and soya predominating, and are usually formulated by specialist nutritionists and manufactured in large volumes at specialized feed compounding facilities.

The animals are most commonly housed in controlled environment buildings, to maximize the efficiency of feed use by ensuring that they are kept at all times under thermoneutral conditions, and to control the lighting patterns which are important for development, growth and egg output in poultry. However, there are some intensive systems where animals are kept outdoors on a large scale, in so-called “free range” pig and poultry systems. In these intensive outdoor systems, there is little or no use of foraging to contribute to nutrient supply, so that nutrition of the animals is still predominantly controlled by the owner and based on imported concentrate feedstuffs.

The high production levels of the animals in intensive systems can challenge their metabolic homeostasis. Pigs are expected to produce offspring at rates of up to 30 piglets per sow per year, and to grow at rates in excess of 1 kg/d during fattening. Laying hens are expected to produce up to one egg a day at peak lay, whilst meat chickens now reach their slaughter weight at only 5–6 weeks of age. For animals to sustain these levels of production, they need to be fed highly specialized, concentrated diets since their feed intakes have not increased proportionately to their production levels.

Feed is usually given ad libitum or to appetite to the growing animals, and feeding systems are highly automated. These animals should never therefore experience hunger through prolonged absence of feed, although breakdown of the automated supply systems can occur and give temporary situations of feed deprivation. However, in badly designed accommodation with inadequate feeding space, low ranking animals may be unable to access adequate feed and be subject to aggression from more dominant pen mates in attempting to do so (Manteca and Edwards, 2009). Animals may also be temporarily deprived of feed or water for specific purposes in the production cycle. This includes forced moulting for laying hens (Patwardhan and King, 2011), or feed withdrawal prior to transport to reduce gut fill, and hence improve hygiene and reduce nausea during travel (Warriss, 1998).

The situation for the breeding animals is very different to that of the growing animals. Here, high feed intake and maximal growth rate is undesirable, both economically in terms of food cost and for the animals themselves in terms of health problems. Unlimited nutrition results in very fast growth, leading to long term problems in skeletal structure, circulatory system failure and later obesity. To optimise health and reproductive performance, whilst minimising feed cost, feed supply to parent stock of pigs and meat chickens is consequently severely restricted to only about 30% of their voluntary intake. Although supplying adequate nutrients for good health and performance, this gives rise to a state of chronic hunger which, because of the highly controlled indoor housing conditions, the animals cannot alleviate by foraging. In these circumstances the welfare of the animals is impaired, as shown by development of abnormal behavioural patterns such as stereotyped bar biting in pigs or spot pecking in poultry (Lawrence and Terlouw, 1993; Mench, 2002; Merlet *et al.*, 2005). The problem of chronic hunger in restrict-fed breeding animals of monogastric species may be partially alleviated by the use of lower density, higher fibre diets giving increased feeding time and greater dietary bulk to promote satiety (Meunier-Salaun *et al.*, 2001; Nielsen *et al.*, 2011), but this does not provide a fully effective solution. Because of the level of hunger generally experienced by these animals, competition for the feed supplied is high and aggression can give serious welfare problems. Low ranking animals may be bullied or intimidated by higher ranking individuals and thus receive less than their equal share of the feed provided, whilst active competition can result in superficial lesions or sometimes more serious injury (Edwards *et al.*, 1993).

Even when feed is supplied ad libitum, the high metabolic demands of the genetically improved animals can mean that nutrient requirements are not always met. In the case of lactating sows, their high milk output can initially only be sustained by mobilization of body reserves, and severe loss of body condition which compromises rebreeding can sometimes occur, especially in hot climates where appetite is reduced (Black *et al.*, 1993). Early weaned piglets have inadequate ability to ingest solid feed and digest the cereal and plant protein components, because their total reliance on milk for nutrition in early life means that neither their appetitive behaviours nor enzyme systems are fully adapted to consumption of solid feed by the time of weaning. This can result in low food intake in the days after weaning, which causes detrimental changes in the gut structure and microflora, predisposing them to enteric disease (Kim *et al.*, 2012). In the case of laying hens, the high demand for minerals for egg shell production results in mobilization of bone stores. The resultant osteoporosis can cause a high prevalence of breakages of weak bones in birds towards end of lay (Webster, 2004). It has been shown that animals will regulate their overall feed intake according to energy needs and, in choice feeding experiments, that they can select the right balance of specific nutrients to meet the requirements of their current metabolic state. For example, birds will alter calcium intake in relation to level of demand from egg production (Holcombe *et al.*, 1975). It might therefore be expected that, in these situations of general or specific nutrient deficiency, even animals fed ad libitum will experience a form of metabolic hunger. Behavioural changes seen under such conditions support this assumption (D'Eath *et al.*, 2009).

Nutrient imbalances can also occur for individual animals because they are usually housed in groups which may comprise tens, hundreds, or even thousands of individuals. Diets are formulated on a least cost basis to best meet the needs of the population, usually based on the needs of the average animal. Although animals are genetically selected and managed to give groups which are as uniform as possible, biological variability and the effects of health challenges result in differences between individuals which increase over time. This means that the balance of nutrients in the diet formulation will always be slightly suboptimal for many of the animals in the group, and may induce specific hungers in these circumstances.

The highly specialized breeding has in some cases changed nutrient requirements markedly, particularly for many of the vitamins and trace elements. Suboptimal levels of micronutrients, resulting from failure to correctly adjust diets as genetic progress is realized, can result in detrimental effects on health of the animals. For example, suboptimal levels of vitamin D and its metabolites can exacerbate the genetic predisposition to skeletal problems in fast growing lines of poultry (Whitehead *et al.*, 2004), whilst insufficient vitamin E and selenium can result in heart muscle pathology (Brambilla *et al.*, 2002).

The form in which the feed is given can also sometimes cause health problems. Feeds are usually pelleted in order to increase density, improve utilization and reduce wastage. However, the pelleting process can interact with feed components, such as the arabinoxylans in wheat, to induce non-infectious changes in excreta wetness, causing colitis in pigs (Chase – Topping *et al.*, 2007) and wet litter problems in poultry (Collett, 2012). Whilst the animals do not always appear to be directly adversely affected, their living conditions and hygiene deteriorate, such that freedom from discomfort is compromised. Pelleted diets can also have direct effects on animal health and welfare, since they have been shown to increase the prevalence and severity of gastric ulcers in pigs (Wondra *et al.*, 1995).

The high metabolic rates of animals operating under sustained high production levels result in the generation of a lot of body heat. This increases their predisposition to heat stress, especially when kept in hot and humid climatic conditions (Soleimani *et al.*, 2011). Their response to this situation is to decrease voluntary feed intake, in an attempt to reduce heat load, which can impact adversely on production, result in excessive loss of body condition at times of high metabolic demand, or result in inadequate micronutrient intake if diets are not adjusted appropriately.

CONCLUDING REMARKS – FEEDING OPTIONS FOR DIFFERENT PRODUCTION SYSTEMS THAT IMPROVE ANIMAL WELFARE AND PROFITABILITY

Extensive production systems

1) Under extensive production systems, animal welfare and profitability can be achieved by reducing the impact of climatic variables on ruminant nutrition by balancing stocking density with existing natural resources (present and forecast), purchasing additional feed, moving stock to areas with better feed supplies or reducing stock numbers. Much can be done to prepare cattle and sheep stations to withstand drought, such as adopting moderate stocking rates and planting drought-resistant crops.

2) Comfort and survivability of animals under extreme cold conditions can be improved by maintaining adequate body condition (or body energy reserves) before the cold weather arrives.
3) Maximizing the availability of nutrients to the animals throughout the year is the major challenge. This can be done by improved storage methods to reduce wastage, and the treatment of low quality by-product feeds through fermentation and enzyme technologies to increase nutrient availability. Adequate storage should be provided for water also, to avoid deprivation during the hot season.
4) The variable composition of scavenged and by-product feedstuffs makes planned nutrient supply for monogastrics difficult. Clinical tests could be carried out to detect metabolic deficiencies in the animals, and chemical analyses could inform on ingredient composition. However the cost and infrastructure required for these make them difficult to apply in subsistence situations, and the availability and cost of supplements to remedy deficiencies will limit their use.
5) Protein deficiency is a particular challenge when by-product feedstuffs are used for monogastrics. Fermentation systems may be used to produce microbial protein, and invertebrate sources such as maggot production on waste feeds could be considered.
6) Under protein limiting conditions (common in extensive production systems), an increased supply of amino acids is likely to improve host resistance to gastrointestinal parasites.
7) Providing adequate mineral and micro-nutrient supplementation is an effective way of improving animal welfare and performance.
8) Matching feed nutrients to animal needs requires a level of nutritional understanding by owners. Training and information schemes could assist in disseminating basic knowledge. At a higher organizational level, Farm Assurance schemes with entry level nutrient standards could check compliance, but these are less applicable where product is for home consumption.
9) The health risks associated with scavenging by free-living animals can be countered by the use of anthelmintics, vaccination and bioactive phytotherapies. Improved animal health will benefit both welfare and productivity.
10) Malnourishment of sheep in extensive systems can be minimized by providing energy supplementation before lambing and/or grouping ewes based on lamb load and feeding the groups accordingly.
11) When animals are exposed to toxic-compounds, it is important to ensure adequate nutrition (which provides more resilience) and also to adapt the animals progressively to these secondary compounds.

Mixed-crop production systems

1) The animal welfare level associated with nutrition of ruminants under this production scenario can be improved by the implementation of forage preservation (silages and hays) at times of fodder surplus, improved and more open declaration of purchased energy and protein rich supplements and the provision of balanced rations to optimize rumen function, which in turn improves feed intake and feed conversion efficiency.
2) The challenge in mixed-crop systems is to better integrate the nutrient management of crop and animal production enterprises within the system. Planning of

the cropping cycle to include appropriate amounts of both energy and protein crops, and matching the animal numbers to available feed supply, allows the system to be relatively self-sufficient and reduces dependence on external markets where costs may fluctuate. Risk of crop failure can be reduced by utilizing a mix of higher yield annual crops and more robust perennials.

3) The efficient use of animal manures facilitates high crop yields and reduces the need for purchased fertilizer. Using straw from the crops to supply bedding into animal systems can improve animal welfare, while the resultant straw-based solid manure acts as a slow release fertilizer and can improve long term soil structure and health by increasing organic matter.
4) Because of the variation in crop composition, there can be errors in nutrient supply if incorrect assumptions based on average nutritional values are made. Analysis of crops produced each year allows more precise diet formulation. Training of farmers, or the use of professional nutrition advisers, can ensure that animal requirements are correctly estimated.
5) Year-round feed supply can be ensured by good crop storage systems. Where growing conditions or storage conditions result in fungal contamination and production of mycotoxins, the use of mycotoxin binders in feed can improve animal health and performance. However, availability or cost of these may deter use in some countries.

Intensive production systems

1) The highly specialized genotypes and diet formulation approaches, and the large scale of operation which typifies intensive production systems, mean that the nutritional welfare of the animals is best safeguarded when expert nutritionists are involved in the diet formulation process. Appropriate training of these experts is essential to safeguard welfare by ensuring correct supply of both macro- and micro-nutrients in the diet, by matching nutritional density to the intake capacity of the animals concerned, and by ensuring correct choice of raw materials for their digestive capacity. For example, young animals have a lower voluntary food intake and require more digestible feed ingredients, e.g. pre-cooked cereals and animal-derived, rather than vegetable-derived, protein for monogastrics.
2) Feed and water provision to the animals must ensure reliable supply. Where automated systems are used they must be regularly checked and maintained, and should have alarm systems to alert staff in case of breakdown.
3) Feed provision must ensure that all animals are able to access their allocated share of feed without being subject to aggression. Where feed is available ad libitum, adequate trough space must still be provided. Where feed is restricted, the ability of all animals to access a fair share must be ensured by widespread feed distribution or by use of protected individual feeding places. The latter option will be impractical for poultry, but will reduce bullying and feed related aggression in pregnant sows. This will contribute to optimal body condition of all animals and hence improve reproductive performance and longevity. In the case of suckling piglets, where litter size in prolific genetic lines may exceed the number of available teats, husbandry interventions such as cross-fostering and supplementary feeding can ensure all individuals receive the necessary nutrient supply.

4) It is recommended that at least 25 cm of feedbunk space are available for cattle. The surface of the feedbunk should also be smooth to facilitate regular cleaning and the avoidance of microbial growth. Animals should have feed available at any time.
5) Rumen acidosis, as a consequence of the attempt of nutritionist to provide as much energy (mostly in the form of carbohydrate to the cow) to sustain high milk yield, can be minimized by properly balancing the ration, supplementing alkalinizers and buffers, and controlling particle size in order to minimize sorting. It is important to note that rumen acidosis also occurs under intensive grazing systems, and thus action should be taken also under these conditions. Minimizing rumen acidosis not only should improve animal welfare, but also improve feed conversion and thus profitability.
6) Beef cattle reared under intensive conditions are equally as exposed to rumen acidosis and its consequences on laminitis as are dairy cows. Problems are especially common during the transition from the growing, usually with large proportions of roughage in the ration, to the fattening phase when the amount of roughage being offered could be quite limited.
7) Adequate supplies of vitamin E and selenium may foster immune function and decrease the risk for mastitis or metritis in ruminants.
8) After birth, calves should be fed adequate amounts of good quality colostrum. Following colostrum feeding, calves should receive 6 L/d of milk or milk replacer, and then be weaned at about 2 months while calves are in groups (to use social facilitation to foster solid feed intake). Finally, calves should have access to fresh water ad libitum since day 1 of life. These practices should improve welfare, growth, and diminish incidence of disease.
9) The problem of chronic hunger in restrict-fed breeding animals of monogastric species may be partially alleviated by the use of lower density, higher fibre diets giving increased feeding time and greater dietary bulk to promote satiety. The use of appetite suppressants can also be considered. However, these approaches will result in diets with a higher cost per unit of nutrients, since fibrous materials are less efficiently utilized, and will increase excreta volume. The cost penalty may be reduced if cheaper fibrous by-product ingredients are utilized, and this will have the added advantage of reducing the overall carbon footprint of the food production system. However, even with higher bulk diets, the animal is still unlikely to feel fully satiated throughout the day and will experience a high level of foraging motivation. The presence of a foraging substrate in the form of bedding or daily provision of a foraging material, such as chopped straw or wood shavings, allows the animals to express foraging behaviour in a relatively natural way and reduces the risk of development of abnormal stereotyped behaviour patterns. Where bedding cannot be provided, for example in regions where straw is unavailable or in systems with slatted flooring and liquid manure management, the provision of good alternative enrichment devices, such as pecking blocks for chickens or compost racks for pigs, is important for their welfare.
10) In hot climatic conditions, adequate water availability, use of cooling systems such as water curtains or sprinklers, and formulation of diets with higher nutrient density and low thermogenic properties (more fat, less fibre) can assist monogastric animals to maintain nutrient intake when appetite is depressed.

11) Improvement of welfare associated with freedom from pain, injury and disease in intensive production systems can be achieved by genetic as well as management approaches. The risk of metabolically-related health problems associated with highly selected genetic lines, such as leg weakness, can be reduced by modification of breeding goals. Some specific diseases can also be controlled in this way, for example by selecting animals with intestinal resistance to F4 E. coli adhesion which will be less susceptible to enteric disease. Furthermore, selection against undesirable behavioural traits such as aggressiveness is also possible in both pigs and poultry.
12) The enrolment of farms in Quality Assurance schemes offers the possibility for independent audit of the adequacy of nutrition and feeding practice, and thus provides additional safeguards for animal welfare.

Opportunities and challenges to enhance animal welfare through animal feeding approaches in ruminants

ASSESSING WELFARE

Establishing objective and validated indicators of animal welfare is among the most important issues involved in nutrition and welfare. There is a need for better integrated and more robust (and validated) welfare measures than the ones currently available and used. Without solid data on welfare it is difficult to assess changes induced by different nutritional schemes.

NUTRIENT BALANCE

During the productive cycle of ruminants, nutrient imbalances are common. For instance, in lactating cows under intensive conditions, cows are typically overfed during the last 3 weeks before calving, and then the same cows experience a severe negative energy balance. It is advisable to limit energy consumption of dry cows (even, and especially, during the last 3–4 weeks before calving). Adequate nutrition during the pre-partum period should result in reduced metabolic disorders post-calving, as well as improved longevity.

In high-producing dairy cattle, it is common that animals undergo a marked negative energy balance leading to mobilization of body reserves. On occasions, this mobilization may result in accumulation of fatty acids in the liver and ketone bodies in the blood. This situation can be controlled by limiting the dry period to 50–60 d (longer periods may render cows excessively fat and limit their intake after calving) and feeding low energy diets to maximize intake before calving (but controlling body condition).

A common problem in both beef and dairy cattle under intensive feeding systems, but also in dairy cattle consuming large amounts of lush pastures, is rumen acidosis. Prevention of ruminal acidosis requires a minimum of total fiber and physically effective fiber to be provided in the ration, in conjunction with a ration that minimizes sorting (as discussed above). There needs to be a concerted effort to inform those involved in feeding mixed rations to all classes of livestock of the need to produce consistent rations (both within and between days) in which correct feed ingredient loading and mixing sequences have been followed to minimize the opportunity for ration selection.

Under extensive production conditions, nutritional imbalance usually is a consequence of the use of marginal lands or dry seasons. Under these conditions it is important to provide mineral as well as protein supplements in conjunction with adequate water availability. These practices should not only improve welfare, but also reduce mortality and morbidity. It is especially important that nutritional action is taken ahead of the dry season to allow animals building sufficient nutrient reserves to rely on when nutrient availability is low. The same scenario applies when ruminants are likely to be exposed to extreme cold conditions. Also, soil deficiencies may lead to nutrient imbalances and malnutrition. Under these situations, animal welfare and survival can be improved by externally supplementing the deficient minerals.

In small ruminants, dams carrying multiple pregnancies consuming low-energy diets are at risk of experiencing pregnancy toxemia. Pregnancy toxemia (which if untreated may result in death) can be avoided or minimized by providing sufficient energy supply, controlling plane of nutrition at matting and forming separate groups of ewes according to lamb load to facilitate accurate delivery of nutrients.

UNDESIRABLE BEHAVIOR

It is not uncommon to have animals expressing some undesirable behaviors that may lead to injury, aggression, feed sorting, etc... Most of these issues can be overcome by social aspects, group composition, and facility design, but some nutritional aspects can also contribute to diminish their incidence. Among these nutritional aspects are included: provision of an adequate balance of minerals, use of a total mixed ration that is homogeneous in particle size distribution, and avoidance of non-nutritional factors.

Some alternative methods to minimize undesired behavior propose allowing animals to choose from various feed alternatives. Within the field of nutrition, this approach involves a paradigm shift in the way animals are fed, acknowledging their role as active players in feeding systems, as opposed to passive entities that just respond to prescriptions and formulations devised by humans. Several producers in the US are now applying this potential new paradigm, which may contribute to a reduction in nutrient imbalances and veterinary costs.

INFECTIOUS AFFLICTIONS

Proper nutrition allows cell-tissue integrity and optimises defence mechanisms (namely the immune system) avoiding (or reducing) any disease. Some high-producing animals may suffer from infectious pathologies such as mastitis and metritis. The incidence of such problems can be minimized to some extent by supplementing important nutrients for adequate immune function. Examples of these nutrients include vitamin E, selenium and especially protein (needed for the synthesis of antibodies).

TOXICITY ISSUES

Extensively grazed cattle and sheep are more likely to encounter toxic plants than those fed a more controlled diet. Toxic plants have immediate welfare effects and are most common in extensive grazing situations. Increased weed seed transmission to novel grazing lands may increase this problem. Frequent overgrazing and climatic extremes also allows increased weed colonization of existing grazing lands. Training animals to avoid poisonous plants is a useful strategy to minimize feed toxicity. Animals should be introduced slowly to poisonous plants. However, toxicity levels increase, in some plants, in relatively short periods of time, even within hours (e.g., larkspur). Furthermore, conditioned feed aversion training may be effective for reducing use of poisonous plants by livestock. Mothers that learn to avoid plants may pass this information to the next generations. The offspring eats what mom eats and this is a powerful and efficient mechanism of information transfer in livestock. This is why producers are encouraged to use their own replacements or buy replacements from neighbors, or from similar areas. Animals not familiar with their environment are prone to increased levels of stress and to an increased risk to ingest poisonous plants.

Finally, use of medicines in supplements to counteract the negative effects of poisonous plants is another effective mechanism to reduce toxicosis. For instance, polyethylene blocks the negative post-ingestive effects of tannins in sheep and cattle.

FACILITIES

In many situations ruminants are kept and fed indoors (at least a fraction of the total ration). It is important that the design and measures of the feeding system are in accordance with the size of the animals to avoid neck lesions. Also, sufficient feeding space (at least 30 cm per cow) should be available. The surface of the feedbunk should be smooth and easy to clean to avoid feed orts being fermented and fostering undesirable microbial growth.

PARASITE CONTROL

Hosts become sensitized following recognition of parasite antigens and host innate immunity is the first line of defense; these parasite antigens also trigger differentiation, maturation and proliferation of lymphocytes associated with cell-mediated and humoral immune responses (Balic *et al.*, 2000; Claerebout and Vercruysse, 2000; McClure *et al.*, 2000). According to this nutritional framework, young growing animals that encounter parasites for the first time would be expected to prioritise allocation of scarce nutrients to the acquisition of immunity over growth to avoid succumbing to the negative effects of parasitism before reaching reproductive maturity. However, in reproducing animals that have acquired immunity against nematodes, the nutrient demands of reproduction may be so high that the expression of immunity to parasites suffers when nutrient resources are scarce (Coop and Kyriazakis, 1999).

Several plants contain antiparasitic agents. Shrubs and legumes in particular contain tannins and saponins, which have antiparasitic effects. For instance, it has been suggested that grazing on chicory, a plant rich in terpenes, reduced the parasite burden of growing sheep (Tzamaloukas *et al.*, 2005, 2006). By grazing or browsing these plants sheep and goats reduce their parasitic burdens. Some secondary compounds and other plant derivatives also enhance immunity through other mechanisms such as an increase in local immunity at the intestinal level. Studies in Japan show phenolic compounds enhance local immunity in cattle. In addition, adequate protein nutrition enhances immunity and thus resistance to parasitic infections.

Although the relevance of nutrients such as vitamins and minerals should not be underestimated, most research on effects of host nutrition on resistance to nematodes has concentrated on metabolisable protein (MP) nutrition. This seems sensible since many components of the immune effector responses are proteinaceous in nature (Balic *et al.*, 2000) and require an adequate supply of amino acids. In addition, parasitism further increases MP requirements for maintenance, arising from parasite-induced repair of damaged host tissue (Coop and Kyriazakis, 1999). This leads to the expectation that, under protein limiting conditions, an increased supply of amino acids (or protein) will improve host resistance to gastrointestinal parasites (Athanasiadou *et al.*, 2008).

Ectoparasites are also a problem worldwide and there is some evidence that terpenes and other fat-soluble secondary compounds (e.g., extracts from the Neem tree) when ingested by sheep reduce ectoparasite loads. Another effective alternative to combat parasitism is the use of commercially-available drugs every 6 months.

SALINITY

Research in Australia has shown that exposing mothers to saltbrush enhances tolerance of salt of the offspring. Elicited changes involve modified kidney anatomy and physiology and modified hormonal responses, such that salt is more efficiently eliminated from the body.

MORBIDITY AND MORTALITY IN YOUNG STOCK

Adequate provision of colostrum at birth is essential to ensure proper immune protection of calves for the first 3–4 weeks of life. Colostrum should be fed as early as possible after birth (ideally within the first 6 hours of life). It is more desirable that colostrum is bottle-fed as opposed to leave the calf to directly suck from the dam. Calves struggle finding the teats and often fail to consume sufficient amounts of colostrum or do it too late. At least 4 L of colostrum should be consumed the first 12 hour of life.

The commercial and apparent economic advantage of offering just 4 L of milk per day to suckling calves renders the animals with hunger and with a weak immune system. It is recommended to feed 6 L of milk or milk replacer per day until weaning age (about 56 of age).

Finally, provision of forage to young calves is often not recommended as it has been shown to reduce starter feed intake in individually-housed calves (Phillips, 2004), impair rumen papillae development (Nocek and Kessler, 1980), and decrease overall feed digestibility (Leibholz, 1975). However, feeding only starter feed to pre-weaning calves may result in lower ruminal pH (Beharka *et al.*, 1998) and reduced rumen motility (Clarke and Reid, 1974), leading to hyperkeratinization and clumping of rumen papillae (Bull *et al.*, 1965). The provision of a suitable forage source may stimulate the muscular layer of the rumen (Tamate *et al.*, 1962) and promote rumination (Hodgson, 1971; Phillips, 2004). Recently, Castells *et al.* (2012) concluded that free-choice provision of chopped forage to young calves improved overall feed intake and performance without impairing digestibility. Furthermore, depending on forage type, non-nutritive oral behaviors can be reduced, and rumination increased. The best results seem to be obtained with chopped oats hay, while chopped alfalfa hay should be avoided as, this may compromise total feed intake and performance.

CHALLENGES AND FUTURE RESEARCH

The most important challenge is to reach a consensus on pertinent welfare indicators that can be affected by nutrition. Measurements required to assess animal welfare due to nutrition may be different from those required to measure animal welfare during transportation or housing and the required measurements may be on a case-by-case basis. Behavioral measurements, including number of visits to the feed space, walking and ruminating activity, chewing non-food materials, and other aberrant behaviors may be important variables to explore in order to assess proper nutrition and welfare. Animal choice and preferences may be variables that need to be considered with more attention. There is an opportunity to integrate animal-based robust welfare measures with nutritional status of the animals. In this regard, researchers are encouraged to work together to construct a welfare measuring system that is objective, repeatable, and capable of validation. Today, this does not exist, and without agreed indicators, it is a real challenge to assess improvements or impairments in the welfare of animals.

The current drive to improve productivity from livestock has led to some nutritional strategies that may place the animal at risk or threatening welfare. In general, there is the perception that high production is linked with poor welfare, but it should be acknowledge that at any given time, high production is usually accompanied by high welfare. The challenge under this situation is to sustain welfare over time. Thus, more holistic studies, such life cycle, and long-term cost-benefits of these systems are needed. An example of challenges imposed by high production is rumen function. A common problem is rumen acidosis that may lead to laminitis among other disorders. There is a need to clearly establish the link between rumen acidosis and laminitis through conducting nutritional interventions and evaluating welfare indicators (pain, self-selection of analgesic, dietary components, etc.). Furthermore, there is a need to continue improving nutrient utilization of feedstuffs by ruminants through improved rumen fermentation. Overall, more research is needed on production systems integrating welfare outcomes and performance. Of special importance is attempting to adapt, rather than directly transferring, knowledge from one production system or geographical location to another. More specifically, there are doubts whether negative energy status actually challenges the welfare status of the early-lactation cow. Research should be conducted to assess the impact of different degrees of negative energy balance on immunocompetence, behavior, endocrine changes, and emotions.

Another important aspect is undernourishment in calves seen in both intensive and extensive systems of production. Improving the nutritional status of these animals will reduce mortality and morbidity, especially under extreme climatic conditions. In this regards, there is a need to explore and develop better climate forecasting models, better whole-farm management models integrating pasture, soil, stocking density, and breeds. Also, tribal management systems (weeds, fire, deferred or buffer grazing) should be studied to improve both welfare and productivity. The same problem as seen in calves and heifers can be observed in dry cows. These animals, often regarded by the farmers as "non-producing" animals tend to be neglected or receive a low priority in terms of amount and quality of nutrition.

Intensive livestock feeding systems commonly provide uniformly formulated foods based upon table values of nutrient requirements. If all nutrient requirements are met for the "average" member of the herd, then it follows that adequate nutrition is achieved. Nevertheless, individuals within a herd vary substantially in their intake and preferences for feeds, needs for nutrients and tolerance of excesses of nutrients in their diets. Even in extensive systems, variation in dental arcade causes individual sheep and goats to forage with different efficiencies. Sheep and cattle of uniform age, sex, and breed vary in their preferences for foods. Some animals prefer foods high in energy, whereas others prefer foods of medium or even low energy. There are clear differences in the susceptibility to acidosis in feedlot cattle. Thus, what traditionally has been considered normal foraging behaviour and adequate nutrition for the "average" animal may not be so for specific individuals. A solution to this problem may involve acknowledging the role of livestock as active players in feeding systems, as opposed to passive entities that just respond to prescriptions and formulations devised by humans.

In terms of nutrition, the need for improved feeding and forage preservation methods and conduct practical feeding trials to investigate feed formulation, and feed delivery methods with the aim of improving production parameters and welfare concomitantly was stressed.

Parasitism is another important challenge to animal welfare, especially under extensive production systems. In this regards there is an opportunity to improve animal productivity by improving resistance to parasites via nutrition and plant management.

Another major challenge that was identified involved the provision of food for a growing human population in a manner that is respectful with animal welfare. In this sense, more research is needed on livestock systems that include acceptable animal welfare outcomes. Adapt knowledge from developed to developing countries more appropriately, review the state of the art knowledge for applicability to development countries with respect to nutritional demands, feeding management demands, climatic situation and logistical requirements vs availability.

Finally, domestic and wild ruminants are constantly challenged by predators. In the USA, wolves are a growing concern. Predators do not only kill or injure animals but grazing animals will increase vigilance times and substantially reduce grazing time. In addition, they may avoid certain foraging areas if they perceive the risk of predation. Thus, these "landscapes of fear" negatively impact animal nutrition and welfare. More research in this area is needed to find protection for these animals or reduce the risk of exposure.

Opportunities and challenges to enhanceanimal welfare through animal feeding approaches in monogastrics

UNDERSTANDING AND DEALING WITH CHRONIC HUNGER

There is a very significant opportunity to improve welfare by reducing chronic hunger in animals on restricted feeding systems (D'Eath *et al.*, 2009). There are a number of situations where chronic hunger arises. These include the absence of sufficient feed in subsistence systems, the deliberate restriction of feed for breeding animals in intensive systems, and the possibility of nutrient specific hungers arising from imbalances between the diet supplied and the metabolic needs of the animal.

The biggest challenge, in both pig and poultry feeding, is to alleviate hunger whilst restricting feed in order to avoid obesity. There is significant societal concern about the high level of abnormal stereotyped behaviours seen in many intensive monogastric production systems as a consequence of hunger in these animals (Lawrence and Terlouw, 1993; Spoolder *et al.*, 1995; Mench, 2002). This also impacts on other aspects of welfare because of the potential for serious competition for feed when it is given and the general increase in aggressiveness of animals whose foraging motivation is frustrated (Edwards, 1992). In order to develop effective approaches to deal with chronic hunger, both fundamental and applied research are necessary, in addition to better implementation of existing knowledge.

The first requirement is to understand the animals' perception of hunger and to quantify in a better way how this influences its affective state. This will require both (neuro) physiological approaches, looking at the effects of the hunger on neuropeptides and gene expression, and behavioural approaches, using new techniques for the assessment of affective state such as conditioned place preferences. Once tools to quantify hunger are available, the more subtle issues of nutrient specific hungers, particularly for micro-nutrients, and the role of appetite suppressants can be investigated (Sandilands *et al.*, 2006). A more critical evaluation of the role of bulky and high fibre feeds can be made, different raw materials can be evaluated and quantitative recommendations for the types of fibre which best promote satiety can be developed (Meunier-Salaun *et al.*, 2001; Nielsen *et al.*, 2011).

A related challenge in dealing with the adverse consequences of hunger is the prevention of injurious abnormal behaviours (sometimes called vices, such as tail biting in pigs and feather pecking in poultry) which can result from the frustration of foraging motivation (Dixon *et al.*, 2010; Taylor *et al.*, 2010). At the fundamental level, there is a need to understand the neurological mechanisms which mediate these behaviours so that effective intervention strategies to deal with their various nutritional and environmental trigger factors can be developed. At a more applied level, the definition of which forms of environmental enrichment are adequate for the expression of motivated foraging behaviour would allow better strategies for managing hungry animals in intensive systems. This would involve determining the extent to which opportunity to perform different behaviours under hunger conditions can affect the animals' affective state.

MATCHING DIETS TO NUTRITIONAL NEEDS

In many cases, it is not the absence of feed which causes a welfare problem, but the feeding of an inappropriate diet. Both pigs and poultry show a high degree of "nutritional wisdom", being able to detect dietary imbalances and remedy these if an appropriate variety of feed sources is available (Rose and Kyriazakis, 1991). When fed on a single compound diet in intensive systems, the animal does not have this possibility and so understanding in more detail how genetic, environmental and health factors affect the need for each specific nutrient is important for correct diet formulation.

In order to tailor diets to animals in a way that improves welfare, it is therefore important to understand the animals' nutritional objectives and to design diets that match both these and the economic objectives of the farmer. This might allow, for example, targeted manipulation to regulate intake in ways that maximize production output or product quality, without generating unpleasant (nutrient specific) hunger states.

Particular challenges are posed by the design of diets for local breeds of livestock, since most current nutritional research and recommendations are based on improved breeds managed in intensive systems. Local breeds are generally slower growing, have greater appetite, partition more energy into fat reserves and have more robust health status. These characteristics need to be better defined in nutritional terms for a wide range of local breeds in use in different countries, and the nature of any genotype-nutrition interactions specified. In particular, it is important to understand if there are genetic differences in hunger-causing nutritional states, since local breeds with lower metabolic demands may have evolved to deal better with situations of food or specific nutrient deficiency.

In improved breeds which have been highly selected for production characteristics, there are opportunities to mitigate the effects of problems associated with genetically induced fast growth and the partitioning of nutrients to production functions. Examples of such challenges are the skeletal and metabolic problems experienced by fast growing meat chickens, and the osteoporosis seen in laying hens. These might be addressed through nutritional interventions targeting regulation of calcium, phosphorus and vitamin D metabolism.

Another widespread welfare challenge arises from understanding and alleviating environmental conditions that influence the animals' feeding behaviour, feed intake or nutrient partitioning. As examples, thermal stress will change appetite (Verstegen and Close, 1994), conditions causing fearfulness will induce a physiological stress response and change nutrient partitioning (Wellock *et al.*, 2003; Virden and Kidd, 2009), and health challenges will affect the requirements of the immune system for specific amino acids needed to mount an immune response (Kogut and Klasing, 2009; Le Floc'h *et al.*, 2009). Further development of current models for calculation of nutrient requirements to incorporate such factors would allow more targeted formulation strategies to better meet the needs of animals in the wide variety of conditions which exist in practical farming.

DEVELOPING MORE SUSTAINABLE NUTRITIONAL STRATEGIES

Whilst a good understanding of nutritional requirements for the optimization of performance has been developed over recent years, the opportunity to use nutritional approaches to address other sustainability goals is less well exploited. Societal goals such as the supply of food which is both safe and nutritious to humans, whilst generating low environmental impact from production systems, have a major nutritional component.

Producing safe food involves the exclusion of zoonotic organisms and hence the control of bacterial and parasitic infection. This is also an important objective for the health of the animals themselves. In the past, there has been widespread use of in-feed antimicrobial and anthelminthic additives to control disease in animals, both clinical and sub-clinical, and hence promote growth and productivity. Whilst very effective in this function, the practice of routine prophylactic dietary inclusion of antimicrobials has given rise to concerns about its role in promoting the development of antibiotic resistant strains of bacteria (Chesson, 2006). These can affect the efficacy of treatment for disease in both the animal population, but also in humans. Similarly, parasites resistant to the common anthelmintic chemicals have emerged. There is significant opportunity to develop better nutritional strategies to promote health without the input of chemical therapeutics, for example by formulating diets which promote more beneficial strains of gut micro-flora and competitive exclusion of pathogens. Organic acids, prebiotics, probiotics and phyto-chemicals all have a potential role to play as natural antibiotics or anthelmintics.

The challenge of minimizing environmental impact involves designing diets not just for animal performance but also for post-animal consequences of manure composition. There are significant opportunities to model nutritional effects of diets on excreta composition and its environmental consequences. This would allow the implementation of least cost formulation strategies for overall environmental impact, including lowest carbon footprint from dietary ingredients, rather than just for animal performance (Rigolot *et al.*, 2010; Mosnier *et al.*, 2011). Such approaches can be relevant for animal welfare, since excreta composition can influence litter quality, and hence air quality in livestock buildings (Namroud *et al.*, 2010). It can also affect environmentally-damaging emissions of ammonia and greenhouse gases from excreta once removed from the buildings to storage or distribution to land, and the nutrient availability and fertilizer value for crop production. Therefore, reduction in excretion of nitrogen surplus to nutritional requirements, which can increase ammonia volatilisation, is desirable from both an environmental and an animal welfare perspective. Ammonia causes environmental acidification, damaging to vegetation, and is also irritating to the eyes and mucus membranes of the respiratory tract of the animals themselves, as are dust particles generated if the food is given in dry meal form. In other instances, there may be conflicts between environmental and welfare objectives. For example, keeping animals on bedded systems allows better expression of foraging behaviour but can increase emissions of ammonia, and of greenhouse gases from bedding fermentation.

IMPLEMENTING KNOWLEDGE AND SOCIO-ECONOMICALLY APPLICABLE SOLUTIONS

A great deal of knowledge already exists on ways to improve welfare through nutrition, both directly by meeting known nutrient requirements and indirectly by addressing some of the issues associated with hunger. There are significant opportunities to improve welfare through application of this knowledge in the field, but a major challenge lies in promoting effective dissemination and motivating uptake. Animals are kept in a wide variety of socio-economic circumstances, and farmers therefore have different opportunities and motivations to improve animal welfare. Social science research to identify the most effective approaches for each situation would be of great benefit.

Knowledge dissemination depends on having advisors with appropriate competence. There is currently little overlap in education, and little dialogue, between people trained as nutritionists and those trained as animal welfare scientists. There is a need to educate nutritionists to understand animal welfare, including both physiological and psychological aspects, and to educate animal welfare scientists to better understand nutritional physiology, nutrient partitioning and the metabolic states underlying hunger. In this way integrated strategies to optimize both performance and welfare of animals could be more effectively developed and disseminated.

The knowledge base of advisers and farmers at local level also needs to be improved, particularly in regions of lower socio-economic status, so that they can understand nutrient values and correctly apply these under field conditions. This is particularly challenging in relation to the formulation of diets from diverse local ingredients, and particularly by-product ingredients, where scientific characterisation is scarce and variability is high. The development of quick and simple field methodologies for raw material evaluation would be of assistance in this respect. Examples might include simple flotation devices to assess specific gravity and dry matter content of liquid by-products, or colour charts to assess degree of thermal damage in heat processed materials. The parallel development of kknowledge transfer materials to disseminate such approaches could significantly reduce the extent of inappropriate diet formulation.

Finally, there is currently much wastage of valuable feed resources through poor storage and preservation. This gives great opportunity to improve the nutritional status of animals without the need to increase primary feed production. The challenge is to develop simple and affordable technologies without major structural or industrial requirements which can be applied in developing countries. Refinement of simple fermentation technologies is an obvious example. In this way seasonal variation in feed supply could be buffered and animals maintained in better nutritional state throughout the year. This offers the advantage of a correspondingly more regular supply of animal protein or financial income to the human population.

Guidelines and policy options promoting sustainable animal feeding that enhance animal welfare, animal productivity, animal product quality and profitability

In terms of policy, it is important to emphasize that welfare recommendations need to go hand-in-hand with profitability. Some proposed practices aimed at improving welfare might reduce levels of profitability. On the other hand, some interventions will increase the profitability, and these should be given priority.

In addressing the opportunities and challenges to promote welfare of animals through better nutrition, there is a need for integrated activity from governments, professional bodies, scientists, extension workers and industries to support the implementation of good practice by the farmers themselves. In many cases, although not all, nutritional approaches which improve animal welfare will also improve productivity, product quality and hence profitability. Examples include correct matching of diets to nutrient needs, good characterization and storage of raw materials, and identification of natural therapeutic substances. Such examples are easier to promote to farmers than situations where there is some conflict between enhancing animal welfare and maintaining profitability, for example the alleviation of chronic hunger or the provision of environmental enrichment.

Most importantly, there should be a concerted effort of scientists, politicians, farmers and food-chain industry to develop and validate indicators, in order to allow an international endorsement of specific acceptable minimum welfare standards related to nutrition. Some indicators should account for the life cycle of the long-term effects. Social knowledge about responsible farming practices that consider longevity, long-term performance, and overall life-cycle should be improved. Showing and promoting the positive relationship between animal welfare and production with respect to good nutritional programmes should be fostered through farm programmes and extension services.

For opportunities which were identified in the previous section, specific actions can be highlighted and the relevant actors identified.

ASSESSING AND ASSURING WELFARE

1) Inter-governmental organizations should foster the international endorsement of specific acceptable nutritional animal welfare indicators or parameters and minimum welfare standards related to animal nutrition. To harmonise basic minimum standards for welfare relating to nutrition, so that trade distortions do not result from initiatives for welfare improvement, international agreement should be sought regarding the status of certain contentious practices, for example forced moulting, force-feeding or very early weaning. This requires governments and relevant IGOs to enter into discussion with a view to formulating

and implementing international minimum standards. Similarly, an internationally orchestrated effort should take place to achieve an international endorsement of feed quality and safety standards involving the concerted effort of scientists, politicians, producer and the food chain industry.

2) To minimize mistakes due to inadequate implementation or transfer of technologies from different geographical regions and production systems, there should be a requirement of independent in-depth assessment (quality, impartial) of the welfare and performance impact of any foreign or new technology before it is adopted (for this, it is necessary that the research community agrees on validated and objective welfare indicators).
3) There is a need to foster industry certification requiring welfare acceptable practices whilst providing adequate knowledge and suitable technology. Donors and governments should support this process to achieve globally-recognized certification parameters in order to avoid misinformation by industry representatives, caused either by unawareness or commercial interest, and actively promote the distribution of knowledge. This could be tackled by training and certification of all persons providing advice on feeding.
4) To ensure and promote awareness of good practice in relation to the welfare consequences of feeding, appropriate nutritional standards should be incorporated into Quality Assurance schemes and independently assessed on a regular basis. This requires leadership from Quality Assurance bodies who set standards and implement assessments, and support from retailers and NGOs to promote goods produced under such Assurance to consumers.
5) A number of welfare problems in ruminants are elicited by the feeding of poor quality or unsafe feeds. There is a need for evaluation of feed safety, quality and provenance using agreed standards and protocols with the feed industry legally required to produce feed according to such standards.

UNDERSTANDING AND DEALING WITH CHRONIC OR SEVERE HUNGER OR THIRST

1) To understand the control of food intake and animals' perception of hunger, methodologies to measure affective state in relation to metabolic indicators should be developed. In doing this, it is possible to draw on knowledge from human studies, which benefit from the advantage that affective state can be verbalized. This is a task for scientists, supported by governmental funding bodies and industry. In applying this knowledge, there is then a need for better practical measures of hunger, malnutrition and undernutrition in order to evaluate animal welfare in the field. Once such measures exist, they can be implemented by veterinarians, extension workers or farmers themselves on a day to day basis. They can also be used to independently verify good nutritional practice by assessors in Farm Assurance programmes.
2) To minimize welfare impacts from disruption of feed and water supply, including the breakdown of automated systems which put large populations of animals at risk, more effective monitoring and alarm systems should be put in place. This requires technical development by engineers, manufacture and marketing of appropriate systems by industry and their purchase and operation by farmers. The capital cost should be at least partially offset by reduction in the current impact of such events on animal growth and performance. Because of

the welfare importance of this issue, it is appropriate for governments to consider whether a legislative requirement is justified.

3) To minimize the risk of hunger or undernutrition arising from certain farm practices driven by economic considerations, for example forced moulting of poultry or early weaning of piglets, there should be re-evaluation of the economic justification of such practices and development of more welfare friendly, but equally economically sound, alternatives to generate win-win situations. This requires the combined inputs of scientists and economists to develop solutions, extension workers to disseminate these solutions and farmers to apply them.
4) Matching diets to nutritional and welfare needs.
5) To ensure that those involved in the formulation and manufacture of diets and the provision of nutritional advice (e.g. nutritionists, feed company personnel, veterinarians) fully understand the welfare implications, both positive and negative, of their advice, welfare training should be provided as part of nutrition courses. This requires implementation by educationists in colleges and universities, and by professional bodies in schemes for continuing professional development. To transmit such knowledge at the appropriate technical level to ensure that farmers also understand the welfare implications of their decisions on feeding practice requires outreach activities by extension services, feed companies and veterinaries with whom the farmers have regular interaction and trust. In the previous years, there has been a generalized decrease in the extension activities of many governments. Government should assume more responsibility for the provision of advisory bodies and extension services using currently available technologies (e.g. web).
6) To promote understanding of the nutritional needs of animals under extensive and semi-intensive conditions, where feed ingredients are more variable and seasonal in supply, extension workers should be provided with the training and necessary tools for calculating balanced diets which take into account the available resources. Such tools might include tables of nutrient requirements for different genotypes and circumstances, tables of typical composition of the anticipated range of raw materials, and simple on-farm tests to fine tune estimation of their nutritional value, and diet formulation software utilizing these data. The financing and delivery of such training and tools should be the responsibility of governments, educational establishments and NGOs.
7) An important part of the information on raw material characterization will be the limitations on inclusion of certain ingredients because of the antinutritional factors that they contain. There should be a synthesis and dissemination of the available information on this subject by the feed industry and extension workers. FAO could play an important role in this through inclusion of such information in updates of their Factsheets, especially those for tropical plants.
8) Where diet analyses indicate nutritional deficiencies, which are particularly likely for micronutrients such as vitamins and trace elements, microfinancing institutions should empower their officers to support nutritional programmes by making available financing for the purchase of the (micro) supplements required to make balanced diets. These could improve animal welfare but also animal health, the efficiency of feed use and profitability of production.
9) To remove other sources of inefficiency in nutrient use, practices that increase nutrient uptake in the gut from ingested feeds should be encouraged. These

could include use of parasiticides and of enzymes which release nutrients otherwise unavailable to monogastrics, for example phytase which liberates bound phosphorus or carbohydrases breaking down indigestible non starch polysaccharides. To determine the (cost) effectiveness of such approaches, there should be research and practical surveys into the current levels of nutrient loss through malabsorption and the efficacy of different approaches to remedy this.

IMPLEMENTING KNOWLEDGE AND SOCIO-ECONOMICALLY APPLICABLE SOLUTIONS

1) Due to economic pressures, there is frequently a focus on short-term production goals which can affect the nutritional welfare of animals. Development and promotion of socially-responsible (ethically, economically, welfare, environmentally, quality and safety) production is required. Government, industry, donors – research, NGOs, national and international bodies should promote the uptake of indicators such as morbidity and mortality, minimizing the focus on short term production parameters by increasing the evidence base and distribution of knowledge of socially responsible and welfare-prone farming practices.
2) In the case of ruminants, a common welfare problem related to nutrition is the utilization of marginal lands for animal production. Poor land management, overstocking, and poor prediction of the impact of climate change on food availability pose a thread to ruminant welfare. To address this threat, there needs to be an integration of disciplines (soil management, agriculturalists, sociologists, pasture specialists, nutritionists and veterinarians) and a combined approach of knowledge transfer. Government should resume its responsibility to provide advice and policy on sustainable land management. Climate change policies may impact on animal welfare and should consider animal welfare. The trade offs should be considered when drafting recommendations
3) To ensure enough resources to provide an adequate regional feed supply for livestock in extensive systems, governments and community groups should develop and implement models to match the livestock population to the available feed materials. This needs to consider the seasonal fluctuations in feed availability and the ability to store and utilize raw materials to smooth out such fluctuations, or the strategically timed birth and slaughter of animals to most efficiently exploit seasonal surpluses. To maximize the use of scarce feed resources, there should be dissemination of best practice on storage to minimize nutrient loss, protect valuable but more labile components such as vitamins and maintain feed hygiene. Such dissemination activities could be facilitated by NGOs.
4) Within planning of regional food supplies, there should be contingencies which can ensure the provision of adequate resources to safeguard animal welfare under emergency conditions, such as climatic extremes causing floods, fires or crop failures, or breakdown of infrastructure in the event of conflict. Where feed supplies cannot be maintained, there should be plans for emergency slaughter of animals and salvage of the maximum amount of human food as part of this process. Such plans, and their implementation by governments and community groups, can be facilitated by NGOs, IGOs and donor groups.

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FAO HEADQUARTERS, ROME, ITALY, 26–30 SEPTEMBER 2011

Agenda

EXPERT MEETING ON IMPACT OF ANIMAL NUTRITION ON ANIMAL WELFARE

Facilitation Room A048

EXPERT MEETING ON IMPACT OF ANIMAL NUTRITION ON ANIMAL WELFARE

26–30 SEPTEMBER 2011

DAY 1: Monday, 26 September

09:30-10:00	Welcome coffee	
10:00-10:30	Welcome of participants	B. G. Tekola, FAO
	Introduction, objectives of the meeting and agenda	D. Battaglia and H. Makkar, FAO
10:30-11:00	Presentations of participants	All
11:00-12:30	Resource persons' presentations	
12:30-14:00	**Lunch**	
14:00-15:30	Presentations by Experts	Chairperson: S. Edwards
	Nutrition and cattle and sheep welfare	C. Phillips
	An update of nutritional factors affecting ruminants	G. Bertoni
	The interphase between nutrition and animal welfare in a number of farm species. Feeding behaviour and the consequences of restrictive feeding in pigs and poultry	B. Nielsen
15:30-16:00	**Coffee break**	
16:00-17:30	Presentations by Experts	Chairperson: C. Phillips
	Restricted feeding practices and alternative feeding systems to avoid hunger and on how nutrition can affect host resistance and resilience to parasitic infestations	B. Tolkamp
	Nutrition and welfare of dairy cattle: calves, lameness and metabolic aspects	A. Bach
	Food choice and nutritional well-being in livestock	J. Villalba
17:30–19:00	**Cocktail on FAO terrace**	

DAY 2: Tuesday, 27 September

09:00-11:00	Presentations by Experts	Chairperson: G. Bertoni
	Role of nutrition to prevent injurious behaviour in pigs	S. Edwards
	Decreasing stress, enhance poultry welfare and optimizing productivity through nutritional manipulations and improved human-animal interactions	I. Zulkifli
	The role of chemical and physical nutrition in rations designed to achieve sustained high standards of animal health and welfare in profitable systems of milk production	D. Beever
	Effects of feeding management on cattle productivity and welfare	M. Paranhos da Costa
11:00-11:30	**Coffee break**	

DAY 2: Tuesday, 27 September (cont.)

11:30-12:30	THEMATIC ACTIVITY 1: Identify feeding options for different livestock production systems (Extensive, mixed crop-livestock, and intensive) that improve animal welfare while increasing profitability of the livestock producers and ensuring safety and quality through the food chain *Work in two different groups focusing on: i) ruminant and ii) monogastric animals*	
12:30-14:00	**Lunch**	
14:00-15:30	Thematic activity 1 continues	
15:30-16:00	**Coffee break**	
16:00-17:00	Plenary: Presentation of the work on Thematic activity 1 by two groups and general discussion	All Chairperson: I. Zulkifli
17:00-18:00	THEMATIC ACTIVITY 2: Identify specific Case Studies that through nutrition-led improvements in animal welfare have also increased safety and quality of animal products, animal health and profitability of the livestock production systems [1] *Work in two different groups focusing on: i) ruminant and ii) monogastric animals*	

DAY 3: Wednesday, 28 September

09:00-10:30	Thematic activity 2 continues	
10:30-11:00	**Coffee break**	
11:00-12:00	Plenary: Presentation of the work on Thematic activity 2 by two groups and general discussion	All Chairperson: B. Nielsen
12:00-13:30	**Lunch**	
13:30-15:30	THEMATIC ACTIVITY 3: Identify challenges and opportunities to enhance animal welfare through animal feeding approaches[2] *Work in two different groups focusing on: i) ruminant and ii) monogastric animals*	
15:30-16:00	**Coffee break**	
16:00-17:00	Thematic activity 3 continues	
17:00-18:00	Plenary: Presentation of the work on Thematic activity 3 by two groups and general discussion	All Chairperson: J.Villalba
19:30	**Joint dinner**	

DAY 4: Thursday, 29 September

08:30-10:30	THEMATIC ACTIVITY 4: Prepare an outline of a technical document on the impact of animal nutrition on animal welfare[3]	All Chairperson: D. Beever
10:30-11:00	**Coffee break**	
11:00-12:00	Thematic activity 4 continues	

(cont.)

[1] The Experts and Resources persons are requested to prepare on this aspect before the meeting and come prepared with the specific Case Studies they are aware of. The aim is to publish these as a stand-alone FAO document in 2012.

[2] Including the identification of future research areas that provide better understanding of the linkages between animal nutrition and animal welfare (the experts and resource persons are requested to give serious thoughts to these issues before the meeting).

[3] It will comprehend state-of-the-art knowledge

EXPERT MEETING ON IMPACT OF ANIMAL NUTRITION ON ANIMAL WELFARE

26–30 SEPTEMBER 2011

DAY 4: Thursday, 29 September (cont.)

12:00-13:00	THEMATIC ACTIVITY 5: Draft guidelines and policy options promoting sustainable animal feeding that enhance animal welfare, animal productivity, animal product quality and profitability *Work in two different groups*	
13:00-14:00	**Lunch**	
14:00-15:30	Thematic activity 5 continues	
15:30-16:00	**Coffee break**	
16:00-18:00	Thematic activity 5 continues	

DAY 5: Friday, 30 September

08:30-10:30	Guidelines and policy options discussed and agreed in plenary	All
10:30-11:00	**Coffee break**	
10:30-12:30	Guidelines and policy options discussed and agreed in plenary (continues)	All
12:30 -13:00	Conclusions and closure of the meeting	B. G. Tekola
13:00	Departure of participants	

EXPERTS

Alex Bach (Spain)
David Beever (UK)
Giuseppe Bertoni (Italy)
Sandra Edwards (UK)
Birte Nielsen (France)
Mateus Paranhos da Costa (Brasil)
Clive Phillips (Australia)
Bert Tolkamp (the UK)
Juan Villalba (Argentina/USA)
Idrus Zulkifli (Malaysia)

RESOURCE PERSONS

Roland Aumüller, Globalgap
John Deen, World Veterinary Association (WVA)
Maria Ferrara, European Commission DG-SANCO
Miguel Angel Granero Rosell, European Commission, DG-SANCO
Uta Hesterberg , World Society for the Protection of Animals (WSPA)
Stefano Messori, Istututo G. Caporale, Teramo
James Moynagh, European Commission DG-SANCO
Lea Pallaroni, International Feed Industry Federation (IFIF)
Andrea Rosati, World Association for Animal Production (WAAP)

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