# The Future of Animal Feeding: Towards Sustainable Precision Livestock Farming

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## Summary

***Sustainable precision livestock farming*** is a way forward in a world in which pig production will increasingly be affected by many external factors. These include surging demands for meat and struggling supplies of feed raw materials, compounded by globalisation of trade and competition for natural resources. Simultaneously there is growing concern about food and its impact on health, and the impact of production methods on animal welfare and planetary resources. Throughout, producers are facing reduced profit margins. *Sustainable precision livestock farming* integrates the technological approach of precision livestock farming with the social and ecological aspects related with consumer and societal demands. Optimization of productivity and efficiency within the constraints of the concept are important objectives, as well as maximization of the profit for all stakeholders. Animal feed plays a crucial role as it is the biggest cost factor in pig production and at a critical junction in the chain. Several indicators demonstrate that further optimization of animal feeding is potentially still possible. The genetic potential is only partially utilized, the utilization of most nutrients appears to be low and there is a huge variation in performance among farms and, within farms, among pigs. New science and technologies seem to offer many opportunities for innovation in animal feeding. Key drivers for future innovation are basically (gen)omics, microsystem- and nanotechnology and information & communication technology (ICT). These mainstream technologies are the foundation of many application technologies of relevance for animal feeding. However, technology access and acceptance by consumers and society needs to be managed in a proper way.

In summary, the future of animal feeding will be dependent on the specific objectives defined when applying the concept of *sustainable precision*

*livestock farming*. The latter may become a 'licence to produce' for operators in the pork chain, will maximize profits and is required for 'feeding the future'.

## Introduction

The livestock sector, including pig production, is highly dynamic. However, dynamics seem to differ worldwide. In developing economies, the livestock sector is evolving in response to rapidly increasing demand for livestock products due to the human population growth, higher prosperity and urbanization. In developed economies, demand for animal products is stagnating, while many production systems are improving their efficiency and environmental sustainability. In the future, production will increasingly be affected by globalisation of the trade in feed commodities and livestock products, competition for natural resources, particularly land and water, competition between feed, food and biofuel, and by the need to operate in a carbon-constrained economy. Moreover, livestock production will be increasingly affected by consumer and societal concerns and legislation. There is considerable uncertainty as to how these factors will play out in different regions of the world in the coming decades (Thornton, 2010).

A way forward in the development of profitable modern pig production will be the concept of *sustainable precision livestock farming* (Den Hartog, 2009). This concept aims to integrate the technological approach of precision livestock farming with the social and ecological aspects related with consumer and societal demands. Optimization of productivity and efficiency plays a crucial role, as well as maximization of the profit for all stakeholders in the pork chain. In this paper, the necessity for and rationale behind the concept will be discussed, with a special focus on animal feeding.

## Animal Feeding at a Critical Junction

Animal feeding is at a critical junction in the pork chain, i.e. between crop cultivation and meat processing. Surging demands and struggling supplies result in stressed surroundings in which animal feed operators and farmers need to balance their activities continuously, taking into account animal requirements as well as customer, consumer and societal demands. As animal feed contributes to more than 60% of the total costs in pig production, and profits in the sector are usually under pressure, optimizing feed and feeding programmes have received and will receive much attention in order to maximize efficiency and optimize productivity.



## Surging Demands

The global livestock sector, including pig production, is characterized by a dichotomy between developing and developed economies. Total meat production increased between 1980 and 2010, from 45 to about 270 million tonnes. Much of this growth was concentrated in countries that experienced rapid economic growth, particularly in East Asia, and revolved around poultry and pigs. As a result, global growth in consumption of livestock products, including pork, per capita has markedly outpaced growth in consumption of other major food commodity groups. In developed economies, on the other hand, production and consumption of livestock products are now growing only slowly or stagnating, although at high levels (FAO, 2009a). In such markets surging demands are more related to quality, both in terms of product quality and safety, and production systems.

Around 1995 and 2007, developing economies had overtaken developed economies in terms of consumption and production of meat, respectively. Most of the increase in meat production and consumption has been from monogastrics; poultry meat production has been the fastest-growing subsector, followed by pork production. Increases from large and small ruminants have been much more modest. The result has been major changes in the composition of meat output globally, with significant differences between regions and countries (FAO, 2009a). Pork accounts for over 40 percent of global meat supplies, in part because of high levels of production and rapid growth in China, where more than half of world's pork production takes place (FAO, 2010).

By 2050, the world's population will reach 9.1 billion, 34 percent higher than today. Nearly all of this population increase will occur in developing countries. Urbanization will continue at an accelerated pace and will increase from 49 percent today to about 70 percent of the world's population. Income levels will be many multiples of what they are now. In order to feed this larger, more urban and richer population, food production must increase by 70 percent. Annual cereal production will need to rise to about 3 billion tonnes from 2.1 billion today and annual meat production will need to rise by over 200 million tonnes to reach 470 million tonnes. The growth in the future demands of livestock products will be almost exclusively seen in developing economies (FAO, 2009b).

It is expected that the number of pigs in the next decade will increase significantly but level off by 2020 and even may go down in the decades afterwards. In contrast, the number of poultry, and to much lesser extent large and small ruminants, will grow steadily until at least 2050 (Rosegrant, et al., 2009).

## Struggling Supplies

Basic food and feed commodity prices have shown a decline in the period from the early 1950s till about early 1990s. The trend lines since then have been steady, although there continue to be fluctuating patterns (Sarris, 2009). However, the food crisis of 2007-2008 shook up the sector and forced policymakers to review the drivers of agricultural commodity prices and the long-term demand and supply potentials of food worldwide. Not only internationally traded food and feed commodity prices for particularly oilseeds, cereals and meat were spiky; but the prices of crude oil, metals and fertilizer also increased manyfold from 2003 to 2008.

Several drivers that affected the food crisis of 2007-2008 have been analysed by many authors and think tanks around the world. They include:

- growing worldwide demand for basic food commodities due to fast and sustained economic and population growth in emerging economies, especially China and India,
- rising demand for cereals (corn in the U.S.A.), sugar cane (Brazil) and rapeseed oil (in Europe) for biofuel production,
- rising energy prices and strategic geopolitical concerns about the strong dependence of the economy on the oligopolistic fossil energy market,
- adverse weather conditions and rising temperatures attributed to global warming/climate change,
- a sharp decline in global food and feed commodity stocks, exacerbated by bad harvests in many regions around the globe, slowing rates of increases in farm productivity and under-investments in agricultural production and infrastructure over the past decade,
- negative effects of the financial crisis and economic downturn on the macroeconomy and stability of commodity markets and prices, and
- lack of investment in agriculture to improve productivity, especially in developing economies (Rabobank, 2010).

It may be expected that volatility in food and feed commodity prices and even struggling supplies due to scarcity will continue in the coming years and, as a consequence, affect pig production. This could even become more serious, because of trade barriers often caused by a lack of harmonized legislation and the great dependency on global sourcing. It should not be forgotten that producing the additional food needed to feed all people and livestock in 2050 will require a 9 percent expansion of arable land, a 14 percent increase in cropping intensity and a 77 percent increase in yields (FAO, 2009b).



## Meeting Consumer and Societal Expectations

In developed markets, consumer and societal expectations are changing rapidly. Prosperity, changing lifestyles and media attention have resulted in increased awareness and concerns, and new attitudes towards food (Grunert, et al., 2004; Perez, et al., 2009). These include both product quality and safety, and production systems. Governments are increasingly developing policies in these areas, many of which result in the more stringent regulation of pig production and a subsequent reconfiguration of existing production patterns. Even in the absence of regulations and standards, changes in consumer preferences for meat products due to lifestyle changes, food safety concerns, health perceptions, and other reasons, will increasingly affect production decisions in the future.

The main ecological issues associated with pig production concern water, soil and air pollution, climate change, land and water use, and biodiversity. Water pollution arises from the inappropriate disposal of pig manure. Nutrients in manure, principally nitrogen and phosphorous, are a significant component of pollution from agriculture to surface water, groundwater and marine waters, damaging ecosystems through eutrophication, drinking water suitability and degrading their recreational use. Water bodies can also be affected by organic effluents and pathogens contained in manure. Water pollution is more of a local or regional concern, although cross-border pollution can occur (OECD, 2010).

Soil pollution due to pig farming is often the result of the use of copper and zinc in diet formulations. Although most soil types are deficient in copper and zinc, land that has received repeated applications of manure might eventually accumulate excessive levels of these minerals, which are toxic to many plants and some foraging animals. Unlike excess land application of nitrogen and phosphorus, zinc and copper remain bound to soil and do not migrate to water supplies except during soil erosion. Therefore, accumulation may occur and will eventually result in a non-sustainable situation (Jongbloed and Lenis, 1992).

Air pollution includes odour, dust, ammonia and greenhouse gas emissions. Odour emission is the result of anaerobic microbial fermentation in the gut of pigs and in the manure pits. Together with dust emission it is a concern in densely populated areas. High levels of air-borne ammonia in pig houses adversely affect animal welfare and worker health. Moreover, it has been deemed responsible for acid rain and decreased biodiversity, and, as a consequence, affected the public perception (Aneja, 2006).

Attention to climate change is relatively new. The livestock sector currently contributes about 18% of the anthropogenic global warming effect. It is estimated that intensive pig and poultry systems are responsible for about one third of the total livestock contribution (FAO, 2006). The greenhouse gasses responsible include carbon dioxide, methane and nitrous oxide. Carbon dioxide emissions are partly the result of land use and land use change, e.g. deforestation, required for crop cultivation. Another source is from fossil fuel consumption used for the production and transportation of feed commodities and livestock products. Methane emission is from enteric fermentation and manure storage. Nitrous oxide is from manure, both during housing, storage and application (Blonk and Ponsioen, 2009).

The list of concerns is growing steadily and often restricted to certain markets. Animal welfare and viability of rural areas have received much attention in Europe and are nowadays part of the policies and regulations of the European Union authorities. In the Netherlands, the discussion on multiple antibiotic resistance, a major concern in public health care, has resulted in a gentlemen's agreement for the voluntary reduction of the use of veterinary antimicrobial agents in livestock sector up to 50% by 2013 (compared to 2009) and a ban on the production of medicated pig feeds by 2011. Moreover, the Dutch public debate on intensive livestock farming more or less prevents the expansion of individual pig farms.

## Towards *Sustainable Precision Livestock Farming*

Optimizing the productivity and efficiency of pig production, taking into account all customer, consumer and societal demands, is definitely vital for the future of the sector. Continuous improvement by innovation is nothing new and many steps have already been made in all parts of the chain. However, further steps are required to realize relevant objectives and to improve sustainability, in terms of people, planet and profit.

For the future of animal feeding the concept of *sustainable precision livestock farming* will become important. Precision livestock farming is seen as a way forward in a world in which there is growing concern about food and its impact on health and animal welfare and in which producers are facing reduced profit margins. It covers the life cycle management of animals, exploiting multiple identification and associate sensory and location technologies to optimize feeding and applying control to achieve objective yield factors, improved animal health and optimized usage of resources with respect to such factors. Moreover, traceability and information management is an integral part of the concept (BrightAnimal, 2010). With respect to animal feeding it aims to integrate relevant factors dealing with feed, animal, microbiota, farms and their interactions. *Sustainable precision livestock farming* integrates the technological approach of precision livestock farming with the social and ecological aspects related to consumer and societal demands. Optimization of



productivity and efficiency within the constraints plays a crucial role, as well as maximization of the profit for all stakeholders in the pork chain (Den Hartog, 2009).

## Potential for Improvement

Productivity and efficiency in pig production have increased tremendously in the last decades. In the Netherlands, the number of piglets raised per sow per year increased by more than 65%, the feed conversion ratio of fattening pigs improved by 20% and the nitrogen, phosphorous and ammonia emissions per hectare decreased by 50% in the period between 1975 and 2005. Several indicators demonstrate that further optimization of the productivity and efficiency in pig production is potentially still possible. The genetic potential is only partially utilized, the utilization of most nutrients appears to be low and there is a huge variation in performance among farms and within farms among pigs (Den Hartog, 2009). In pigs, the productivity is on average 30-40% below their genetic potential, because of suboptimal conditions and health status. Retention of nitrogen and phosphorous in fattening pigs is on average about 37 and 44%, respectively. Other nutrients seem to have even lower retentions, i.e. Cu and Zn between 2-7%; K, Na, Mg and Cl between 10-15%, and Ca 57% (Den Hartog and Sijtsma, 2008).

In addition to the nitrogen and phosphorous footprints, the carbon footprint of the pork chain, expressed as greenhouse gas (GHG) emissions, has the potential for improvement. Under Dutch circumstances, feed and farming contribute to about 61% and 37% of the total GHG emissions in the pig production chain up to the slaughterhouse, respectively (Kool, et al., 2010). It is estimated that by optimizing crop cultivation, feed composition and feed efficiency with existing techniques, the potential for reduction may be about 10%. The latter can be even higher in case of improved manure management. Although a lot has already been done in that area, methane and nitrous oxide emissions from pig manure still contribute significantly to the total carbon footprint, i.e. about 19% and 11%, respectively. A lower reduction potential is foreseen for the carbon footprint in industrial processing of feed materials and feed as these activities contribute only to about 2% of the total GHG emissions (Blonk and Ponsioen, 2009).

## Key Drivers for Innovation

Science and technology will offer opportunities for further innovation in pig production. Key drivers are basically (gen)omics, microsystem- and nanotechnology and information and communication technology (ICT). These mainstream technologies are the foundation of many application technologies and are characterized by different dynamics. Developments are radical in nutrigenomics and microsystem- and nanotechnology, and continuous in ICT. As a consequence, future implementation in pig production will follow the same dynamics.

With respect to *sustainable precision livestock farming*, and more precisely animal feeding, several application technologies have already shown their added value or have the potential to become the breakthrough technologies in innovation.

## (Gen)omics

### Recombinant DNA Technology

Some of the '-omics' technologies, such as genomics, have already been applied successfully in plant breeding. Genetic engineering based on such technologies has led to the rapid spread of genetically modified crops with specific agronomic traits, usually leading to higher productivity (yield per hectare). To date, the broadest application of GMO technology is patent-protected food crops which are resistant to commercial herbicides or are able to produce pesticidal proteins from within the plant, or stacked trait seeds, which do both. Most of the transgenic varieties grown today are known as first generation transgenics, because the transgenic trait provides benefits to crop farmers. Plants of the second generation may directly benefit the feed producers and pig farmers with nutritional enhancement, enzyme activity, immune enhancers or even natural antimicrobial substances. Currently, there is no such transgenic variety on the market (ISAAA, 2009).

### Fermentation

Another application of the 'omics' technologies is in industrial fermentation. Industrial fermentation is the intentional use of fermentation by microorganisms, such as bacteria and fungi, to make products useful for humans or animals. Fermented products or those derived from fermentation have several applications in animal feeding. Amino acids and enzymes are well known; both are crucial for optimization of pig performance. However, fermentation can also be used to upgrade raw materials. Digestibility of nutrients in general can be improved and the amino acid profile adapted closer to ideal patterns. In addition, biologically active compounds are often formed, which may have a positive impact on the health status of pigs (Niba, et al., 2009).



### Marker Technology

Currently, '-omics' technologies are also being successfully applied in animal breeding. The tools of molecular genetics are likely to have considerable impact in the future. For example, DNA-based tests for genes or markers affecting traits that are difficult to measure, such as meat quality and disease resistance, will be particularly useful. This will offer opportunities as there is a continuing trend in which pig breeding focuses on other attributes in addition to production and productivity, such as product quality, increasing animal welfare, disease resistance and reducing environmental impact (Leakey, et al., 2009).

### Nutrigenomics

The nutritional requirements of farm animals with respect to energy, protein, minerals and vitamins have a long research history. Initially, direct end points of animal performance, such as feed intake, body weight gain, feed conversion ratio, digestibility and health status have been used as indicators. More recently, indicators on cell and tissue level were introduced. As a result, amino acid catabolism, and immune, oxidative and intestinal health status can be measured nowadays. Nutrigenomic technologies, such as genomics (DNA level), transcriptomics (gene activity at mRNA level), proteomics (protein level), metabolomics (metabolite level) and epigenetics (phenotype and gene expression level caused by mechanisms other than changes in the underlying DNA sequence) enable to refine such measurements, in particular in combination with bioinformatics and systems biology. Bioinformatics plays an important role in meaningful integration and interpretation of data, and systems biology in mathematical modelling (Hendriks, 2009). The end result will be a precise determination of the nutrient requirement of a pig under the specific conditions, e.g. production phase, health status, farm management, and environment and social interaction. Alternatively, nutrigenomics also studies how feeds (nutrients, additives or other compounds) affect genes and gene expression. Nutrigenetics, another nutrigenomic technology, visualizes how genetic differences between individuals can affect the response to nutrients/compounds in the feeds (Smits et al., 2009). By using these techniques, it will no longer be necessary to look at extreme nutritional treatments, induced deficiencies, or long-term production responses to understand the basic effects of diets.

Bacterial nutrigenomics may offer opportunities in microbiota management. Microorganisms do play an important role as partners in pig existence as might be illustrated by the fact that the number of microorganisms is usually 10 times higher than the number of body cells. They not only provide pigs with vitamins K and B12 that their own genome cannot synthesize, microorganisms are also involved in the differentiation of the gut and its associated immune system. They can regulate the transcription of host genes involved in several important intestinal functions. Furthermore, gut bacteria feed on dietary nutrients, and on products excreted by the host. As was indicated by the positive effects of antibiotic growth-promoters on animal production results in the past, gut bacteria are not to be underrated as competitive consumers of feed ingredients. In addition, they can also digest compounds that are resistant to mammalian digestive enzymes. Digestion-resistant carbohydrates not only provide energy to bacteria in the large intestine of pigs, but by their degradation products, in particular organic acids, also to the host. Moreover, butyric acid, one of the organic acids from bacterial fermentation, stimulates gut epithelial cell proliferation and healing. Intestinal microorganisms are indispensable physiological partners for proper functioning of the host. However, the benefit for the host can turn into a disadvantage, when pathogens severely damage host cells due to their ability to interfere with the host's gene expression or physiology. Nevertheless, for the host the benefits of bacterial colonization by far outweigh possible disadvantages. Evidently, pigs and other mammals have co-evolved with bacteria so that their bodies do not develop properly without them. In addition, the intestinal microbiota in its totality is viewed as the first line of defence to pathogens, because of its competition with invading pathogens for space, cellular receptors and nutrients and their role in balancing the immune system (Smits et al., 2009). Although many aspects need to be exploited, bacterial nutrigenomics is seen as a breakthrough technology.

All these powerful (gen)omics tools will undoubtedly revolutionize the way we feed pigs and manage pig production systems. Nevertheless the real breakthrough will be middle and long term (Fekete and Brown, 2007; Brown and van der Ouderaa, 2007; Hendriks, 2009, Smits et al., 2009).

## Microsystem and Nanotechnology

### Biosensors

With respect to microsystem technology in relation to *sustainable precision livestock farming*, biosensor technology in particular may offer opportunities. A biosensor is an analytical device that converts a biological response into an electrical signal. The term 'biosensor' is often used to cover sensor devices used in order to determine the concentration of substances and other parameters of biological interest even where they do not utilise a biological system directly. The main requirements for a biosensor approach to be valuable in terms of research and commercial applications are the identification of a target molecule, availability of a suitable biological recognition element, and the potential for disposable portable detection systems to be preferred to sensitive laboratory-based techniques in some situations. Although it is already a multi billion dollar business, to date



applications in pig farming are limited. Nevertheless, there are many potential applications of biosensors of various types in pig production. In particular, the monitoring of macro- and micronutrients, additives, pathogens, contaminants and toxic metabolites in- and outside the animal may offer the possibility to fine tune performance in a well controlled environment. Moreover, it is a powerful tool in research (Luong, et al., 2008).

### Nanotechnology

Nanotechnology refers to an extremely dynamic field of research and application associated with particles of 1–100 nm in size (the size range of many molecules). Some particles of this size have peculiar physical and chemical properties, and it is such peculiarities that nanotechnology seeks to exploit. Nanotechnology is a highly diverse field and includes extensions of conventional device physics, completely new approaches based upon molecular self-assembly and the development of new materials with nanoscale dimensions.

Some food and nutrition products containing nanoscale additives are already commercially available, and nanotechnology is in widespread use in advanced agrichemicals and agrichemical application systems (Brunori, et al., 2008). The next few decades may well see nanotechnology applied to various areas in animal management. Nanosized, multipurpose sensors are already being developed that can report on the physiological status of animals. Advances can be expected in drug delivery methods using nanotubes and other nanoparticles that can be precisely targeted. Nanoparticles may be able to affect nutrient uptake and induce more efficient utilization of nutrients by pigs. One possible approach to animal waste management involves adding nanoparticles to manure to enhance biogas production from anaerobic digesters or to reduce odours (Scott, 2006). There are, however, considerable uncertainties concerning the possible human health and environmental impacts of nanoparticles and these risks will have to be addressed by risk assessment and regulation (Speiser, 2008).

## ICT

### Farm automation and full system control

ICT consists of all technical means used to handle information and aid communication, including computer and network hardware as well as necessary software. Although indispensible in the whole pork chain, ICT has led and will lead into a revolutionary development of farm automation and full system control. Both are necessary for optimization of productivity and efficiency, and can significantly reduce labour costs. Automated feeding systems enable precision feeding leading to less spoilage of nutrients, and together with automated climate control will result in better animal health and welfare, and higher pig performance.

### Near-infrared Spectroscopy

Another application of ICT of relevance for animal feeding is near-infrared spectroscopy (NIRS). Over the past 30 years, NIRS has proved to be one of the most efficient and advanced tools for continuous monitoring and controlling of process and product quality in food and feed production. Current applications of NIRS in feed production are dominated by quantitative assessments of macronutrients in both raw materials and end products. This can be done almost without sample preparation or the need for sophisticated laboratories, thereby saving time and reducing costs. The development of new applications and the improvement of existing applications is going fast - mainly due to improvements in ICT. The accuracy of nutrient measurements and energy levels is increasing rapidly and even the detection of certain micronutrients, undesirable substances and microorganisms seems to be feasible. Moreover, fingerprinting of raw materials and end products is becoming a powerful feed and food safety tool. ICT enables the continuous in-line measurement of nutrients in feed production and subsequent correction of the composition during the processing, resulting in higher predictability (Ozaki, 2006, Woodcock, et al., 2008). In combination with remote internet analysis (RINA), the management of NIRS network will become even more efficient as calibration support, data storage and operational knowledge can be focussed on one location while the equipment is installed at any place in the world.

### Dynamic Predictive Modelling

ICT is also the basis for dynamic predictive swine modelling programs such as Watson® 2.0 (Nutreco Canada, 2010). Such tools not only simulate nutrient requirements but also simulate responses to physical, social (health and feeding behaviour), economical and environmental changes. The new generation of predictive models focuses on nutritional optimization whereby solutions (e.g. requirements) are no longer static values solely based on biological responses (e.g. maximizing lean gain) but can also be expressed in terms of economic responses. The consequence of this process is that optimal nutritional, management and marketing solutions can be identified according to:

- specific farm conditions,
- genetics and health status,
- variable market and ingredient prices,
- processor-specific grading grids, and



- most importantly, producer-specific objectives (e.g. maximization of net profit per year or per place, minimize cost per kg of gain, minimize feed:gain, or minimize nitrogen and phosphorous excretion) (France and Kebreab, 2008).

## New Technology Access

Breakthroughs in technology will appear in many disciplines, in institutes, universities and companies, all around the world. For implementation in pig production it is of utmost importance to have access to such technologies. Researchers in pig production need to stay alert and should spend sufficient time on networking in completely other disciplines and searching the internet. An open innovation approach seems to be helpful. The central idea behind open innovation is that in a world of widely distributed knowledge, companies cannot afford to rely entirely on their own research, but should instead buy or licence processes or inventions (i.e. patents) from third parties. In addition, internal inventions not being used in a firm's business, should be taken outside the company (e.g., through licensing, joint ventures, spin-offs).

## Acceptance of New Technologies

Consumer trust and confidence is crucial for a successful implementation of new science and technologies in pig production. Much can be learned from the consumer reaction on the introduction of the first generation genetically modified (GM) crops in Europe. Although the European Union has one of the most stringent authorisation systems in the world and the European Food Safety Authority applies sound scientific risk assessments, consumer acceptance is still fragile even many years after the authorisation of the first GM event. GMO has therefore also become a political issue often resulting in a delay in the approval procedure and local trade barriers for approved GM feed commodities. In practice, import of feed commodities with traces of non-EU-authorised but safe products has nearly become impossible. The consequence for the European pig feed industry is that in 2009 it could not make use of US soybeans, corn and derivatives, which resulted in severe economic losses.

Managing consumer and societal acceptance definitely needs openness and transparency. Communication with interested stakeholders, corporate reporting and building relationships with citizens and organizations will be as important as the implementation of new science and technologies.

## Conclusions

Pig production has faced and will face many opportunities and challenges in the near future. The focus in the past was mainly on improving productivity and efficiency. This has led to profound structural changes in the pig production sector. These include: a move from smallholder mixed farms towards large-scale specialized industrial production systems, a shift in the geographic locus of demand and supply to the developing economies, and an increasing emphasis on global sourcing and marketing.

Although improving productivity and efficiency remains an important objective, consumer and societal demands need to be taken into account as well. The concept of *sustainable precision livestock farming* will become important. It integrates the technological approach of precision livestock farming with the social and ecological aspects associated with consumer and societal demands.

Animal feed plays an important role in the concept as it is the biggest cost factor in pig production. Moreover, animal feeding is at a critical junction in the pork chain, i.e. between crop cultivation and meat processing. Surging demands for animal products and struggling supplies of feed commodities have resulted and will result in stressed surroundings in which animal feed operators need to balance their activities continuously. Several indicators demonstrate that further optimization of the productivity and efficiency in pig production is potentially still possible. The genetic potential is only partially utilized, the utilization of most nutrients appears to be low and there is a huge variation in performance among farms and within farms among pigs. New science and technologies seem to offer many opportunities for innovation. Key drivers are basically (gen)omics, microsystem- and nanotechnology and ICT. These mainstream technologies are the foundation of many application technologies which sometimes have already been implemented successfully in pig production, including animal feeding. In the future, such technologies will certainly offer opportunities for innovation in all parts of the chain. However, technology access and acceptance by consumers and society needs to be managed in a proper way.

In conclusion, the future of animal feeding will be dependent on the specific objectives defined when applying the concept of *sustainable precision livestock farming*. The latter is a way forward in a world in which production will increasingly be affected by surging demands and struggling supplies, globalisation of trade, competition for natural resources and a growing concern about food and its impact on health, animal welfare and the planet, and in which producers are facing reduced profit margins. It may become a 'licence to produce' for operators in the pork chain, will maximize profits and is required for 'feeding the future' (Nutreco, 2010).



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