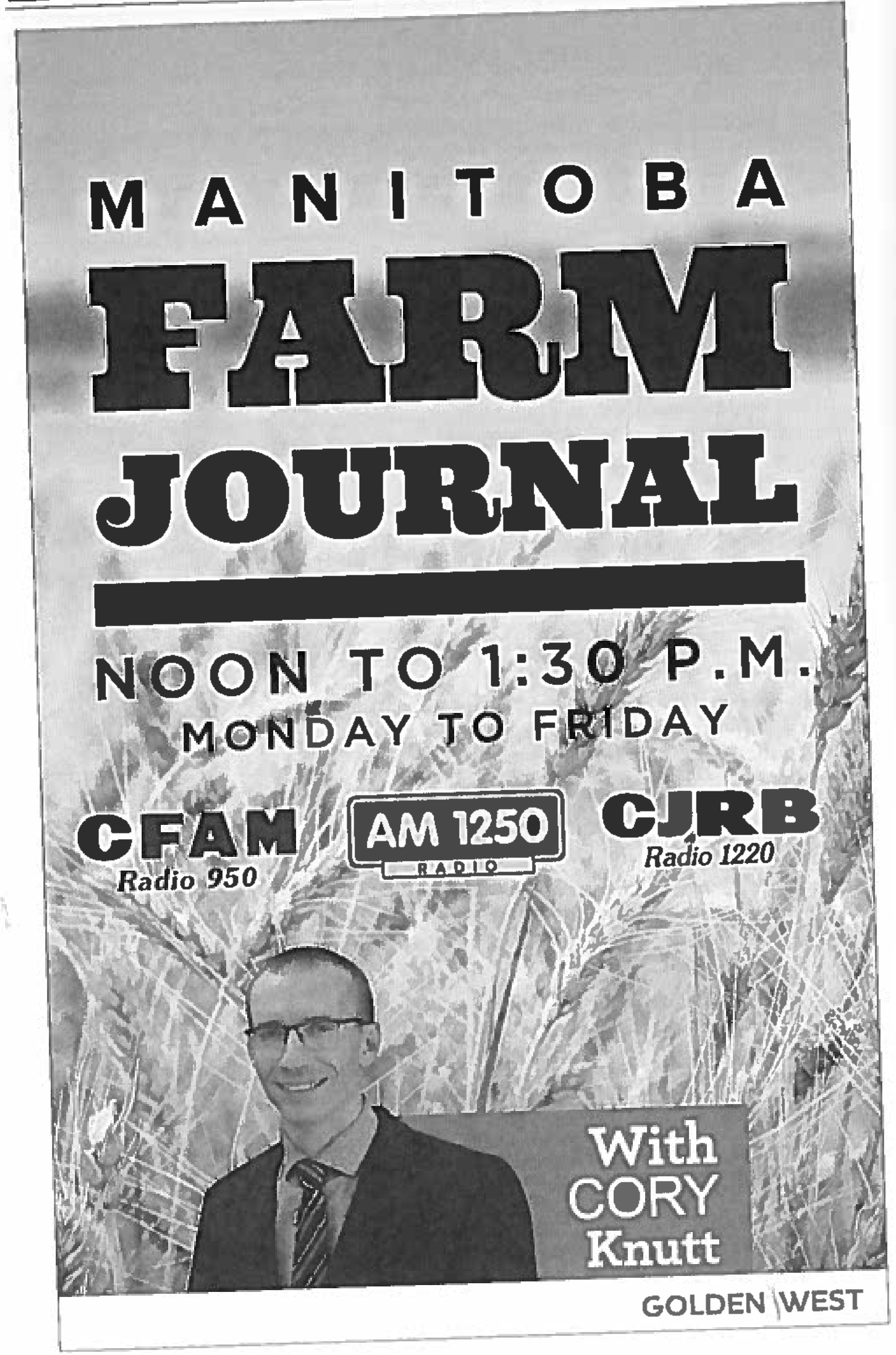

PRECISION NUTRITION CAN SIGNIFICANTLY REDUCE FEED COST BY IMPROVING NUTRIENT EFFICIENCY AND REDUCING N AND P EXCRETION

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Introduction

Precision livestock farming is an innovative production system approach, which is based on intensive and integrated use of advances in animal sciences and in the new technologies of information and communication. Its main objective is the on-line continuous and automatic monitoring of animals to support farmers in the management of animal production such as feeding strategies, control growth rates, and health management (Berckmans, 2004). A relevant contribution in this regard of precision pig farming is the development of precision feeding systems (Niemi *et al.*, 2010; Pomar *et al.*, 2015; Andretta *et al.*, 2016), which lays the basis for addressing key issues in today intensive livestock farming which are:

(1) reducing feeding costs by improving feed and nutrient efficiency

(2) improving production system sustainability by increasing profitability and reducing production footprints

(3) increasing food safety through traceability and

(4) improving animal health by the automatic monitoring of individual animals and the responsible use of antibiotics.

The development of sustainable precision pig farming, and in particular precision farming, requires a better understanding of the natural variability that exit among individual animals in terms of their physiological, behavioural and production responses. This paper presents briefly the key elements required for the development of sustainable precision livestock farming and recent results on the application of this production approach.

[1] This paper is an updated version of a previous one published as Pomar, C., and J. Pomar. 2012. Sustainable Precision Livestock Farming: A Vision for the Future of the Canadian Swine Industry Advances in Pork Production (2012) No. 23. pp 207-213.

Precision feeding

Feed costs are by far the greatest input cost in pork production (65-75%) and improving feed efficiency has great impact on profitability. In growing-finishing pig operations, feeding programs are proposed to maximize population responses at minimal feed costs. However, nutrient requirements vary greatly between the pigs of a given population (Pomar *et al.*, 2003; Brossard *et al.*, 2009; Hauschild *et al.*, 2010) and for each pig these requirements change over time following individual patterns (Hauschild *et al.*, 2012). In order to optimize population response, nutrients are provided at levels that satisfy the requirements of the most demanding pigs of the herd, with the result that most of the pigs receive more nutrients than they need to express their growth potential (Hauschild *et al.*, 2010). This is because for most nutrients, underfed pigs exhibit reduced growth performance while overfed ones exhibit near optimal performance. In the context of feeding groups of pigs, nutrient requirements should be seen as the balance between the proportion of pigs that are going to be overfed and underfed (Hauschild *et al.*, 2010), acknowledging that this proportion will change within each feeding period.

Precision farming or precision agriculture is an agricultural management concept that relies on the existence of infield variability. Precision feeding is based on the fact that animals within a herd differ from each other in terms of age, weight and production potential and therefore, each has different nutrient requirements. Precision feeding involves the use of feeding techniques that allow the right amount of feed with the right composition to be provided at the right time to each pig in the herd. Essential elements for precision feeding in livestock production systems include (Pomar *et al.*, 2015),

- the precise evaluation of the nutritional potential of feed ingredients,
- the precise determination of nutrient requirements,
- the formulation of balanced diets that limit the amount of excess nutrients, and
- the concomitant adjustment of the dietary supply and concentration of nutrients to match the evaluated requirements of each pig in the herd.

After the nutritional potential of feed ingredients has been determined and has been improved by the addition of enzymes (e.g., phytases) or feed treatments, the nutrient requirements of animals should be precisely estimated. When applied to pig populations, nutrient requirements are defined as the amount of nutrients needed for specified production purposes such as optimal growth rate and protein deposition (Hauschild *et al.*, 2010). Furthermore, this definition should be considered in the context of feeds provided to heterogeneous populations over long periods (Ferguson *et al.*, 1997; Knap, 2000; Pomar *et al.*, 2003). Nutrient requirements of a given population are affected by factors related to the animal (e.g., genetic potential, age, weight and sex), the feed (e.g., nutrient composition, digestibility and anti-nutritional factors) and the environment (e.g., temperature and space allowance) (Wellock *et al.*, 2004). Because of the complexity of animal responses and the many factors modulating these responses, mathematical models are proposed to simulate animals' growth and estimate nutrient requirements (van Milgen *et al.*, 2008; NRC, 2012). These models are calibrated in relation to a reference population to ensure that the levels of nutrients optimizing animal responses are adequately estimated. These models are, however, challenged by the difficulty of identifying the right reference population for its calibration, the inadequacy of most of these models to represent population heterogeneity and the fact that animals from actual populations may follow different feed intake and growth patterns than the ones observed in the reference population.

Because animals within a herd have different nutrient requirements to estimate the optimal level of nutrients to be provided to a group of pigs at a given time, or during a given period, is difficult to estimate. In fact, there are two important sources of variation that should be controlled to improve animal production efficiency. These sources of variation are the variation between animals within the group and the changes in individual or group nutrient requirements over time. These two sources of variation are identified as animal-dependent and time-dependent sources of variation.

Phase feeding is used to address the time-dependent variation in nutrient requirements and it is implemented by supplying nutrients to the evolving requirements of a growing pig population. Phase feeding involves feeding a number of successive diets, each differing in protein, energy or amino acid content, to match the requirements of the pigs, normally at the beginning of each feeding phase (NRC, 2012; Pomar *et al.*, 2014). The economic and environmental benefits of this concomitant nutrient adjustment increase with the increase in the number of feeding phases (van der Peet-Schwering *et al.*, 1996; Letourneau Montminy *et al.*, 2005; Pomar *et al.*, 2014; Joannopoulos *et al.*, 2015). Blend feeding has been proposed to reduce the costs of feed storage and management when the number of feeding phases increases (Feddes *et al.*, 2000). Although increasing the number of feeding phases should have little effect on animal performance, daily phase feeding compared to a three-phase feeding program can reduce in growing-finishing pig protein intake by 7% and N excretion by 12% (Pomar *et al.*, 2014). Further improvements of phases feeding on nutrient efficiency are limited by the large nutrient requirements variability that exists between the pigs in commercial farms.

Precision feeding is proposed to alleviate the limitations of actual feeding systems in which optimal dietary nutrient levels are determined *a priori* and served to heterogeneous populations during specified periods of time. Controlling the animal- and time-dependent sources of variation on nutrient requirements can further help the reduction of nutrient intake and excretion. The conceptual basis of the practical application of precision feeding was described (Pomar *et al.*, 2015) and then implemented in a mathematical model estimating individual pig's nutrient requirements in real time (Hauschild *et al.*, 2012). This model was calibrated in two animal trials (Zhang *et al.*, 2011; Zhang *et al.*, 2012; Cloutier *et al.*, 2015) and the overall approach of estimating real-time amino acid requirements had been challenged in two validation trials (Andretta *et al.*, 2014; Andretta *et al.*, 2016). This model further updated and will soon be evaluated in commercial conditions. Andretta *et al.* (2014) and (Andretta *et al.*, 2016) showed that daily adjustment of the diet to the requirements of each pig of the herd resulted in a 27% reduction in total lysine supply, without detrimental effects on growth. This additional 20% reduction in lysine intake in relation to group-fed pigs could be obtained by feeding the animals individually and thus controlling simultaneously the time-dependent and the between-animal variation. Although feed cost reduction depends to a great extent on feed prices, it is expected that feed cost can be reduced by 1-3% when only controlling the time-dependent variation while a 8-10% reduction can be obtained when controlling both sources of variation.

Managing feeds and animals by advanced computerized technologies

The proposed sustainable precision livestock farming system automatically collects in real-time individual feed intake and body weight information. This information is used to estimate optimal nutrient concentration of diets to be given daily to each pig of the herd using new modelling approaches. To this end, new automatic and intelligent precision feeders (AIPF) are under development. This feeder identifies each pig when its head is introduced into the feeder, and the feeds are blended according to the estimate lysine requirements of the day and delivered upon the animal request. A serving consists of the amount of feed delivered at each animal request. A time lag is imposed between servings to ensure that pigs ate each serving before requesting a new one. Serving size is progressively increased during the growing period and ranges from 15 to 40 g. The amount of feed served during each feeder visit is considered a meal. Pigs tend to leave the feeder hopper empty or with very small amounts of feed after each visit. This ensures that each pig received the assigned amount of blended feed. A decision support system (DSS) under development will control the AIPF using artificial intelligence technologies, modified feed formulation programs, mathematical growth models, actual scientific and technical nutritional knowledge, optimization algorithms and advanced database software and analysis techniques. Feeding pigs individually with daily tailored diets formulated based on its own real-time patterns of feed intake and growth represents a fundamental paradigm shift in pigs feeding. Besides the fact that animals are fed individually, the application of precision feeding techniques in growing-finishing operations implies that optimal dietary nutrient concentration is no longer a static population characteristic, but a dynamic process that evolves independently for each animal modulated by its own intrinsic (e.g., genetics, health, nutritional status) and extrinsic (e.g., environmental and social stressors, management) driving forces.

The proposed DSS will know past nutrient intake and growth patterns of each pig. Available scientific knowledge and available new technologies of information and communication offer many new opportunities to improve the sustainability of the Canadian swine industry. For example, real-time individual pig information can be processed for early identification of changes in individual feed intake patterns, which can be an indication of animal sickness, feed inadequacies or growth disorders. Early identification of diseases can significantly contribute to reducing the utilization of antibiotics, reduce veterinarian costs and the negative impact diseases on animal performance.

Information technologies allow real-time farm information to be available and the DSS be controlled, off-farm. Actual and forecasted feed consumption and body weight of individual animals can be analyzed and used for optimal slaughter strategies. Feed and nutrient efficiency will be known in real-time and feeding programs can then be

established and programmed off-farm according to the production objectives. These objectives can be established in relation to the animal (e.g., maximal growth rate, protein deposition, minimal fatness) to the farm (e.g., minimal feed costs per kilogram of gain, maximal pigs per year) or to the environment (e.g., controlled nutrient excretion and footprint).

Conclusions and perspectives,

The practical implementation of sustainable precision livestock farming requires the design of new feeding equipment and computer software. The implementation of these systems presents, however, significant challenges that are related to their complexity, reliability and cost effectiveness. Actual ongoing projects supported by Canadian Swine Research and Development Cluster initiatives have been planned to perform the required animal studies to optimize the formulation of premixes, to develop numerical strategies for early identification of changes in individual feed intake patterns, to update and calibrate the actual model used for real-time prediction of amino acid and phosphorous requirements and evaluate the technical, economic and environmental impact of precision feeding in Canadian commercial farms.

Precision livestock farming is proposed to the Canadian swine industry as an essential tool to enhance sustainability and competitiveness. For this purpose, innovative feeding systems controlled by effective decision support systems are developed to,

A. Feeding pigs within a herd according to their individual daily nutrient requirements to:

   (1) reduce feeding costs by reducing expensive (protein, phosphorous and others) excess nutrient supply;

   (2) reduce feed fabrication, storage, management and shipping costs by using the same premixes to all farms; and

   (3) reduce nitrogen, phosphorous and other polluting manure constituents and thus the soil surface required for manure applications.

B. Managing feeds and animals by advanced computerized technologies to:

   (1) allow real-time off-farm monitoring of feeds and animals for optimal slaughter and production strategies;

   (2) reduce labour requirements and costs by automatic monitoring and management of feeds and animals; and

   (3) allow early identification of diseases and precise application of individual treatments, thus improving herd performance and reducing veterinarian costs.

C. Allowing easy application of optimal production strategies within each herd to:

   (1) automatically manage individual feed supply (e.g., *ad libitum* or restricted feeding) and composition (e.g., providing higher levels of phosphorous to future reproduction gilts, limiting or enhancing fatness to market pigs.) to

manipulate growth rates and composition of each pig to address specific production or target markets;

(2) facilitate the evaluation of new feeds and feed sub products; and

(3) facilitate the determination of nutrient requirements.

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