Chapter 9

Genetic Technology, Sustainable Animal Agriculture and Global Climate Change

John P. Phillips, Professor Emeritus,

Department of Molecular and Cellular Biology,
University of Guelph, Ontario, Canada

World food demand is expected to more than double in the next 50 years. During this time, our planet will likely undergo dramatic climate change that will impose new challenges on our capacity to maintain even current levels of food production let alone meet the anticipated demand. All of us at this conference were born and raised during the last century when the globe experienced a doubling of the human population. Little did we know then how our lives would depend on the remarkable increase in global food production that characterises that century, an increase underwritten by astonishing advances in genetics and agricultural science. Nor did we realise that the 20th century expansion of the global larder came at such great environmental cost, a cost born largely by the conversion of natural ecosystems to agriculture with the resulting destruction of the essential services those ecosystems provide. Genetics has always been the currency for assuring population success in changing environments. Although technology alone will be insufficient, the development and application of new advanced genetic technologies will be absolutely necessary to feed the world our children and grandchildren will know as their own. The Enviropig™ *represents a model of environmental-genetic innovation with the potential to dramatically enhance the sustainability of animal agriculture in an increasingly hungry world intoxicated by its own waste.*

The global environmental challenge

> "During the next 50 years…, demand for food by a wealthier and 50% larger global population will be a major driver of global environmental change. Should past dependences of the global environmental impacts of agriculture on human population and consumption continue, 10^9 hectares of natural ecosystems would be converted to agriculture by 2050. This would be accompanied by 2.4-to-2.7 fold increases in nitrogen- and phosphorus-driven eutrophication of terrestrial, freshwater, and near-shore marine ecosystems…. This eutrophication and habitat destruction would cause unprecedented ecosystem simplification, loss of ecosystem services, and species extinctions. Significant scientific advances and regulatory, technological, and policy changes are needed to control the environmental impacts of agricultural expansion." (D. Tilman *et al.*, 2001)

Although the Green Revolution has seen a doubling of global grain production in the last 35 years, it has done so at high environmental cost. In their landmark paper, David Tilman and colleagues (2001) present a convincing but sobering forecast of current and future agricultural impacts on global ecosystems. Agriculture impacts ecosystems through (i) the generation of greenhouse gases, (ii) the consumption and release of limiting resources like N, P and water that affect ecosystem function and (iii) the conversion of natural ecosystems to agriculture. Tilman *et al.* (2001) predict that these sources of global transformation could rival those arising from climate change in environmental and societal impacts. Clearly, the status quo in agriculture cannot continue; an environmentally sustainable revolution (Conway, 1997) is needed.

Global pork production

Pork is one of the principal global sources of dietary animal protein (43% Pork, 27% Poultry, 26% Beef/veal, 4% Other). By 2004, world pork consumption had reached approximately 15.9 kg/person/year, having risen from 9.2 kg/person/year in 1970, and is predicted to reach 17.9 kg/person/year in 2015. The top five consumer countries (China, European Union, United States, Brazil and Canada) consume 76.1% of global pork production while the top 20 countries consume 93.7%. If the predicted consumption of 17.9 kg per person per year in 2015 is reached, pork production will need to grow to 130 Mmt (Roppa, 2005). To support the 2004 level of consumption a global swine herd totalling 1.278 billion will be required, with China contributing over half of this total at 622 million, the EU 246 million, USA 103 million, Brazil 38 million and Canada 23 million, to list the top five.

Pigs and phosphorus pollution

Phosphorus pollution is one of the greatest threats to freshwater and marine environments. Animal waste is a leading source of phosphorus pollution from agriculture (Jongbloed and Lenis, 1998), and its effect exceeds that of inorganic fertilisers or other anthropogenic fluxes (Smil, 2000). In the USA alone, over 100 mt of animal manure is produced annually with the liberation of 1 mt of phosphorus into the environment each year (Walsh *et al*., 1993). Freshwater eutrophication degrades the quality of drinking water creating an offensive taste and odour (Smil, 2000). Increased nutrient inputs into near-coastal waters cause serious environmental degradation that is a major threat to coastal environments upon which large populations in developing countries depend for survival (Jickells, 1998; Harvell *et al*., 1999; Jackson *et al*., 2001).

As so starkly demonstrated by Tilman (2001), "…the demand for food by a wealthier and 50% larger global population over the next 50 years will be a major driver of global environmental change." Moreover, the effects of food shortages are compounded by decreasing availability of unpolluted potable water. Given past experience, limitations on the availability of potable water in the future will be compounded and exacerbated by more intensive agricultural activities (Tilman *et al*., 2001). A large part of this pollution is expected to rise from increased production of monogastric food animals, pigs and poultry, primarily in developing countries (Delgado, 2003), but contributions will come from other food animals as well. Pig production in developing countries has increased at a linear rate of 10% per year since the early 1970s while pig production in developed countries has remained comparatively constant over the same time period.

Because the burden of increased food demand is certain to be borne largely by monogastric food animals, a major effort should be made to increase the capacity of these animals to utilise dietary nutrients more efficiently. As with other human-caused burdens, the best way to reduce the phosphorus impact of animal agriculture is to minimise the inputs at source. The production of food animals will continue to be a key contributor to the agricultural economy in developing countries, and depending upon geographic location the challenges will include one or all of the following: (i) production of sufficient animal feeds, (ii) prevention and treatment of animal diseases, and (iii) development of systems to reduce pollution from animal waste. Meeting these objectives will require innovations at many different levels and at many different points in diverse animal production systems.

Enhancing phosphorus utilisation and reducing P output in pork production

Cereal grains such as corn and barley, and plant-based protein supplements fed to pigs and poultry contain upwards to 80% of their P in the form of *myo*-inositol hexakis dihydrogen phosphate (phytate) complexed with minerals (Jongbloed and Kemme, 1990). Pigs do not digest P in this form, instead it is concentrated in the feces by a factor of three- to four-fold (unpublished data). As a consequence of the poor digestibility of P in cereal grains, supplemental phosphate is included in the ration to meet the dietary requirement for optimal growth. The resulting high P manure makes an excellent fertiliser when properly applied to P-depleted soils. However, when the P concentration exceeds the retention capacity of the soil, P leaches rapidly into normally phosphate-limited freshwater and marine systems causing eutrophication (nutrient enrichment with subsequent algal growth) with the death of fish and aquatic animals, and impacting on water quality (Diaz, 2001; Jongbloed and Lenis, 1998). Animal waste is a leading source of phosphorus pollution from agriculture (Jongbloed and Lenis, 1998) and its effect exceeds that of inorganic fertilisers or other anthropogenic fluxes (Smil, 2000).

Consequently, reducing the fecal and urinary output of nutrients from pigs is a clear and urgent requirement. To achieve this, several different approaches can be taken, including (i) formulation of rations to avoid exceeding the dietary requirements of the animal, for example, reduction of the concentration of supplemental phosphate in rations (Shen *et al*., 2002), or replacement of a portion of the crude protein by essential amino acids (Lenis *et al*., 1999); (ii) improvement in feed digestibility by addition of supplemental enzymes including phytase (Simons *et al*., 1990) or β-glucanase and xylanase (Bedford and Schulze, 1998); (iii) feeding of more digestible cereal grains, for example, low phytate cereal grains (Sands *et al*., 2001) and (iv) establishing genes in the host that enhance the metabolic potential of food animals (Ward, 2000). The expression of genes coding for novel enzymes in food animals constitutes a rational strategy for enhancing digestive capabilities. Development of the Enviropig™ represents the leading edge of a revolution that will ultimately change the pork industry, and directly tackles the elusive goal of producing animals with markedly reduced environmental impact.

The Enviropig™: a genetic technology for meeting the global environmental challenge

The Enviropig™ is a trademark for pigs expressing the PSP/APPA salivary phytase transgene. The generation of pigs expressing this transgene has been described in detail (Golovan *et al*., 2001a and 2001b) and is the subject of recent reviews (Forsberg *et al*., 2005; Forsberg *et al*., 2003). From 33 initial independent founder lines carrying the transgene, several lines were selected for further development and testing. Selected data will be used here to illustrate the efficacy of the transene in these lines. For example, hemizygous weanling and growing-finishing pigs from the WA line tested for true digestibility of dietary P in soybean meal as the sole source of P using an ileal cannulation methodology (Fan *et al*., 2001) were found to digest 88% and 99%, respectively, of the dietary P, as compared with non-transgenic pigs that digested 49% and 52% of dietary P, respectively (Golovan *et al*., 2001b). Fecal matter from the weanling and growing-finishing hemizygotes contained 75% and 56%, respectively, less P than that of non-transgenic pigs fed the same diet. Because the transgenic phytase pigs digest practically all of the dietary P, the residual P entering the terminal ileum of these pigs presumably consists primarily of differentiated enterocytes released from the mucosa during the process of continual epithelial regeneration (Ramachandran *et al*., 2000).

Boars and gilts hemizygous for the phytase transgene fed a conventional cereal grain diet lacking supplemental P during the finishing phase had fecal P concentrations that were 67% and 64% less than the corresponding non-transgenic pigs in the same trial (Golovan *et al*., 2001b). The initial observations on the G_o pigs have been reinforced by more comprehensive data obtained from feeding trials with other lines of phytase transgenic pigs. Although the amount of P excreted in the urine was not determined in the initial studies, more recent data on weanling, growing and finishing pigs shows that Enviropigs™ fed on diets without supplemental P excrete substantially less phosphorus in the urine than conventional non-transgenic pigs fed on diets containing supplemental P (unpublished data). It has been reported that urinary P accounts for 6%, 9% and 27% of P excreted by weanling pigs, growing pigs and sows, respectively (Poulsen, 2000). Overall, our combined urine and fecal P data from several lines of the Enviropig™ clearly demonstrates that pigs expressing the salivary phytase transgene digest and utilise virtually all of the phytate P in their diet throughout their growth to market weight. Moreover, recent studies demonstrate that when fed diets that do not contain traditional P supplements, Enviropigs™ perform equal to or better than their conventional counterparts fed on diets containing supplemental P as measured against commercial production indices such as rate of gain, reproduction, susceptibility to disease, and industry-standard carcass characteristics. Overall, the data predict that in settings of commercial production, total P output (urinary + fecal) from Enviropig™ herds will be at least 50% lower than that of conventional herds. By any measure, this represents a quantum phenotype of astonishing environmental potential in meeting the goal of environmental sustainability of animal agriculture.

The Enviropig[TM] provides a simple and reliable means for reducing the environmental impact of pork production. Although P is the third most expensive nutrient fed to pigs, the cost of phosphate is not a major constraint and overfeeding of this compound has been a common practice. However, in many jurisdictions, the land base for spreading of manure is a serious limitation. To assess the benefit of Enviropig[TM] genetics in terms of land area for spreading manure, we used the NMAN 2001 manure management computer simulation program developed by the Ontario Ministry of Agriculture and Food (*www.omafra.gov.on.ca/scripts/english/engineering/nman/default.asp*). Simulating a 350 sow farrowing-to-finishing pig operation, the spreading of manure from non-transgenic pigs on low-erodable soil theoretically requires 151 hectares to avoid application of excess P. Replacing conventional pigs with Enviropigs[TM] would reduce the land area required for manure spreading by 33% at which point manure N – not P – would become limiting. It is generally recognised that for each 1% decrease in crude protein in the diet there is an 8% to 10% reduction in manure N (Le Bellego *et al.*, 2001; Lenis and Jongbloed, 1999). Using the NMAN program to simulate the relationship between decreasing manure N and reduction in land required for spreading of manure, it can be shown that if the N content of the manure was reduced by up to 40%, the area of low-erodable soil required for spreading could be reduced by 60% (*i.e.* to 100 hectares), before P would be applied in excess.

Introducing the genetics for salivary phytase into swine herds around the world using artificial insemination will be relatively straight forward and has the potential to markedly reduce P-loading into the environment on a global scale. This represents the kind of quantum technology that will be required for animal agriculture to attain a sustainable global equilibrium. As a technology it is simple, effective and stable and requires little management. The Enviropig[TM] is on the leading edge of genetic advancements that will reduce the environmental footprint of animal agriculture through enhanced metabolic capacity. These pigs, and other transgenic animals under development elsewhere, must undergo safety and quality testing and approval in the country of origin and in countries to which the product is exported before being released into the marketplace. Such testing of the Enviropig[TM] is currently in progress.

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