Breeding Poultry for Environmental Performance: A Life Cycle-Based Supply Chain Perspective

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Introduction

The production of animal products is a key contributor to anthropogenic environmental change (Steinfeld *et al.* 2006). At the same time, the increasing prominence of sustainability concerns in governance discourse is serving to heighten awareness of the importance of improving environmental performance in animal husbandry systems. This is particularly true of the three largest livestock sectors: beef, pork and poultry. As of 2000, the poultry sector alone furnished 31% of global meat production volumes. By 2050, this proportion is anticipated to increase to 44% (FAO 2006). Poultry production is generally recognized as the most efficient, large-scale terrestrial animal production technology (Flachowsky 2002). Nonetheless, the magnitude of current and projected production volumes, along with the underpinning flows or resources and wastes mobilized, suggest that improving the ecological efficiency of poultry production (i.e. minimizing the material/energy and waste intensity per unit production) should be considered a priority objective.

Historically, much attention regarding the environmental dimensions of industrial-scale poultry production has focused on farm-level interactions. In particular gaseous emissions of ammonia and the attendant effects on local air quality and acidification concerns have been investigated by numerous researchers (for example, see De Boer *et al.* 2000; Ullman *et al.* 2004; Wheeler *et al.* 2006). Comparable to most industrial food production systems, however, contemporary broiler production is predicated on the existence of extensive, tightly coupled industrial supply chains. These supply chains furnish the requisite material and energy resources mobilized towards poultry production, process and distribute poultry products, and cycle the attendant manure and processing co-products back into agricultural and animal feed production streams. For this reason, only a limited subset of pertinent environmental interactions associated with poultry production are observable and manageable at the farm level. Accounting for and managing the broader environmental interactions of industrial poultry production thus requires a supply chain perspective, and analytical tools of commensurate scope.

Life cycle assessment is an ISO-standardized biophysical accounting framework which can contribute strongly to understanding and managing the environmental dimensions of poultry production from a supply chain perspective. Specifically, LCA can be used to: (1) characterize the flows of material and energy inputs and outputs associated with each stage

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of the poultry supply chain, and (2) apply a suite of peer-reviewed impact assessment methods to quantify how these flows, along with attendant waste emissions, contribute to a suite of resource and emissions-related environmental concerns. Such an approach facilitates the identification of key leverage points within existing supply chains for improving eco-efficiencies. It also allows for scenario modeling the implications of alternative management strategies. Moreover, since LCA affords the opportunity for assessing poultry production systems according to multiple environmental performance criteria, it allows for a nuanced understanding of tradeoffs associated with specific management interventions.

Poultry breeding has historically been undertaken primarily for economic motivations – in other words to improve animal performance in the interest of maximizing economic efficiency. In light of increasing recognition of the important contribution of livestock production to environmental concerns at local, regional and global scales, there is growing interest both in continuing to improve the ecological efficiency of poultry production as well as to manage the scale of the industry such that its resource and waste assimilatory demands do not transgress the carrying capacities of host ecosystems at all relevant scales. There is, hence, a sound rationale for orienting poultry breeding towards the express purpose of improving environmental performance in poultry production systems. The purpose of the present analysis is to discuss the relevance of life cycle assessment research of intensive poultry production systems to poultry breeding for environmental objectives.

Results and discussion

Life Cycle Perspectives on Environmental Performance in Poultry Production

Life cycle assessment is intended to provide a supply chain perspective on environmental performance. When applied to poultry production systems such analyses must therefore take into account the full complement of supply chain inputs and emissions at each life cycle stage of interest. For upstream processes, this must encompass the production of poultry feed ingredients, including fuel use for field operations and crop drying, the production of fertilizers/soil amendments, seed and pesticides, as well as emissions from fertilizers and crop residues to air, soil and water media. It must further include crop processing, the operation of reduction fisheries and fishmeal reduction pants, as well as feed input transportation and poultry feed milling operations. Other pertinent upstream nodes are the maintenance of breeder flocks and hatcheries. At the farm level, on-farm energy use, litter management, mortalities, and material use must be accounted for. Downstream of the farm, poultry product processing, which may furnish materials for poultry by-product meals and oils cycled back into the poultry feed production supply chain, must also be considered. Depending on the scope of the analysis, product packaging, refrigeration, and distribution might also be evaluated.

Life cycle assessment has already been used to characterize environmental performance in the US broiler supply chain (Pelletier 2008), as well as for alternative egg production systems in both the Netherlands (Mollenhorst *et al.* 2006) and the UK (Williams *et al.* 2006). It has also been applied to determining the comparative environmental impacts of feeding conventional versus GMO corn for broiler production in Argentina (Bennett *et al.* 2006). Pelletier and colleagues are currently working with the American Egg Board to characterize the life cycle environmental impacts of contemporary commercial egg production and processing systems in the Midwestern United States.

This research consistently underscores the pivotal importance of feed production in the life cycle impacts of both egg and broiler production. In other words, from a supply chain perspective, farm-level interactions are of much lesser importance to overall impacts than are activities occurring far from the farm site, along various nodes of industrial feed provision supply chains. For example, Pelletier (2008) found that feed provision accounts for 80% of supply chain energy use, 82% of greenhouse gas emissions, 98% of ozone depleting emissions, 96% of acidifying emissions and 97% of eutrophying emissions associated with the cradle-to-farm gate production of broiler poultry in the US. On-farm inputs and emissions, largely related to heating and ventilation contributed on average only 9% of these impacts. Similarly, Mollenhorst and colleagues (2006) reported that the production of concentrate feeds for broiler production in the Netherlands was responsible for 53% of acidifying emissions, 84% of eutrophying emissions, 82% of greenhouse gas emissions, 91% of land use and 79% of energy use. In contrast, other aspects of the supply chain, such as hatchery production and processing, contribute minimally to overall impacts.

Pelletier (2008) also showed that each input to poultry feeds commonly employed in the US was characterized by distinct patterns of resource use and waste emissions, with as much as an order of magnitude difference in impact intensities between ingredients. In combination, poultry fat, poultry by-product meal and fishmeal (which together comprised only 7.5% of the modeled feed by mass) contributed on average 41% across impact categories. Feed milling contributed only 6%. For this reason, the concept of least-environmental-cost feed sourcing is of particular relevance to managing the poultry supply chain for environmental objectives. Of the feed inputs modeled, it was found that crop-based inputs (corn and soy meal) had much lower impacts per unit production compared to fish-derived materials and meals and oils from rendered poultry by-products. This is consistent with more recent observations of Pelletier and colleagues (2009), who modeled a diverse suite of commonly sourced inputs to salmonid feeds globally. However, it was also noted that product categories were themselves characterized by large differences between ingredients, and overlapped with other categories at either extreme of the impact intensity spectrum. It was thus suggested that context-specific supply chain analyses will generally be desirable to inform effective, least-environmental-cost feed input sourcing and diet formulation (Pelletier *et al.* 2009). Moreover, formulation decisions need also be attentive to trade-offs among environmental performance variables, since gains in one dimension may come at the expense of losses in another.

Pelletier (2008) further observed that the primary production phase of feed inputs was generally a much more important determinant of impacts than were the processing and distribution components of feed input supply chains. For crop-derived inputs, crop nitrogen use efficiencies were of particular importance due to the resource and emissions intensity of producing and using nitrogen fertilizers.

Life Cycle Perspectives on Poultry Breeding for Environmental Performance Objectives

Given the prevalent role of feed provision in the supply chain environmental performance of poultry production, feed considerations are clearly key leverage points for breeding programs aimed at environmental performance improvements. Fortunately, this objective is very much in-line with the historical and current emphasis on maximizing feed conversion efficiencies. All else being equal, a lower feed conversion ratio will result in a poultry product with correspondingly lower environmental costs. However, all else will rarely be equal, hence, considerable nuance need be brought to bear.

As has already been seen, improved biological feed conversion efficiency will be of little merit if accompanied by increased mortality rates or decreased meat yield rates (Leenstra and Elhardt 1994). Also important, however, is that the environmental gains associated with increased feed conversion efficiency may be easily offset if more environmentally costly feeds are required. An illustrative example is provided by comparing recent work by Pelletier *et al.* (2009) on global salmon aquaculture production systems, and Pelletier and Tyedmers (2010) on tilapia aquaculture production in Indonesia. As carnivorous fish, the diets of farmed salmon contain, on average, 50% fish and livestock-derived materials. In contrast, intensively cultured tilapia are reared on diets which contain only a small (5%) fraction of fishmeal and oil. As a result of this difference, producing one tonne of salmonid feed is, on average, roughly twice as greenhouse gas intensive as is producing one tonne of tilapia feed. However, salmon production in Norway (the most efficient production region) achieves a feed conversion ratio of 1.1, whereas Indonesian tilapia are produced at a feed conversion ratio of 1.7. As a result, Norwegian farmed salmon is only 6% more greenhouse gas intensive than the farmed tilapia modeled.

For this reason, poultry breeding for improved feed conversion efficiency must take into account both the quantity and quality of feed inputs required per unit production. In other words, the required nutritional profile to obtain a specified level of performance for a particular genetic lineage must be considered, along with the environmental costs of the feed inputs necessary to achieve it. It should be remembered that market values are generally poor indicators of relative environmental costs, hence biophysical assessments such as LCA will be required to inform such considerations of comparative environmental outcomes. In general, where equivalent feed conversion efficiencies are achieved, poultry production predicated on crop as opposed to animal-derived feed inputs will prove environmentally superior. This is somewhat intuitive given the inefficiencies inherent to biological feed conversion, which serve to compound the impacts associated with animal-derived feed inputs.

Also of interest is the potential use of synthetic amino acids to obtain optimal nutritional profiles that maximize feed conversion efficiencies whilst reducing environmental costs. Binder (2003) used life cycle assessment to demonstrate the lower environmental impacts of using synthetic DL-methionine in place of DL-methionine from oil seeds in broiler meat production. It was suggested that the production of the former was one sixth as energy intensive as the latter. Further research is necessary to evaluate the environmental costs of the spectrum of synthetic amino acids compared to naturally-sourced equivalents, and how such substitution might stand to improve ecological efficiencies in poultry production.

Continued efforts to breed poultry for improved nitrogen use efficiency are also necessary. The mobilization and loss of reactive nitrogen is an important contributor to a variety of environmental concerns along the poultry supply chain. At the level of feed input production, the synthesis and application of nitrogen fertilizers comprises one of the most energy and emissions intensive aspects of agriculture. Emissions of ammonia from poultry houses are a priority concern for local air quality and acidification impacts. Storage and application of poultry manures to agricultural lands, whilst important for nutrient cycling, is also a critical vector for loss of reactive nitrogen species to air and water, which contributes to a spectrum of issues including climate change, acidification, and eutrophication effects. Poultry breeding programs aimed at optimizing performance on low protein diets, diets predicated on the use of appropriate synthetic amino acid profiles, or improved nitrogen retention in poultry products will therefore likely be instrumental to achieving environmental objectives. As reactive nitrogen mobilization and losses are subject to increasing regulation over time, this consideration will also become more important from an economic perspective. It should be noted, however, that many breeding objectives will be complementary to environmental performance improvement objectives, to the extent that they improve feed use efficiencies whilst minimizing waste. For example, breeding for improved disease resistance may simultaneously improve overall feed use efficiency through decreased mortality.

Beyond feed efficiency and composition concerns, there are of course other breeding objectives which might be exploited in the interest of environmental performance improvements. For example, breeding for improved temperature tolerance may serve to reduce farm-level energy use and emissions. For production systems in temperate climes, the small contribution of these elements from a supply chain perspective suggests that the environmental gains will likely be marginal relative to potential feed-related gains. Potential gains may be greater, however, in regions where farm-level energy inputs are higher.

A final point of interest here is the extent to which poultry breeding might serve to better position the sector for future conditions. Although poultry production is certainly the most efficient, large-scale animal protein production technology, it is also (like pigs) in direct competition for what are often human-edible feed resources. Hence, despite the high feed use efficiencies achieved relative to other terrestrial animal husbandry sectors, there is still generally a net loss of human-edible food energy. With increased demand for poultry products due to increasing population and affluence, in concert with increased competition for land for food, feed and fuel, there may be strong grounds for selecting for strains which perform well on diets not predicated on human-edible feed resources.

Conclusion

As the global poultry sector continues to expand rapidly over the next several decades, poultry breeding for environmental objectives must be increasingly emphasized. Given the highly industrialized nature of contemporary poultry production, which is served by extensive supply chains farm removed from poultry farms, it is imperative that any such breeding programs be sensitive to mitigating environmental burdens from a supply chain perspective. Life cycle assessment research provides a useful means of identifying necessary foci, and evaluating the efficacy of breeding outcomes for environmental performance objectives. In particular, breeding programs aimed at improved feed efficiencies, selection for performance on least-environmental-cost diets, and nitrogen use efficiencies should prove efficacious.

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