Poultry production and the environment – a review

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SUMMARY

Over the past decades, the poultry sector's growth and trends towards intensification and concentration have given rise to a number of environmental concerns. A direct consequence of these structural changes (industrialization, geographical concentration and intensification) in poultry production is that far more waste than can be managed by land disposal is produced, resulting in environmental problems. This paper analyses the environmental impacts arising from intensive poultry production, evaluating such impacts across the food chain and all environmental media. The paper also presents technical options to mitigate environmental impacts, such as improvements to farm management, animal-waste management and nutrition management, along with options to reduce the impacts of intensive feed production.

Key words: poultry, intensification, future, climate

1 INTRODUCTION

Over recent decades the poultry industry has made tremendous adjustments to meet the increasing demand for inexpensive and safe supply of meat and eggs. Over the past three decades, the poultry sector has been growing at more than 5 percent *per annum* (compared to 3 percent for pig meat and 1.5 percent for bovine meat) and its share in world meat production increased from 15 percent three decades ago to 30 percent currently (FAO, 2006a).

This growth has been accompanied by structural changes within the sector, characterized by the emergence and growth of "land-independent" (industrial) farming establishments, and the intensification and concentration of poultry operations. Pressure to lower production costs and increase supply has led to more efficient operations, made possible through the shift to larger, specialized and more integrated facilities, and through improvements in the use of animal genetics, optimized nutrition and new production technologies. The driving forces behind structural change in poultry production are no different than those that affect other livestock commodities: market pull, innovation and economies of scale. Innovation and economies of size that characterize the livestock sector have also served to separate animal production from crop production. Large, specialized facilities today focus on producing animals, and purchase most of their feed. This often means that there is limited access to land on which to spread manure.

The use of large facilities associated with higher concentrations of poultry, has given rise to environmental concerns that are not only limited to the local production settings, but extend to environmental problems at regional and global scales. The obvious, and often limited, impacts observed at production-site level, thus, tend to obscure much larger impacts on the regional and global environment. In this paper we therefore analyse the sector's impacts by zooming out across the three spatial scales. Furthermore, the use of a scale approach is a useful structure for the analysis of environmental impacts because it directly links the outcomes of the review to the policy interventions that are required at the various levels (farm to international).

This paper also adopts the food-chain approach, analysing the environmental impacts arising from poultry production, and evaluating such impacts all the way from feed production to animal production and slaughtering. It considers impacts on all environmental media – air, water and land, at local, regional and global scales. The issue of disease transmission from/to wildlife populations is, however, omitted as other papers in these proceedings discuss this topic.

The next section will give an overview of environmental issues at the level of production and processing (Section 2). We then present an in-depth analysis of the impacts of poultry production as the sector intensifies in certain preferred areas (Section 3). Section 4 deals with global environmental issues associated with the poultry sector. We then briefly present technical options (Section 5), followed by conclusions (Section 6).

2 ISSUES AT THE LEVEL OF PRODUCTION AND PROCESSING UNITS

This section provides an overview of environmental concerns at the local level, arising from two point sources: the animal production site and the abattoir. At this level, impacts are usually directly observed by farmers, neighbours and policy-makers.

2.1 Animal production units

Local disturbances (e.g. odour, flies and rodents) and landscape degradation are typical local negative amenities in the surroundings of poultry farms. Pollution of soil and water with nutrients, pathogens and heavy metals is generally caused by poor manure-management and occurs where manure is stored. Water and soil pollution related to poultry litter is, however, generally not an issue at the production site, as poultry manure is only directly discharged into the environment in exceptional conditions. Indeed, the high nutrient content and low water content of poultry litter make it a valuable input to agriculture. Manure is either recycled on cropland belonging to the animal farm or marketed. In the usual set-up, an intermediary or a processor collects manure from poultry farms. Manure is either resold rough or processed into compost or pellets. Manure products are used as fertilizer, or as animal feed especially for fish and cattle.

In south Viet Nam, the authors observed that end users may be located as far as 300 km from the animal farm where manure is produced. An intermediary will sell manure to the group of users with highest willingness to pay, which can change throughout the year, and from year to year, according to the cropping calendar and the economic conditions. Manure price at the animal-farm gate varies with its pureness (presence of litter) and water content and with the season (demand). On average, 20 kg bags of fresh chicken manure without litter are sold for VND4 000 to 6 000 while 20 kg bags of manure with litter are sold for VND1 500 to 2 000.[1]

Local disturbances

Poultry facilities are a source of odour and attract flies, rodents and other pests that create local nuisances and carry disease. Odour emissions from poultry farms adversely affect the life of people living in the vicinity. Odour associated with poultry operations comes from fresh and decomposing waste products such as manure, carcasses, feathers and bedding/ litter (Kolominskas *et al*., 2002; Ferket *et al*., 2002). On-farm odour is mainly emitted from poultry buildings, and manure and storage facilities. Odour from animal feeding operations is not caused by a single compound, but is rather the result of a large number of contributing compounds including ammonia (NH_3), volatile organic compounds (VOCs), and hydrogen sulphide (H_2S) (IEEP, 2005). Of the several manure-based compounds which produce odour, the most commonly reported is ammonia. Ammonia gas has a sharp and pungent odour and can act as an irritant when present in elevated concentrations.

Odour is a local issue, which is hardly quantifiable; the impact greatly depends on the subjective perception of populations neighbouring the farm. It is, therefore, difficult to evaluate the maximum distance over which odorous gas travels; however, odour problems are generally concentrated within 500 metres of the farm. Although generally not causing any public-health concern, odours can represent a strong local problem that is frequently reported by farms' neighbours as the most disturbing environmental impact. The emission of odours mostly depends on the frequency of animal-house cleaning, on the temperature and humidity of the manure, on the type of manure storage, and on air movements. For these reasons it is generally higher in waterfowl farms than in chicken farms.

Flies are an additional concern for residents living near poultry facilities. Research conducted by the Ohio Department of Health indicated that residences that were located in close proximity to poultry facilities (within half a mile[2]) had 83 times the average number of flies. In addition to the nuisance they cause, flies and mosquitoes can transmit diseases, such as cholera, dysentery, typhoid, malaria, filaria and dengue fever. Although less often reported than flies and mosquitoes, rats and similar pests are also a local nuisance associated with poultry production. As with flies and mosquitoes, they can be a vector for disease transmission. Their presence is mainly related to animal-feed management and especially to storage and losses from feeding systems.

Pesticides used to control pests (e.g. parasites and disease vectors) and predators have been reported to cause pollution when they enter groundwater and surface water. Active molecules or their degradation products enter ecosystems in solution, in emulsion or bound to soil particles, and may, in some instances, impair the uses of surface waters and groundwater (World Bank, 2007).

Land use and landscape

The trend to larger production units, and their regional concentration, certainly has the potential to adversely affect surrounding land use and the appearance of the landscape.

[1] VND = Vientamese dong.

[2] Approximately 800m.

Massive industrial poultry installations can create an adverse aesthetic impact. Impact on land use in highly concentrated areas is manifested through conflict with development needs and in some areas with rural tourism.

Poultry carcass disposal

Improper disposal of poultry carcasses can contribute to water-quality problems especially in areas prone to flooding or where there is a shallow water table. Methods for the disposal of poultry carcasses include burial, incineration, composting and rendering. In the case of recent highly pathogenic avian influenza (HPAI) outbreaks, the disposal of large numbers of infected birds has presented new and complex problems associated with environmental contamination. Large volumes of carcasses can generate excessive amounts of leachate and other pollutants, increasing the potential for environmental contamination.

Buried birds undergo a decomposition process. During this process, nutrients, pathogens and other components of the carcass are released into the environment. As these substances enter the surrounding soil, they may be broken down, transformed, lost to the air, or otherwise immobilized so that they pose no environmental threat. However, there is a possibility that some constituents may eventually contaminate soil, groundwater and surface water (Freedman and Fleming, 2003). Another related problem is the removal of manure from houses that contain infected birds.

Ritter *et al.* (1988) examined the impact of dead-bird disposal on groundwater quality. They monitored groundwater quality around six disposal pits in Delaware. Producers in Delaware were using open-bottomed pits for their day-to-day mortality disposal. These pits are not strictly the same as burial pits, though there are some similarities. Most of these

BOX 1:

Pollution issues resulting from culling campaigns

There is no clear overview of environmental issues associated with culling campaigns. Punctual observations, however, hint that they may be substantial. In Egypt, about 13 millions birds were culled and buried as part of the control measures implemented in response to the HPAI outbreak. We assume an average weight of 1 kg per bird, and estimate that this amounts to the burial of 13 million kg of fresh organic matter. Water resources are particularly at risk as the animals were buried in areas of shallow water and high human population (310 inhabitants/km^2 on average).

Following the recent avian influenza outbreak in Viet Nam, birds were culled and buried next to land used for human food production. The culling site itself was over a kilometre from the affected farm.

In Nigeria, a UNDP study (2006) found there was no adherence to any standard with regard to the location or the depth of the pits dug for the burial of carcasses. In some villages, the carcasses were thrown randomly into nearby bushes or open dump sites.

pits were located in sandy soils with high seasonal water tables. The potential for pollution of groundwater is high with this method of disposal. After selecting the sites, two to three monitoring wells were placed around each pit to a depth of 4.5 metres. Ammonia concentrations were high in two of the wells. Three of the disposal pits caused an increase in ammonia concentrations in the groundwater. Total dissolved solids concentrations were high in all monitoring wells for most dates. Bacterial contamination of groundwater by the disposal pits was low.

2.2 Slaughterhouse

The most significant environmental issue resulting from slaughterhouse operations is the discharge of wastewater into the environment. Like many other food-processing activities, the necessity for hygiene and quality control in meat processing results in high water usage and consequently high levels of wastewater generation (IEEP, 2005). Poultry processing activities require large amounts of high-quality water for process cleaning and cooling. Typical water usage in poultry slaughterhouses ranges between 6 and 30 cubic metres per tonne of product. Large quantities of water are consumed in poultry slaughterhouses for evisceration, cleaning and washing operations (EU, 2003).

Process wastewater generated during these activities typically has high biochemical and chemical oxygen demand (BOD and COD[3]) due to the presence of organic materials such as blood, fat, flesh, and excreta. In addition, process wastewater may contain high levels of nitrogen, phosphorus, and residues of chemicals such as chlorine used for washing and disinfection, as well as various pathogens including *Salmonella* and *Campylobacter* (World Bank, 2007). Poultry by-products and waste may contain up to 100 different species of micro-organisms, including pathogens, in contaminated feathers, feet and intestinal contents (Arvanitoyannis and Ladas, 2007). Typical values for wastewater produced from poultry processing are 6.8 kg BOD per ton live weight killed (LWK) and 3.5 kg suspended solids per ton of LWK (de Haan *et al*., 1997).

Poultry slaughterhouses release large amounts of waste into the environment, polluting land and surface waters as well as posing a serious human-health risk. The discharge of biodegradable organic compounds may cause a strong reduction of the amount of dissolved oxygen in surface waters, which in turn may lead to reduced levels of activity or even death of aquatic life. Macronutrients (nitrogen, phosphorus) may cause eutrophication of the affected water bodies. Excessive algal growth and subsequent dying off and mineralization of these algae may lead to the death of aquatic life because of oxygen depletion (Verheijen, *et al*., 1996).

Slaughterhouses are usually located in urban or peri-urban locations, where transport costs to markets are minimized and where there is abundant labour supply. This situation increases the risk of environmental impacts: first, because slaughterhouses often lack the land required to set up waste-management facilities; second, because the pollutants that

[3] The Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are parameters that give an indication of the concentration of organic compounds in wastewater. Their calculation is based on standardized chemical procedures for determining how fast biological organisms use up oxygen in a body of water. The concentration of suspended solids represents the amount of insoluble organic and inorganic particles in the wastewater (Verheijen *et al.*, 1996).

are emitted add to those emitted by other human activities; and third, because neighbouring communities are directly affected by surface-water and groundwater contamination.

3 WATERSHED-LEVEL POLLUTION ASSOCIATED WITH WASTE MANAGEMENT

Intensification of production and the geographical concentration of production units often results in environmental concerns. The decoupling of crop and livestock production through the migration of livestock production away from crop activities into areas with little or no agricultural land leads to high levels of environmental impact – mainly related to manure mismanagement and nutrient overloads (Naylor *et al*., 2005).

3.1 Poultry manure

Poultry manure contains considerable amounts of nutrients such as nitrogen, phosphorus, and other excreted substances such as hormones, antibiotics, pathogens and heavy metals which are introduced through feed (Steinfeld *et al*., in FAO, 2006b). Leaching and runoff of these substances has the potential to result in contamination of surface water and groundwater resources.

Nutrients

Animals reared in intensive production systems consume a considerable amount of protein and other nitrogen-containing substances in their diets. The conversion of dietary nitrogen to animal products is relatively inefficient; 50 to 80 percent of the nitrogen is excreted (Arogo *et al*., 2001). Nitrogen is excreted in both organic and inorganic compounds. Nitrogen emissions from manure take four main forms: ammonia (NH_3), dinitrogen (N_2), nitrous oxide (N_2O) and nitrate (NO_3^-).

Phosphorus is an essential element for animal growth. Unlike nitrogen, phosphorus is relatively stable once attached to soil particles and does not leach through the soil into groundwater. It does not pose any environmental risks except as a nutrient; it limits biological activity in water resources and builds up in soil when applied in excess. Phosphorus emissions from manure occur in one main form: phosphate (P_2O_5).

Heavy metals

Manure contains appreciable quantities of potentially toxic metals such as arsenic, copper and zinc (Bolan *et al*., 2004). In excess, these elements can become toxic to plants, can adversely affect organisms that feed on these plants, and can enter water systems through surface run-off and leaching (Gupta and Charles, 1999). Trace elements are introduced into poultry diets either involuntarily through contaminated feedstuffs or voluntarily, as feed additives used to supply animals' requirements or – in much greater proportions – as veterinary medicines or growth promoters.

Drug residues

Antimicrobial agents are administered to poultry for therapeutic reasons or to prevent illness (prophylaxis). At much lower doses (subtherapeutic doses) antimicrobial agents are used as feed additives to increase the rate of growth and to improve feed efficiency (Campagnolo *et al*., 2002; Steinfeld *et al*., in FAO, 2006b). Irrespective of dosage, an estimated 75 percent of antimicrobial agents administered to confined poultry may be excreted back into the environment (Addison, 1984). Recent evidence suggests that the interaction between bacterial organisms and antimicrobials in the environment may contribute to the development of antimicrobial-resistant bacterial strains (Chee-Stanford *et al*., 2001). Campagnolo *et al*. (2002), in a study that evaluated the presence of antimicrobial compounds in surface water and groundwater resources proximal to intensive poultry operations in Ohio, found antimicrobial residues to be prevalent – present in 12 water samples (67 percent) collected proximal to poultry farms.

In the United States of America, overall use of antimicrobials for non-therapeutic purposes in animals rose by about 50 percent between 1985 and 2001. This was primarily driven by increased use in the poultry industry, where non-therapeutic antibiotic use increased from 2 million to 10.5 million pounds (907 185 kg to 4 762 720 kg) between the 1980s and 2001 – which amounted to a dramatic 307 percent increase on a per-bird basis (Mellon *et al*., 2001).

Pathogens

Manure also contains pathogens which may potentially affect soil and water resources, particularly if poorly managed. Parasites such as *Cryptosporidium* and *Giardia* spp. can easily spread from manure to water supplies and can remain viable in the environment for long periods of time (Bowman *et al*., 2000).

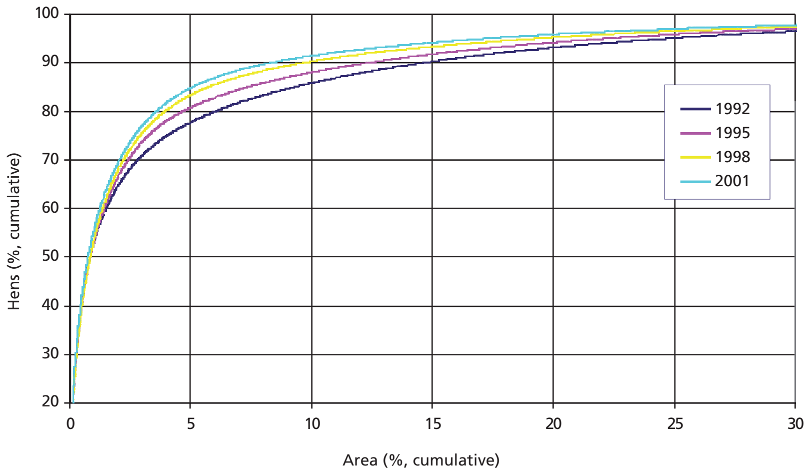
3.2 Regional concentration of production

The trend toward clustering of poultry production in certain preferred locations is ongoing in developed as well as developing economies. An analysis of hen populations at municipio level in Brazil, for example, shows an increasing concentration during the period 1992 to 2001 (see Figure 1). In 1992, 5 percent of the country's total area hosted 78 percent of the chicken population, while in 2001 the same area was home to 85 percent of the population.

Clustering is a process of geographic concentration of production units. This gives rise to groups of interconnected producers, feed mills, slaughterhouses and processing units. Clustering is driven by economies of agglomeration – the benefits that individual units obtain when they locate close to one another. Basically, the more related units clustered together, the lower the unit cost of production and the larger the market that individual units can sell into. In the livestock sector, lower production costs are achieved through competition among suppliers of inputs (e.g. feed mills, veterinary and other services), and specialization and division of labour among producers (e.g. breeding operations, fattening operations and contract farming). If a well-developed transport infrastructure supports this set-up, supply to urban and export markets is often very competitive.

Intensive production, therefore, concentrates in areas favoured by cheap inputs (particularly feed) and services, and by good market outlets for livestock products. Such conditions are found in the vicinity of cities, feed processors and large slaughterhouses, as well as harbours trading feed and animal products. The geographical location of intensive poultry activity is, thus, less and less linked to agricultural and land-use parameters. In other words,

FIGURE 1
Changes in the geographical concentration of chickens in Brazil from 1992 to 2001



poultry production is shifting from agricultural use of the land, based on biophysical criteria (e.g. soil quality, climate, length of growing period) towards industrial use of the land.

3.3 Environmental issues

Gerber *et al*. (2005) summarize some of the major potential impacts of intensive livestock production on land and water resources:

- eutrophication of surface waters, caused by the input of organic substances and nutrients either through wastewater from production, runoff or leakages from storage and handling facilities – affecting aquatic ecosystems and drinking water quality;
- leaching of nitrate, and possible pathogen transfers to groundwater – affecting the quality of drinking water;
- accumulation of nutrients and other elements in soil due to continuous application of excess quantities of manure; and
- impacts of pollution on nutrient-sensitive ecosystems resulting in biodiversity losses.

In most cases, structural changes in the production system have a rather negative impact on manure management practices. In particular, growth in the scale of production and geographical concentration in the vicinity of urban areas, cause dramatic land–livestock imbalances, hampering manure recycling options. Indeed, in such conditions, transport costs associated with carrying manure back to the field are prohibitive.

Contribution to regional-level nutrient overloads

As mentioned above, poultry manure is generally recycled. Despite this apparently safe handling, it often contributes to nutrient-based pollution at regional level. First, areas where poultry production concentrates are also often characterized by high populations of other livestock species, pigs in particular. Poultry manure, thus, contributes to the structural nutrient overload in these areas. Secondly, the manure may be applied to crops or fish ponds in excess or in addition to chemical fertilizers or fish feed, resulting in an over-supply of nutrients. Such saturated systems will release excessive nutrients into the environment.

Excessive levels of nitrogen in the environment lead to a cascade of effects, including (Erisman *et al*., 2001; De Vries *et al*., 2003):

- decreased species diversity and acidification of non-agricultural soils, due to nitrogen deposition related to ammonia and nitrous oxide emission;
- eutrophication of surface waters, including excess algal growth and a decrease in natural diversity due to runoff of nitrogen from agricultural soils;
- pollution of groundwater due to nitrate leaching from agricultural soils and non-agricultural soils; and
- greenhouse gas emissions in the form of nitrous oxide.

Nitrogen pollution has been identified as posing a risk to the quality of soil and water. These risks relate to high levels of nitrates, which can be leached to the groundwater table or to surface water causing eutrophication. In its nitrate form, nitrogen is very mobile in soil solution and can easily be leached below the rooting zone and into groundwater.

The rapid growth of intensive poultry production in many parts of the world has created regional and local phosphorus imbalances (Gerber *et al*., 2005). The application of manure has resulted in more phosphorus being applied than crops require, and increased potential for phosphorus losses in surface runoff. This situation is exacerbated by manure management being nitrogen based. When manure is applied to meet the nitrogen needs of most crops, a substantial build-up of phosphorus occurs in the soil (Burton and Turner, 2003; Sharpley, 1998). Environmental problems associated with phosphorus losses from soils can have significant off-farm impacts on water quality. In some cases, these impacts are manifested many miles from the site where the phosphorus losses in soil erosion and runoff originally occurred (Sharpley, 1998). Too much phosphorus input into a body of water leads to plant overgrowth, shifts in plant varieties, discolouration, shifts in pH, and depletion of oxygen as a result of plant decomposition. A drop in the level of dissolved oxygen in surface water has deleterious effects on fish populations (Ferket *et al*., 2002). Thus, increased outputs of phosphorus to fresh water can accelerate eutrophication, which impairs water use and can lead to fish kills and toxic algal blooms. In general, 80 percent of the phosphorus contained in animal feed is subsequently excreted (Burton and Turner, 2003).

Food- and water-borne diseases are another major issue associated with manure management. Pathogens are mostly transmitted through untreated animal waste. Recycling manure is a cost-effective way to reduce discharge into the environment and contamination of water systems. However, recycling must be controlled carefully in order to avoid transferring pathogens to the human food chain. Nonetheless, manure is usually not treated, even if limited composting may take place when manure is stored over several weeks (on farm or in a middleman’s barn) and crop residues are added.

Soil contamination with heavy metals

With increasing use of metals not only as growth promoters, but also as feed additives to combat diseases in intensive poultry production, manure application has emerged as an important source of environmental contamination with some of these metals. Metals such as arsenic, cobalt, copper, iron, manganese, selenium and zinc are added to feeds as a means to prevent disease, improve weight gain and feed conversion, and increase egg production (Bolan *et al*., 2004; Jackson *et al*., 2003). Typically, animals can absorb only 5–15 percent of the metals they ingest. The majority is therefore excreted in manure. Part is absorbed by the soil, but heavy metals can also end up in water bodies where they become more concentrated.

The environmental risk associated with heavy metals is largely dependent on the soil's ability to adsorb and to desorb these elements, and the potential for leaching or soil-loss to water by erosion. The spreading of animal manure contaminated with heavy metals can lead to an accumulation of these elements in agricultural soils and water bodies. Unlike excess nitrogen and phosphorus applied to land, heavy metals such as zinc and copper remain bound to soil and do not migrate to water supplies except during soil erosion (Ferket *et al*., 2002). The concentrations of copper and zinc needed by animals are moderately low – 8 parts per million (ppm) for copper and 40 ppm for zinc (National Research Council, 1994). Yet, throughout the United States of America, most broiler diets contain levels of 125 to 250 ppm of copper in order to improve feed efficiency. The U.S. Geological Survey has reported that intensive poultry production units in the Delaware–Maryland–Virginia (Delmarva) Peninsula, on the eastern shore of the United States of America are introducing between 20 and 50 tonnes of arsenic into the environment annually (Christen, 2001) (Box 2).

Ecosystem contamination with drug residues and hormones

The excretion of hormones from poultry has been cited as a possible cause of endocrine disruption in wildlife. Endocrine disruptors are a class of compounds (either synthesized or naturally occurring), which are suspected to have adverse effects in animals. They affect organisms primarily by binding to hormone receptors and disrupting the endocrine system. Endocrine disrupting chemicals (EDCs) include pesticides, herbicides and other chemicals that interact with endocrine systems (University of Maryland, 2006).

In poultry production, EDCs can both enter and leave the production cycle. Sources of EDCs during the production phase include contaminants in litter and from grains used as feed. Poultry can also produce EDCs in the form of steroid hormones that are excreted in manure. The steroids of greatest concern are estrone and 17-ß-estradiol. Research has shown that poultry litter contains estrogen (17-ß-estradiol), estrone and testosterone in measurable concentrations, and that these EDCs persist in the litter (Nichols *et al*., 1997; Shore and Shemesh, 2003; Fisher *et al*., 2005). Degradation of steroids in poultry litter during storage is minimal. However, once steroids have reached waterways their degradation is rapid. Research into the endocrine disruption impact of naturally occurring steroids on fish suggests that on runoff from fields where poultry manure has been applied steroid levels are high enough to cause endocrine disruption resulting in reproductive disorders in a variety of wildlife. Endocrine disruption resulting from intensive poultry production has been well documented in the Delmarva Peninsula in the United States of America (Box 3).

BOX 2:

Arsenic use in intensive poultry production in the United States of America

In the United States of America, arsenic is used in poultry production for growth promotion and for controlling intestinal parasites. According to estimates, at least 70 percent of the broiler chickens raised annually in the United States of America (8.7 billion in 2005) are fed arsenic – typically a compound called roxarsone (3-nitro-4-hydroxyphenylarsonic acid). Up to three-quarters of arsenic in feed will pass through chickens into the estimated 26 to 55 billion pounds* of chicken litter or waste created in the United States of America annually. With around 90 percent of chicken waste being currently applied to fields and cropland as "fertilizer", the U.S. Geological Survey has calculated, based on arsenic concentrations in poultry waste, that between 250 000 and 350 000 kg of arsenic is annually applied to land in the United States of America (Rutherford *et al.,* 2003). Because 70–90 percent of arsenic in poultry litter becomes water soluble, it can readily migrate through soils and into underlying groundwater. While soluble or dissolved arsenic poses the greatest risk for environmental contamination, wind or water erosion can transport contaminated soil particles into water bodies (Bellows, 2005). Garbarino *et al.* (2003) estimated that 2 billion pounds of arsenic are annually introduced into the environment from poultry operations in the United States of America. According to the U.S. Environmental Protection Agency (US-EPA, 2007) (http://www.epa.gov/safewater) 13 million Americans drink water contaminated with arsenic beyond the safety standard of 10 parts per billion.

Arsenic as an obstacle to manure management

Apart from its role in the contamination of water and soil resources, arsenic used in poultry production has also become an obstacle to animal waste management. Today, the production of bioenergy and pelletization of animal waste are two important options being explored for poultry waste management. Existing incinerators in the United States of America burn about 680 million kg of poultry litter each year, and the ash from the incineration process is sold as fertilizer. The other new disposal technology is to produce fertilizer pellets directly from poultry waste by drying and pelletizing it. This is currently being implemented in Delaware, where about 55 million kg of pellets are produced annually. Although these two technologies have the potential to reduce or eliminate harmful pathogens in poultry waste, neither can destroy or detoxify arsenic. Preliminary measurements of arsenic concentrations in pelletized waste sold as fertilizer have shown levels between 18 and 22 mg/kg – levels similar to those reported in unprocessed poultry waste. There is, therefore, concern about increased exposure to arsenic through air emissions from energy plants, and contamination of soils and water.

*1 pound = 0.45 kg

Source: Nachman *et al*. (2005)

BOX 3:

Effects of endocrine disruptors from intensive poultry on fish

The Delmarva Peninsula, consisting of eastern Maryland, most of Delaware, and the portion of Virginia east of the Chesapeake Bay, is one of the most densely concentrated poultry producing areas in the United States of America. The region generates 600 million birds and 1.6 billion pounds (726 million kg) of manure (or litter) annually. Excessive land application of poultry wastes has precipitated severe water quality problems in surface waters and groundwaters throughout the region. Impacts include harmful algal blooms, decreases in water clarity, widespread anoxia, and declines in submerged aquatic vegetation. Pollutants and pathogens in poultry litter traditionally linked to environmental degradation include nutrients and protozoan, bacterial and viral agents. In addition, recent attention has turned toward various non-traditional poultry litter-associated contaminants. These include feed additives (e.g. trace metals and antibiotics), poultry house/bedding material impurities (e.g. metals and pesticides) and faecal/urinary steroids (e.g. estrogenic and androgenic hormones). In most vertebrates, sex steroids, specifically 17-ß estradiol (E2) and testosterone, are responsible for gender differentiation, development of reproductive structures and stimulation of breeding behaviours. They are released naturally in poultry urine and faeces and persist at high concentrations and for prolonged durations (more than two years) in litter. Studies conducted on the Delmarva Peninsula and elsewhere have demonstrated the transport of E2 from poultry litter-amended fields to surface waters and groundwaters at levels sufficient to warrant environmental concern. The studies have also confirmed that these contaminants are capable of causing endocrine disruption in aquatic animals.

Source: Fisher *et al*. (2005).

Ecosystem contamination through ammonia deposition

Atmospheric ammonia (NH_3) is increasingly being recognized as a major air pollutant because of its role in regional-scale tropospheric chemistry and its effects when deposited into ecosystems. Ammonia is a soluble and reactive gas. This means that it dissolves, for example in water, and that it will react with other chemicals to form ammonia-containing compounds. The concentrations of ammonia in the air are greatest in areas where there is intensive livestock farming. Agricultural land receiving large inputs of nitrogen from manures normally acts as a source of ammonia, but it may also act as a “sink” and absorb ammonia from the atmosphere. There is little deposition of ammonia gas to intensively managed farmland, which is largely a net source of ammonia (Sutton and Fowler, 1995). Ammonia in the atmosphere can be absorbed by land, water and vegetation (known as dry deposition). It can also be removed from the atmosphere by rain or snow (wet deposition). Impacts of ammonia deposition include; soil and water acidification, eutrophication caused by nitrogen enrichment with consequent species loss, vegetation damage, and increases in emissions of the greenhouse gases such as nitrous oxide.

4 IMPACTS ON THE GLOBAL ENVIRONMENT

Environmental impacts of poultry production are not always confined to specific areas; they also include impacts of a global dimension. Two issues are of relevance: the production of concentrate feed and greenhouse gas production related to energy use in animal production processes and in the transport of processed products. This section analyses these two issues in the context of poultry production and the sector's impacts on the environment.

4.1 Feed production

Overview on feed consumption

The extraordinary performance of the poultry sector over the past three decades has partially been achieved through soaring use of concentrate feed, particularly cereals and soybean meal (FAO, 2006a). We estimate that in 2004 the poultry sector utilized a total of 294 million tonnes of feed, of which approximately 190 million tonnes were cereals, 103 million tonnes soybean meal and 1.6 million tonnes fishmeal.

Estimates put the global use of cereals for feed (all species included) at 666 million tonnes, or about 35 percent of total world cereal use (FAO, 2006a). This implies that in 2004 cereal utilization as feed by the poultry sector represented about 28 percent of the cereal and 75 percent of soybean meal used by the livestock sector.

The estimates for feed utilization by the intensive poultry sector were obtained by applying a two-step approach. The first step estimates total feed use in poultry systems by applying a "utilization approach", i.e. total feed utilization is obtained by multiplying total production (for poultry meat and eggs) by the corresponding feed conversion ratio which reflects both the intensity and efficiency of the livestock system.

The second step involves apportioning the total feed obtained per region based on the concept of "feed baskets". Feed baskets represent the different components that make up a feed ration in any given country. The major elements of feed baskets in intensive poultry systems are usually cereals, oilseeds and fishmeal (Steinfeld *et al*., in FAO, 2006b), while those in mixed systems are to a greater extent made up of agro-industrial by-products (oilmeals, fishmeal) and crop residues, and contain less cereal. In calculating feed use the following assumptions were made.

1. Cereals make up the bulk of the feed baskets in intensive poultry production – an estimated 60 percent. The rest is shared between oilseeds (mainly soybean) and fishmeal (ibid.). However, cereal use for poultry production differs across countries, with maize dominating in Brazil, China and the United States of America, and wheat in the European Union (EU). In mixed systems, we estimate that cereals make up about 30 percent of the feed basket, with the remainder comprising crop residues and agro-industrial by-products.
2. This estimate also assumes homogeneity of poultry production across countries and regions and, therefore, applies an average feed conversion ratio across all regions. For poultry-meat products, an average was taken based on the feed conversion ratios for broilers, turkeys and ducks. For eggs, the feed conversion ratio average was based on the feed conversion ratio for brown-shelled and white-shelled layers. Poultry reared in landless systems are considered efficient users of feed and therefore have lower feed conversion ratios than those in mixed systems.

Demand for feed by the livestock sector has been a trigger for three major global trends: the intensification of feed production, agricultural expansion and erosion of biodiversity. The production of feed has an impact on the environment at various stages of crop production. In terms of the environment, these three trends have had a number of global impacts, which include land and water pollution, air pollution, greenhouse gas emissions, land-use change through deforestation and habitat change, and overexploitation of non-renewable resources.

Environmental impacts related to feed production

Intensive agriculture. Intensification of feed production affects land and water resources through pollution caused by the intensive use of mineral fertilizer, pesticides and herbicides to maintain high crop yields. It is estimated that only 30–50 percent of applied nitrogen fertilizer (Smil, 1999) and approximately 45 percent of phosphorus fertilizer (Smil, 2000) is taken up by crops. Steinfeld *et al*. (2006) estimated that about 20 million tonnes of nitrogen fertilizer were used in feed production for the livestock sector. Based on the estimation that the poultry sector utilizes 36 percent of feed concentrates (cereals and soybean), we can attribute about 7.2 million tonnes of nitrogen fertilizer use to feed production for the sector.

Intensive feed production also contributes to air pollution. The application of nitrogen fertilizer to cropland is a major source of air pollution through the volatilization of ammonia. Assuming an average mineral fertilizer ammonia volatilization loss rate of 14 percent, it has been estimated that global livestock production can be considered responsible for a global ammonia volatilization from mineral fertilizer of 3.1 million tonnes of NH3-N (nitrogen in ammonia form) per year (Steinfeld *et al*., in FAO, 2006b). Based on these same assumptions, the poultry sector can be considered responsible for about 1.1 million tonnes of ammonia volatilization from mineral fertilizer per year.

Intrusion into natural habitats. Increases in feed production, have to some extent been related to the expansion of cropland dedicated to feed. Feed production to satisfy the feed demand of intensive systems indirectly affects the global land base through changes in land use. Area expansion is in most cases at the expense of forested land (deforestation) cleared for crop production. For example, the land area for soybean production in Brazil increased from 1 million hectares in 1970 to 24 million hectares in 2004 – half of this growth came after 1996, most of it in the Cerrado, with the remainder in the Amazon Basin (Brown, 2005). According to Brazil's National Institute of Space Research (Bickel and Dros, 2003), just over 2.5 million hectares of forest in the Amazon disappeared in 2002, with about 70 percent of the 1.1 million hectare expansion of the agricultural frontier in the Amazon region alone attributed to soybeans. Wassenaar *et al*. (2007) project large hotspots of deforestation in the Brazilian Amazon forest related to the expansion of cropland, mainly for soybean. Changes in land use can have profound impacts on carbon fluxes, leading to increased carbon release and fuelling climate change. In addition to changes in carbon fluxes, deforestation also has an impact on water cycles and increases runoff and consequently soil erosion. WWF (2003) estimates that a soy field in the Cerrado loses approximately 8 tonnes of soil per hectare per year.

Erosion of biodiversity. Feed production is also driving biodiversity erosion through the conversion of natural habitats and the overexploitation of non-renewable resources for feed production. Intensive feed production contributes to biodiversity loss through land use and land-use change, and modification of natural ecosystems and habitats. The demand for feed has triggered increased production and exports from countries such as Brazil. Between 1994 and 2004, land devoted to soybean production in Latin America more than doubled to 39 million hectares (FAOSTAT, 2006).

The clearing of vast areas of the biologically rich Amazon rainforest and the Cerrado to produce maize and soybeans for feed has led to the loss of plant and animal species (Box 4).

Overexploitation of natural resources. The production of fishmeal for the poultry sector is an important factor contributing to the overexploitation of fisheries. The world's fish stocks are facing serious threats to their biodiversity. The principle source of this pressure is overexploitation, which has affected the size and viability of the fish populations (Steinfeld *et al*., in FAO, 2006b). FAO (2005) estimates that 52 percent of the world's fish stocks are fully exploited, and are therefore producing catches that are already at or very close to their maximum sustainable yield. Current estimates are that around 40 percent of global fishmeal production is used for the livestock sector of which 13 percent is used by the poultry sector (Figure 2) (Jackson, 2007).

The expansion of the aquaculture sector and its demand for fishmeal as a feed ingredient has led to a reduction in the use of fishmeal by the poultry sector (as illustrated in

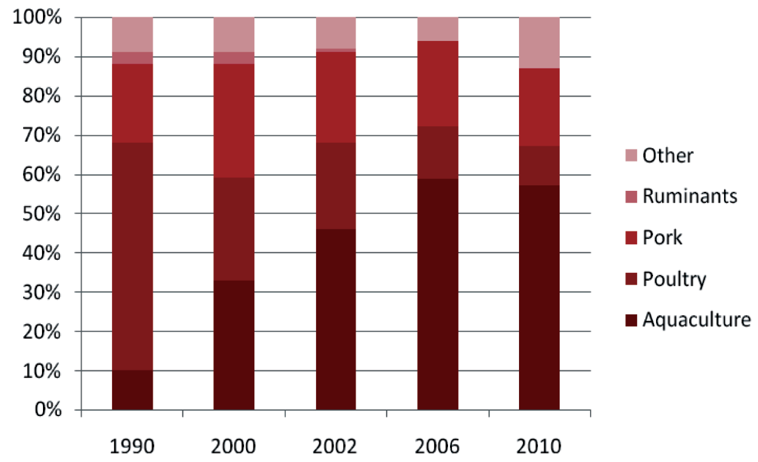
BOX 4:
Soybean production in the Cerrado

The Cerrado is one of the world's biodiversity hotspots. It has an area of 200 million ha and covers a quarter of Brazil, making it the country's second biggest ecosystem after the Amazon. It is regarded as the world's most species-rich savannah. Having approximately 4 400 endemic species in a total of 10 000 species of plants, it is classified as one of the earth's 25 biodiversity "hot spots". However, the areas designated as protected – barely 1.5 percent – are far fewer and smaller than in the Amazon. The Cerrado, Brazil's second major biome, is suffering severe clear-cutting and irreversible losses of its original vegetation and biodiversity. Numerous animal and plant species are threatened with extinction as a result of the expansion of the agricultural frontier, and an estimated 20 percent of threatened and endemic species do not occur in protected areas.

The extent of the destruction of the Cerrado is now evident. Two-thirds of its original vegetation has already been destroyed or severely degraded. Cultivation of soybeans in the Cerrado has since 1970 risen from 20 000 to 29 million tonnes – an increase in Brazilian soybean production from 1.4 percent to 58 percent. As state planning on land use – determining where and how much primary vegetation should be converted to land for agricultural use – exists only in a rudimentary form, soybean expansion is one of the main factors threatening the Cerrado ecosystem.

Sources: Bickel (2005); Klink and Machado, (2005).

FIGURE 2
Past and projected trends in global use of fishmeal by sector



Sources: Marine Aquaculture Task Force (2007); Jackson (2007).

Figure 2). Between 1990 and 2006, the share of fishmeal consumed by the poultry industry decreased drastically from about 58 percent to 13 percent. The poultry sector compensated for this loss by increasing the amount of soybean meal used in feed rations. Despite current and projected decline in the sector's use of fishmeal as a feed input, the role of the industrial poultry sector in the overexploitation and depletion of fisheries can not be ignored.

4.2 Climate change

The relatively high energy input in intensive livestock systems has given rise to concerns regarding greenhouse gas emissions and climate change. The energy consumption of industrially produced poultry is relevant because of the production of carbon dioxide (CO_2) along the production chain. Carbon dioxide emissions are produced by the burning of fossil fuels during animal production and slaughter, and transport of processed and refrigerated products, but importantly also through land use and land-use change, and the use of inputs for the production of feed.

On-farm energy consumption

On-farm energy consumption includes direct and indirect energy input – direct energy refers to fossil energy used for the production process (e.g. energy input for poultry housing systems), and indirect energy to that used as an integral part of the production process (e.g. feed processing). Due to a lack of information on energy use for processing, this estimation of on-farm fossil fuel consumption is limited to quantifying energy use associated with poultry housing.

The energy used for heating, ventilation and air conditioning systems typically accounts for the largest quantity of energy used in intensive poultry operations. Animal housing

TABLE 1
Energy consumption in poultry production

Activity	Estimated energy consumption		
	Broilers[a]	Layers[a]	Turkeys[c]
Local heating	13–20		
Feeding	0.4–0.6	0.5–0.8	
Ventilation	0.10–0.14	0.13–0.45	1.4–1.5
Lighting		0.15–0.40	
Egg preservationb		0.30 –0.35	

Notes: a – Wh (watt hour)/bird/day; b – Wh/egg/day; c – kWh/bird/year.
Sources: World Bank (2007); EU (2003).

facilities are therefore potential sources of carbon dioxide emissions from intensive poultry farms. Other sources of carbon dioxide emissions include energy used for feed preparation, on-farm transport and burning of waste (EU, 2003). Generally, on layer farms, artificial heating of housing is not commonly applied, due to the low temperature needs of birds and the high stocking density. The activities that require energy are ventilation, feed distribution, lighting, and egg collection, sorting and preservation. On broiler farms, the main energy consumption is related to local heating, feed distribution and housing ventilation. Quantification of the energy consumption of intensive poultry farms is a complex undertaking because systems are not homogeneous. The amount of energy consumed varies with the technologies applied, the production characteristics of the farms, and climatic conditions. Table 1 shows energy requirements of some essential activities on broiler, layer and turkey farms in the EU.

A rough indication of the fossil fuel related emissions from intensive poultry systems can be obtained by applying the energy requirements given in Table 1, assuming that the energy consumption for heating during the winter in higher latitude countries is equivalent to the high energy use for ventilation in lower latitudes. By applying these estimates to the global total for intensively produced poultry, it is estimated that about 52 million tonnes of carbon dioxide are emitted per year.

Carbon dioxide emissions from slaughtering

Poultry processing facilities use energy to heat water and produce steam for process applications and cleaning, and for the operation of mechanical and electrical equipment, refrigeration and air compressors. In poultry abattoirs, fossil fuel is mainly used for process heat, while electricity is used for the operation of machinery and for refrigeration, ventilation, lighting and the production of compressed air. Ramírez *et al*. (2004) in an analysis of energy consumption in the EU meat industry found poultry slaughtering to be more energy intensive (3 096 MJ/tonne dress carcass weight) than other meat sectors (1 390 MJ/tonne dress carcass weight for beef and 2 097 MJ/tonne dress carcass weight for pork).

Using the Ramírez *et al*. (2004) estimates of energy consumption values for poultry, we estimate that carbon dioxide emissions from poultry slaughtering facilities amount to 18 million tonnes. This estimate is obtained by applying the energy consumption data to total poultry meat production and multiplying by the respective carbon dioxide emission factors for both electricity and natural gas.

Carbon dioxide emissions from international trade

International trade in poultry meat contributes significant carbon dioxide emissions – induced by fossil fuel use for the shipping of poultry meat. Steinfeld *et al*. (in FAO, 2006b) estimated carbon dioxide emissions by combining traded volumes with respective distances, vessel capacities and speeds, fuel use of main and auxiliary power generators for refrigeration, and their respective emission factors. Based on this analysis, trade in poultry meat was found to contribute an estimated 256 000 tonnes of carbon dioxide (representing about 51 percent of the total carbon dioxide emissions induced by meat-trade ocean transport). The addition of transportation within national boundaries, involving shorter distances, but much larger quantities and less efficient vehicles, would certainly increase significantly the sector's greenhouse gas emissions related to transportation.

Greenhouse gases emissions from feed production

Emissions of greenhouse gases such as carbon dioxide and nitrous oxide are influenced in an indirect way by intensification of feed production, which requires energy input for the production of mineral fertilizer and the subsequent use of this fertilizer in the feed production process.

Carbon dioxide (CO_2). This greenhouse gas is produced by the burning of fossil fuels during the manufacture of fertilizer. By applying energy use per tonne of nitrogen fertilizer (estimated at 40 GJ per tonne) and the IPCC (Intergovernmental Panel on Climate Change) emission factor for natural gas (17 tonnes of carbon per terajoule) to total nitrogen fertilizer use in the production of feed for poultry production (estimated at 7.2 million tonnes) and applying the ratio of the molecular weight of carbon dioxide to the molecular weight of carbon (44/12) results in an estimated annual carbon dioxide emission of 18 million tonnes – about 44 percent of that ascribed to the livestock sector.

Nitrous oxide (N_2O). Poultry production is indirectly associated with the greenhouse gas nitrous oxide because of the sector's high concentrate-feed requirements and the related emissions from arable land due to the use of nitrogen fertilizer. FAO–IFA (2001) reported a 1 percent N_2O-N (nitrogen in nitrous oxide) loss rate from nitrogen mineral fertilizer applied to arable land. By applying this loss rate to the total nitrogen fertilizer attributed to the poultry sector, we estimate that nitrous oxide emissions from poultry feed related fertilizer to be 0.07 million tonnes of N_2O-N per year – about 35 percent of the global nitrous oxide emissions attributed to the livestock sector from mineral fertilizer application.

Overall, intensive poultry production (indirectly and directly) contributes an estimated 3 percent of the total anthropogenic greenhouse gas and is responsible for about 2 percent of the total greenhouse gas emissions from the livestock sector. This estimate however does not include emissions from land use and land-use change associated with feed production or emissions related to transport of feed.

TABLE 1
Summary of greenhouse gas emissions related to poultry production

	Million tonnes carbon dioxide equivalent
Carbon dioxide	
Nitrogen fertilizer production for feed	18
On-farm energy consumption	52
Slaughtering	18
International trade (transport)	0.3
Nitrous oxide	
Indirect fertilizer emissions	0.02
Total	88.3
Share of the livestock sector	2%
Share of anthropogenic emissions	0.3%

Note: These estimates do not include emissions related to land use and land-use change, nor intra-national transportation.

5 TECHNICAL MITIGATION OPTIONS

The magnitude of environmental impacts is highly dependent on production practices and especially on manure management practices. We introduce here a number of techniques and management practices that are available to control the environmental issues described above. Lack of awareness and capital are often cited as the two factors hampering the implementation of such practices.

5.1 Farm management

Taking environmental issues into account in all management strategies at the farm level can reduce the impacts felt at the level of production.

Odour emissions can be controlled by:

- minimizing the surface of manure in contact with air – frequent collection of litter (once a week in dry seasons and twice a week in rainy seasons), closed storage (bags or closed sheds);
- cooling animal manure, achieved as a positive side effect of cooling the animal houses – cooling systems can be equipped with biofilters and air scrubbers that trap odours from the ventilation airflow;
- lowering litter's water content – achieved by the incorporation of hydrophilic products such as hashes, rice husk, peanut husk, dust or sawdust;
- applying deodorant products to feed or directly to animal houses; and
- building wind protection structures.

The proliferation of flies and mosquitoes can be controlled by:

- minimizing the surface of manure in contact with air – frequent collection of litter (once a week in dry seasons and twice in rainy seasons, i.e. at shorter intervals than the length of the larvae development cycle), closed storage (bags or closed sheds);
- lowering litter's water content – achieved by the incorporation of hydrophilic prod-

ucts such as hashes, rice husks, peanut husks, dust, sawdust or available dry crop residues;
- applying insecticides (this practice may however have significant public health-related side effects);
- building wind protection structures;
- positioning nets around the farm.

Rat proliferation can be controlled by:
- minimizing feed losses during storage and feeding;
- raising cats or keeping snakes in cages close to the poultry barn to scare rats; and
- use of poison or traps.

Visual impact and landscaping can be improved by:
- use of screening trees around the farm facility to reduce the visual impact of farm infrastructure and of noise, dust, light and odour;
- use of the natural topography and terrain of the site and the existing vegetative cover to maximize visual screening; and
- use of construction materials that minimize visual impact.

5.2 Animal waste management

Soil and water pollution is controlled through the implementation of good fertilization practices. In brief: environmental risks are reduced when manure is applied in amounts and at times that correspond to crop or fish-pond uptake. Water pollution is often an acute problem in waterfowl production, especially when the flock is concentrated on relatively small ponds. There is currently a lack of information with regard to the effects of waterfowl production on surface water and groundwater resources.

Water- and food-borne disease propagation can be prevented by:
- storing manure in closed buildings or bags – a storage system allows producers to hold manure until a convenient and optimum time for use; storing poultry manure in closed buildings reduces the emissions of gaseous compounds to the air, and the risk of environmental contamination as compared to the risk associated with leaving manure exposed;
- storing the manure for one to two months before its application on land or fish ponds;
- composting manure – potentially reduces or even eliminates certain pathogens and fly larvae, and improves the handling characteristics of manure and other residues by reducing their volume, weight and moisture content (most manure and other organic residues usually contain high nitrogen content and are, therefore, subject to nitrogen loss during composting);
- drying (with machine or by spreading out) – minimizes the moisture content of manure, inhibits chemical reactions, and thus reduces emissions (the best way to prevent ammonia emissions from poultry litter and manure is to reduce microbial decomposition, which can be accomplished by drying the freshly produced manure as soon as possible and keeping it dry);

- timing and rate of manure application – this is a critical management factor; manure must be applied at the correct time of year to prevent losses to surface water, groundwater and the atmosphere, and to optimize the utilization of manure nutrients by growing plants; proper timing is a function of several variables, including weather, soil conditions and stage of crop growth; and
- dead-bird management and disposal, which must comply with legally accepted practices including rendering, composing, incineration and burial; a contingency plan should be in place for disposal of large numbers of dead birds in the event of disease outbreaks; in addition, consideration should be given to impacts on the physical environment – e.g. burial pits should be at least 3 metres above the maximum groundwater table.

5.3 Nutrition management

Nutritional management aims to reduce pollution load by limiting excess nutrient intake and/or improving the nutrient utilization efficacy of the animal. It not only affects the quantity of mineral outputs from animals and the characteristics of manure, but also has cross-media effects – reducing the pollution load of soil, water and air. Nutrition management can also allow improvement to feed conversion ratios through optimal diet balancing and feeding regimes, and improvement to feed digestibility. This reduces the amount of feed used per unit of livestock product. Relevant measures include:

- formulating feeds that closely match the nutritional requirements of birds in their different production and growth stages to reduce the amount of nutrients excreted; options in this category include phase feeding, split-sex feeding or feed formulation on an available-nutrient basis;
- use of low-protein diets supplemented with amino acids, and low-phosphorus diets with highly digestible inorganic phosphates;
- improving feed digestibility and nutrient bioavailability through the use of dietary supplementary enzymes such as phytase, highly digestible genetically modified feedstuffs such as low-phytate maize, and highly digestible synthetic amino acids and trace minerals; and
- using good quality, uncontaminated feed (e.g. in which concentrations of pesticides and dioxins are known and do not exceed acceptable levels) which contains no more copper, zinc, and other additives than is necessary for animal health.

5.4 Feed production

The key to reducing the negative environmental impacts associated with intensive agriculture for feed production lies in increasing efficiency, i.e. increasing production while reducing the use of inputs that adversely affect the environment. The negative effects of feed production can be greatly reduced with appropriate cultivation (e.g. minimum tillage), integrated pest management (IPM) and targeted fertilizer inputs. Technologies are available for many different environments to conserve soil and water resources and to minimize the use and impact of inorganic fertilizers and pesticides.

Good agricultural practices require the application of available knowledge to the utilization of the natural resource base in a sustainable way for the production of safe and healthy food. Management of resources such as soil and water by minimizing losses of soil, nutrients and agrochemicals through erosion, runoff and leaching into surface water or groundwater is a criterion for good agricultural practice. Good agricultural practice will maintain or improve soil organic matter through the use of appropriate mechanical and conservation tillage practices; will use soil cover to minimize erosion loss by wind or water; and will ensure that agrochemicals and organic and inorganic fertilizers are applied in amounts, at times and using methods, appropriate to agronomic and environmental requirements.

IPM uses an understanding of the life cycle of pests and their interactions with the environment, in combination with available pest control methods, to keep pests at a level that is within an acceptable threshold in terms of economic impact, while giving rise to minimum adverse environmental and human health effects. Recommended IPM approaches include: use of biological controls such as predators, parasites and pathogens to control pests; use of pest-resistant varieties; mechanical and biological controls; and, as a last resort, chemical controls including synthetic and botanical pesticides. Other IPM approaches encompass pesticide application techniques that aim to increase the efficiency of chemical applications.

Minimal tillage practices in agronomic crops such as soybean and maize reduce the loss of nutrients from the field, they also improve the water-stability of soils and reduce soil erosion; this often results in higher levels of soil organic carbon and reduces carbon emissions.

Enhancing the efficiency of water use in feed production by improving irrigation efficiency and water productivity is a further method of reducing adverse environmental impacts. Water productivity can be improved by methods including selection of appropriate crops and cultivars, better planting methods, minimum tillage, timely irrigation that matches water application with the most sensitive growing periods, nutrient management and drip irrigation.

6 CONCLUSIONS

This paper has focused on poultry production in intensive systems and its impacts on the environment. The assessment captures most of the issues associated with poultry production, as environmental impacts related to backyard or mixed extensive systems are marginal because of the limited concentration of wastes and reliance on locally available sources of feed, such as food residues, crop residues or feed collected by free-ranging birds. The review has also demonstrated the need to look beyond the farm level in order to understand the sector's impacts on the environment, as many of the impacts of production are felt beyond the point of production.

Generally, the environmental impacts of the sector are substantial. Poultry production is associated with a variety of pollutants, including oxygen-demanding substances, ammonia, solids, nutrients (specifically nitrogen and phosphorus), pathogens, trace elements, antibiotics, pesticides, hormones, and odour and other airborne emissions. These pollutants have been shown to produce impacts across multiple media. These impacts can be summarized as follows.

Surface water impacts. Impacts are associated with waste spills, as well as surface runoff and subsurface flow. The oxygen demand and ammonia content of the waste can result in fish kills and reduced biodiversity. Nutrients contribute to eutrophication and associated blooms of toxic algae and other toxic micro-organisms. Human and animal health impacts are associated with drinking contaminated water (pathogens and nitrates) and contact with contaminated water (pathogens and Pfiesteria). Trace elements (e.g. arsenic, copper, selenium and zinc) may also present human health and ecological risks. Antibiotics, pesticides and hormones may have low-level but long-term ecosystem effects.

Groundwater impacts. Impacts associated with pathogens and nitrates in drinking water may cause underlying groundwater to become unsuitable for human consumption.

Air/atmosphere impacts. Impacts include those on human health (caused by ammonia, hydrogen sulfide, other odour-causing compounds, and particulates), and contribution to global warming (due to carbon dioxide and nitrous oxide emissions from the production process and other related activities such as feed production and transport of finished products). Additionally, volatilized ammonia can be re-deposited and contribute to eutrophication, acidification and damage to vegetation and sensitive ecosystems.

Soil impacts. Nutrients and trace elements in animal manure can accumulate in the soil and become toxic to plants.

Other indirect impacts include ecosystem destruction and biodiversity erosion associated with the expansion of feedcrop production into natural habitats and the overexploitation of non-renewable resources for feed production.

Compared to other livestock species, however, poultry performs well from an environmental perspective. A substantial comparative advantage that poultry has over other animal sectors relates to its efficiency in feed conversion. Poultry's feed conversion ratio represents a major contribution to the profitability of the industry in terms of reduced feed inputs as well as in waste output. For cattle in feedlots, it takes roughly 7 kg of grain to produce a 1 kg gain in live weight. For pork, the figure is close to 4 kg per kg of weight gain, for poultry it is just over 2 kg, and for herbivorous species of farmed fish, such as carp, tilapia, and catfish, it is less than 2 kg (Brown, 2005). Another comparative advantage lies in the low water content and high nutrient content of poultry manure. It is, thus, often handled with more care than manure from other species – especially pigs – as recycling is generally economically profitable.

Technologies exist that have the potential to produce substantial reductions in environmental impacts. The problem is one of cost, corresponding incentives/disincentives and awareness. Given the strong reactivity of the sector (large companies, foreign direct investment, demand growth), getting economic incentives and disincentives right within a framework of market forces should be sufficient to minimize environmental impacts.

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