
# CHAPTER 2. GLOBAL DRIVERS OF WATER POLLUTION FROM AGRICULTURE

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Population growth and changes in consumption patterns, including new dietary preferences, are changing and increasing the demand for food and, consequently, driving the transformation of our food and agricultural systems. Irrigated and rain-fed agriculture, livestock production and aquaculture are expanding and intensifying, and bringing new environmental externalities, including those on water quality. Land clearing for agriculture frequently results in land degradation and increased erosion and sediment loads on waterways. Unsustainable agricultural intensification is associated with greater water abstractions, reduced stream flows and depleted aquifers, all of which increase pollutant concentrations. Agricultural intensification has also increased the export of nutrients, pesticides and other pollutants from farms to water bodies.

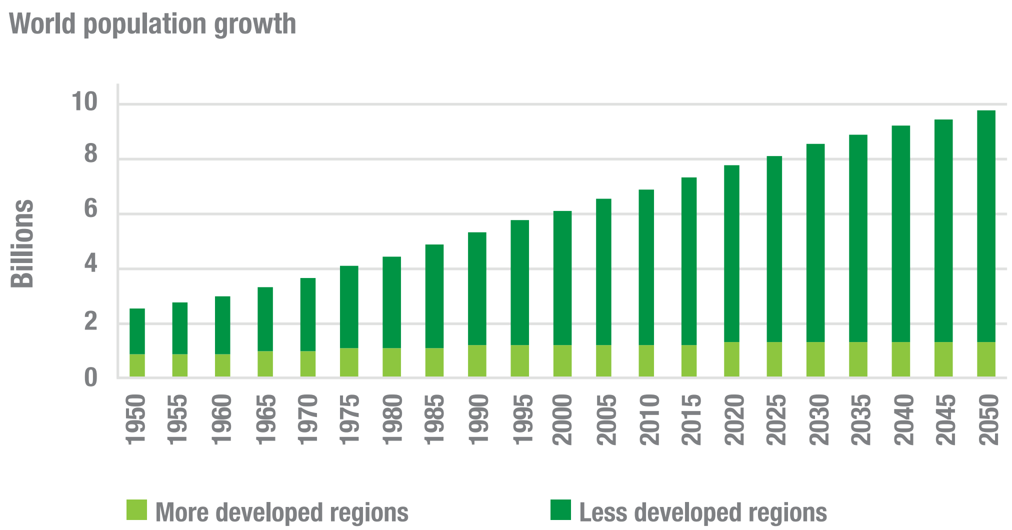
While there are other relevant drivers of change in global agriculture (Hazell and Wood, 2008), this chapter focuses on the most important drivers for agricultural pollution. Section 2.1 analyses the influence of the growing population and changing diets on food demand and production patterns. Section 2.2 reviews how the expansion and intensification of agriculture are influencing the use of agricultural inputs, including land and agrochemicals. In this section, the trends of cropping systems are discussed, with a special focus on irrigation and the use of fertilizers and pesticides (Section 2.2.1), followed by a consideration of trends in livestock production (Section 2.2.2) and the expansion and intensification of aquaculture (Section 2.2.3).

## 2.1 Trends in population, diet and food demand

We are currently 7.6. billion people on earth with more than 50% of the world's population concentrated in India, China, the USA and Europe. Globally, population is projected to reach 9.8 billion people by 2050 (UNDESA, 2017) and most of this growth is forecast to take place in developing countries in Asia and Africa, while the population of OECD countries is expected to remain steady or decline (UNDESA, 2017) (Figure 2.1).

Based on economic growth over the last 35 years, forecasts predict that the global economy will be richer by 2050, with future global GDP 2.4 times greater than at present in real terms (Figure 2.2). Analyses reveal a simple and temporally-consistent global relationship between per capita GDP and per capita demand for crop calories or protein (Tilman *et al.*, 2011). As populations have become richer overall, and despite the continuing large number of people living in absolute poverty, average calorie intake has increased from about 2 000 kcal/capita/day in the 1960s to more than 2 800 kcal/capita/day today, with some countries, such as the USA, Italy, Egypt and Turkey, exceeding 3500 kcal/capita/day on average, with even higher intakes in some locations (FAO, 2017).

**FIGURE 2.1** | **Past and expected global population in developed and developing countries**

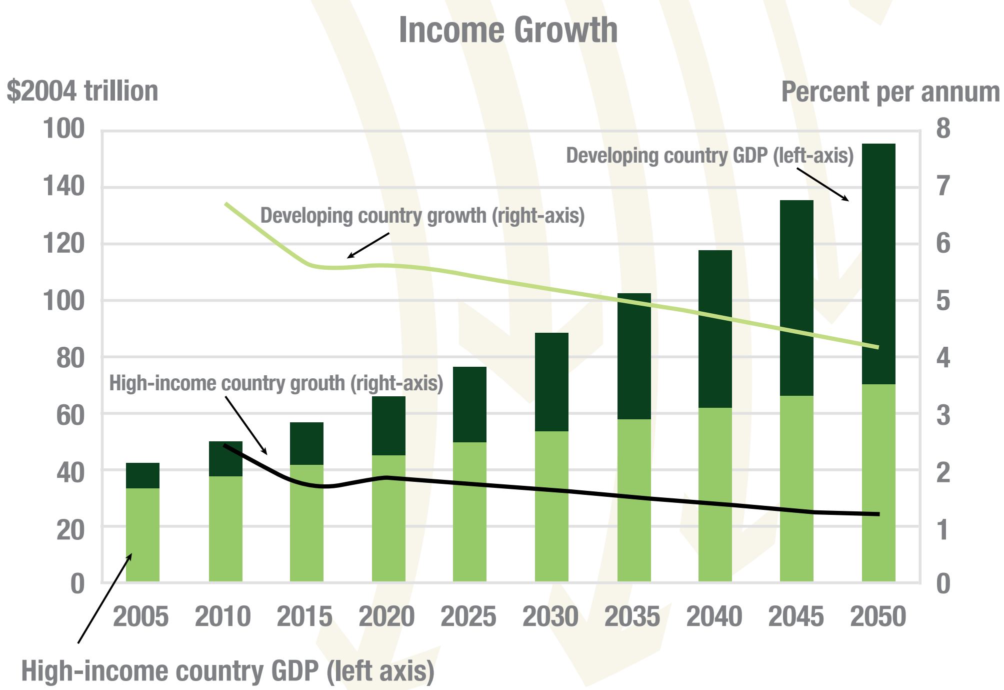



Source: UNDESA, 2017.

Dietary preferences are changing from mostly grains and carbohydrates to a greater consumption of meat, eggs, dairy, oil, fish, vegetables and fruit (Figure 2.3 and Figure 2.4) (FAO, 2009). Trends in meat consumption are a case in point (Delgado, 2003). Between 1961 and 2013, the average annual worldwide meat consumption rose from an average of around 23 kilograms per person to more than 43 kilograms per person (FAO, 2017). Meat consumption is growing rapidly in China, India, South East Asia and Latin America, and is changing the least in sub-Saharan Africa and South Asia. It has been noted that meat-based diets require greater resources per person than vegetarian diets (Cassidy *et al.*, 2013). For example, a meat-based diet requires up to three times more phosphorus per year and person compared to a vegetarian diet (Metson *et al.*, 2012).

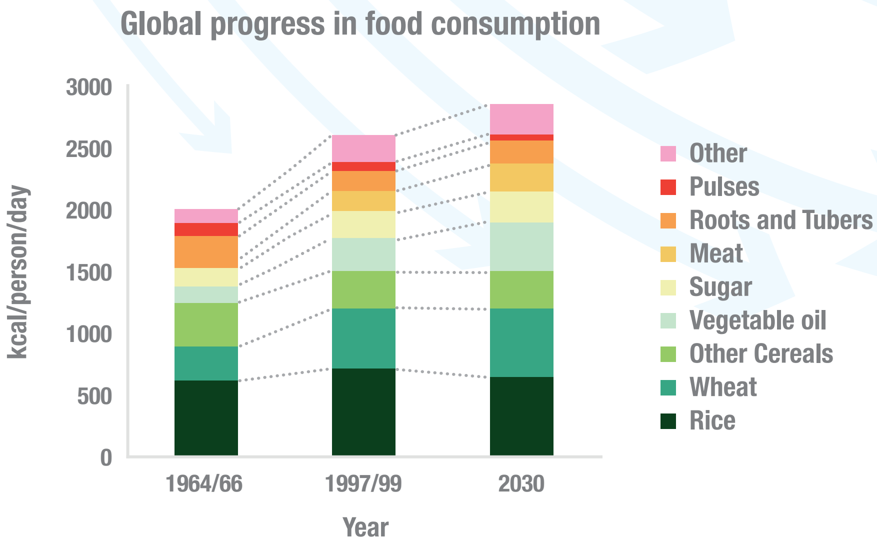
Despite the fact that the demand for cereals in human diets is not expected to increase substantially over the next three decades, the total demand for cereals is anticipated to grow to satisfy the demands for meat production, adding to the expected rise in demand for other crops. As a result, global crop demand will increase by an estimated 70% to 110% by 2050 (Alexandratos, 2009; Tilman *et al.*, 2011).

**FIGURE 2.2** Recent trends and forecast growth in income in low and high-income countries




Source: van der Menssbrugghe, 2009.

**FIGURE 2.3** Global food consumption patterns 1964-2030




Source: FAO, 2009.

The growth in food demand will impose clear challenges on agroecosystems, although there is little evidence that this will change dietary preferences and trends in general. Despite the lack of impact of public awareness campaigns or environmental labeling of foods on diets (Grunert, Hieke and Wills, 2014), it is apparent that targeted policies are needed to make food consumption patterns more sustainable and resource-efficient.

Another key issue relates to food supply and the response of food systems to the projected growth in food demand. Food losses and waste must be reduced as much as possible to bring food-production closer to actual demand, and to minimize the waste of resources and associated environmental impacts. About one-quarter of food production is lost along the food supply chain, which accounts for 24 percent of the freshwater resources used in crop production, 23 percent of total global cropland area and 23 percent of total global fertilizer use (Kummu *et al.*, 2012).

Nitrogen pollution is particularly important for water quality: Grizzetti *et al.* (2013) calculated that the nitrogen delivered to the global environment from food waste amounts to 6.3 teragrams per year, and that, in the European Union, 12 percent of diffuse nitrogen water pollution in agriculture is linked to food waste.

**FIGURE 2.4** Weekly food consumption of an Australian family


Sources: Menzel and D'Aluisio, 2007.

The need to produce more food will very likely result in the additional clearing of land for food production, as well as requiring an increase of productivity on existing lands. Business as usual cannot be sustained. The necessary increases in agriculture productivity cannot be achieved at the expense of the environment, as has been the case over the last 50 years.

## 2.2 Expansion and intensification of agricultural systems

The implications of further intensification of crop, livestock and aquaculture production are worrying: there is potential for this to cause great and widespread harm to ecosystems and human health. Although lower profile than climate change, the challenge of developing a sustainable but highly productive approach to agriculture is beginning to tease the consciousness of both the public and policy-makers. The following sections review the often unsustainable trajectory that agrifood systems have followed over time and identify the ways in which crop production, livestock and aquaculture may have been key contributors to water quality degradation.

### 2.2.1 Cropping systems

The world's population doubled between 1970 and 2015. During that time, the global production of cereals almost tripled, the production of vegetables increased fourfold, tomato production increased fivefold and soybean production increased eightfold (FAO, 2017). This huge increase in production was achieved through the expansion of agricultural land (and irrigation in particular), the introduction of new crop varieties and more intensive use of agrochemicals and agrotechnologies.

In the future, FAO expects that 90 percent of the growth in global crop production will come from intensification. In developing countries, 80% of the necessary production increase will come from increases in yield and cropping intensity, and 20% from expanding arable land. By 2050, the area of arable land will be expanded by 70 million hectares, about 5% of the current area. This includes an expansion of 120 million hectares in developing countries and, in developed countries, a contraction of 50 million hectares in favour of other uses (Alexandratos, 2009).

In many OECD countries, agriculture is generally large-scale, mechanized and often specialized. Under post-war policies, the intensification of agriculture in Europe and the US proceeded apace to provide sufficient, varied, high quality and affordable food for everyone. Increasing economic efficiency, economies of scale and subsidies favoured intensification. The intensity of fertilizer use per hectare in Europe and the US probably peaked in the 1980s, but the use of organic fertilizers (farmyard manure and slurries) are on the rise and require proper management.

At the other end of the spectrum, in many low-income countries, rainfed agriculture is simply too risky to justify widespread and even replacement rates of fertilizer application. The result is declining soil health and fertility, which contributes to land degradation on a broad scale. The intensive use of agricultural chemicals is often associated with irrigation and horticulture. In low income countries, water quality degradation is more often linked to untreated wastewater from urban areas, sediment loads from soil erosion, salinization and water scarcity (which aggravates pollution) (UNEP, 2016). The stockpiling and use of obsolete pesticides is also a growing concern.

Transitional economies are witnessing increasingly intense input use and rising agricultural pollution loads, which exacerbate the environmental impacts from as-yet largely untreated industrial and municipal effluents. China's use of nutrients per hectare – mostly on irrigated (and horticultural) lands – is thought to be among the highest in the world, for example.

## 2.2.2 Expansion of irrigation

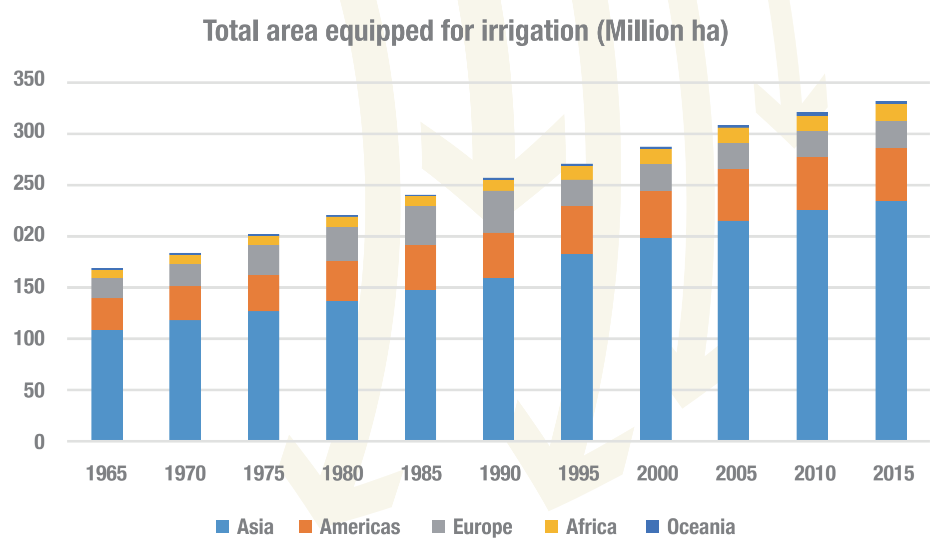
Irrigation is a major factor in agricultural intensification. Irrigation projects have helped to increase food security around the world, particularly in developing countries. Nevertheless, irrigation and drainage have often been associated with a loss of water quality caused by salt, pesticide and fertilizer runoff, and leaching.

Between 1965 and 2015, the total arable and permanent cropped area across the globe increased by 15% from 1 380 million hectares to 1 594 million hectares due to a net increase in the area equipped for irrigation (from 170 million hectares in 1961 to 333 million in 2015), particularly in Asia and the Americas (Figure 2.5) (FAO, 2017).

Currently, more than 50% of the world's irrigated land is located in India, China, the United States and the European Union (Figure 2.6.). Pakistan, India, Japan, Malta and Israel have the highest irrigation intensity, with more than 30% of their agricultural land under irrigation (World Bank, 2013).

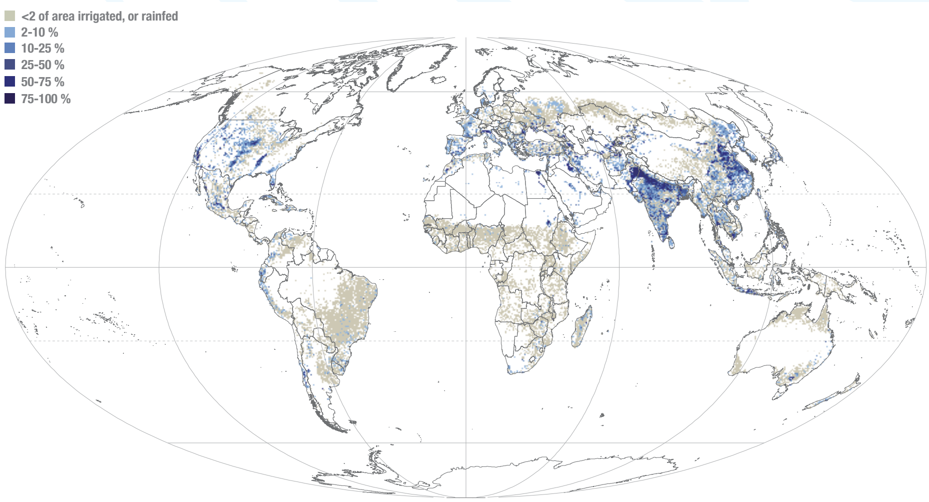
The growth of irrigated agriculture continues but at a changing pace. First, the expansion is likely to slow down in the future, limited by water availability. Also, new developments in irrigated agriculture are making a more efficient and productive use of water in a number of countries, minimizing the leaching of nitrates and other pollutants.

**FIGURE 2.5** **Area equipped for irrigation (1961-2015)**




Source: FAO, 2017.

**FIGURE 2.6** Global map of agricultural irrigated land




Source: Siebert *et al.*, 2007.

The value of irrigated produce has a high and growing share in agricultural production value (in excess of 50%) and in the value of exports (more than 60%), particularly in OECD countries such as Italy, Mexico, Spain and the United States. Farming increasingly uses groundwater, and the share of total use is over 30% in some countries. Groundwater overdraft is now evident in parts of Australia (e.g. the Namoi Valley) Greece, Italy, Mexico and the United States (OECD, 2008).

Irrigated agriculture will continue to be a focal point for intensification. Since irrigation is already a key cause of water scarcity and degradation in many river basins and some groundwater systems, any further intensification needs to be closely observed and managed carefully to avoid further damage to aquatic ecosystems.

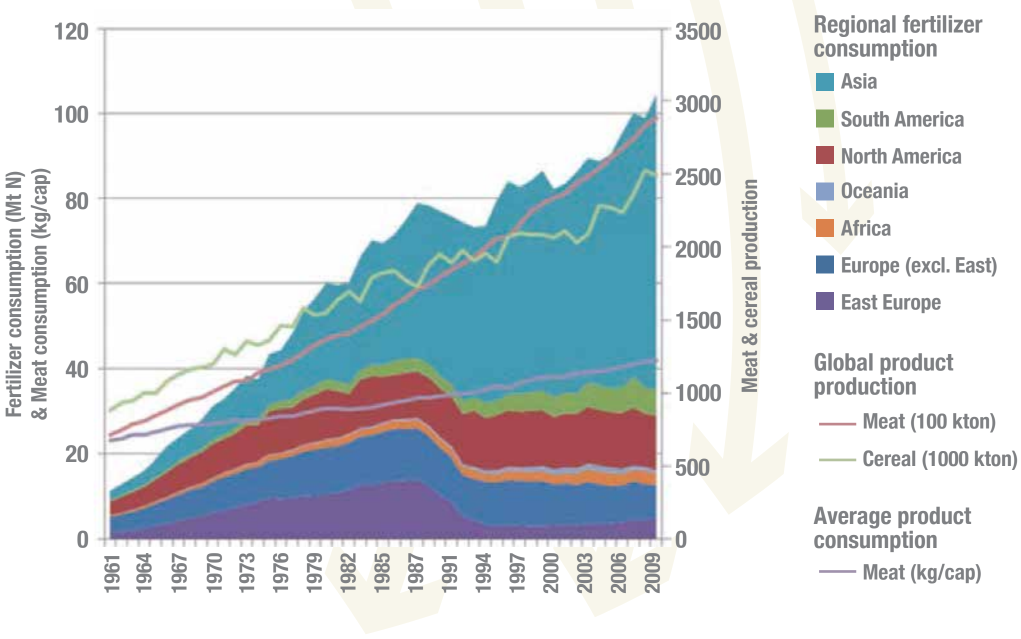
## 2.2.3 Trends in fertilizer use

Nutrients, especially nitrogen (N) and phosphorus (P) are essential for raising crops and animals to feed an increasing world population. Although mineral fertilizers have been used since the nineteenth century to supplement natural nutrient sources, the use of such fertilizers has increased dramatically in recent decades (Figure 2.7). Today, the world consumes ten times more mineral fertilizer than it did in the 1960s (FAO, 2017). Rockström *et al.* (2009) suggested that the mobilization of nutrients may already have exceeded thresholds that will trigger abrupt environmental change in continental-to-planetary-scale systems, including the pollution of ground and surface waters.

Global fertilizer use increased faster than crop production (particularly cereals) until the late 80's. Fertilizer use has grown coupled to crop production from then (Figure 2.7). However, fertilizer is not used on an equal basis around the world, with some countries using too many nutrients and others not enough. North America, Europe, and parts of South and South-East Asia and Latin America tend to overuse fertilizer with risks on water quality, while Africa, Central America and parts of Asia are unable to mobilize adequate nutrients to meet crop demand and food security needs (Sutton *et al.*, 2013). Fertilizer consumption has particularly boomed in East and South Asia over the last 50 years; in northern America and Europe if has been fairly stable or in decline.

The contribution of manure to total fertilizer use has declined over the last 50 to 60 years. Global manure N inputs decreased from 56% to 40% of total N inputs (from manure and fertilizers) from the 1960s to 2014 (FAO, 2018). Nevertheless, manure remains the main nutrient input to agricultural lands in many developing countries. The biggest contribution rates of manure to fertilization can be seen in Africa (84%) and Latin America (73%) (FAO, 2018).

**FIGURE 2.7** **Total mineral fertilizer consumption in major world regions compared with global cereal and meat production and per capita meat consumption**




Source: Sutton *et al.*, 2013.

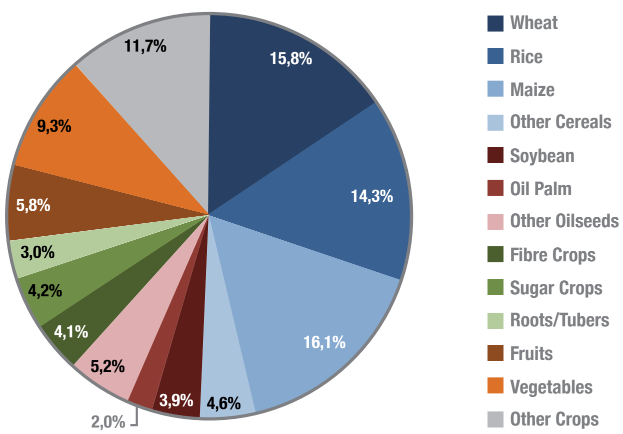
**BOX 2.1 Fertilizer use in China**

In transitional economies, of which China is the most powerful example, farms remain relatively small and landholdings per person continue to decline. Nevertheless, farming is becoming very intensive to keep pace with accelerating local food demand. Fertilizer use – sometimes promoted by perverse incentives – can be extreme and far from cost-effective (FAO, 2013). Although China's agricultural land accounts for only 7% of the global total, its fertilizer use is more than 30% of the fertilizer used around the world (Yan *et al.*, 2008).

On average, in 2015 fertilizer application in China was approximately 446 kg/ha of cropland (229 kg N/ha; 116 kg $P_2O_5$/ha; 101 kg $K_2O$/ha) (FAO, 2017); this is much higher than the recommended upper limit and greatly exceeds fertilizer use in many developed countries. On the North China Plain, the use of N and P fertilizer is reported to be 588 and 92 kg/ha/year, which is 66 and 135 percent more than the crops can assimilate (Vitousek *et al.*, 2009). This excessive use of fertilizer directly endangers soil resources and causes environmental pollution (Sun *et al.*, 2012). Severe environmental degradation is already evident in many of China's rivers and lakes and is causing real concern at all levels of society.

Not surprisingly, the largest portion of fertilizer is used for the production of globally important crops such as wheat, rice and maize (Figure 2.8). However, horticulture (fruit, vegetables and flowers) is generally the most intensive user of fertilizers (and also pesticides), although it accounts for only small proportion of cropped area – typically less than 1% in most countries – with China a notable exception with close to 10%.

**FIGURE 2.8 Distribution of fertilizer use by crop at the global level: 2010-2011/11**




Source: IFA, 2013.

FAO (Alexandratos and Bruinsma, 2012) predicts a 58% increase in total fertilizer use from 2002/2007 to 2050 in a business-as-usual scenario. At the same time, it estimates that growth could be reduced to 17% with 'efficiencies' in nutrient use derived from better fertilizer technologies and application practices. However, the projected patterns of fertilizer use are markedly different in OECD countries, transitional economies such as China and Brazil and developing countries.

In OECD countries, it is expected that: i) increasing efficiencies will further lower farm chemical inputs and exports, due to higher input prices that reflect increasing oil prices; ii) policies and incentives will encourage a greater use of biowaste and bioenergy feedstock on farms; iii) improvements in precision farming will reduce the demand for chemical inputs; iv) there will be greater public pressure to reduce the health risks arising from agricultural pollutants, forcing farmers to adopt better practices; v) a move to decouple subsidies from agricultural production will occur; vi) farmers' behavior will change to comply with national water quality policies and as a result of education and the provision of information.

A simplistic forecast is that transitional and developing countries will follow the same path that OECD countries have charted in the past: intensification and increased (and inefficient) input use to maximize crop and livestock production. This will be moderated by increasing costs of energy and inputs, notably for N-fertilizer (which is highly dependent on oil prices) and for inorganic (rock) phosphate, of which there is a finite supply. Estimates of the time of peak phosphorous have recently been revised to 2035, after which prices can be expected to rise rapidly as global stocks fall (Cordell, Drangert and White, 2009).

### 2.2.4 Trends in pesticide use

Pesticides include insecticides, herbicides, fungicides and plant regulators. Humans have sought to control crop pests since the Ancient Greeks used sulphur as a fungicide. Today, pesticide production is a multi-billion-dollar industry and production is steadily moving from the OECD to transitional and developing countries. When improperly selected and managed, pesticides can pollute water with toxic substances that can affect humans. Pesticides may also affect biodiversity by killing weeds and insects, with negative impacts up the food chain.

Inorganic compounds were commonly used, at relatively low levels of intensity, to control agricultural pests (insects, plant diseases and weeds) until 1945. Since World War II, farmers have widely used organic chemical compounds as insecticides, starting with the highly toxic and persistent organochlorines. DDT and most other organochlorine compounds were banned in the USA in 1972, leading to a slow ripple of regulation through the rest of the world. Organochlorines were banned in China in 1983. Organochlorine compounds were swiftly and progressively replaced by shorter-lived organophosphate products that, in general, do not accumulate in the food chain. However, as knowledge of ecology improves, it has become clear that organophosphate compounds can cause considerable unintended harm. As a result, many of the more toxic compounds have been progressively removed from the market in industrialized countries.

Although considerable use of older pesticides persists, the trend in the developed world is toward using newer pesticides that are more selective, less toxic to humans and the environment, and require less applications per hectare to be effective. A small but growing percentage of these are biopesticides, which are derived from natural materials such as animals, plants, bacteria and certain minerals.

## BOX 2.2 | Examples of chemical pesticides

**Organochlorine insecticides** were commonly used in the past, but many have been removed from the market due to their health and environmental effects and their persistence in the environment (e.g. DDT and chlordane).

**Organophosphate pesticides** affect the nervous system by disrupting the enzyme that regulates acetylcholine, a neurotransmitter. Most organophosphates are insecticides. They were developed during the early 20th century, but their effects on insects, which are similar to their effects on humans, were only discovered in 1932. Some are very poisonous (they were developed in World War II as nerve agents). However, they are usually not persistent in the environment.

**Carbamate pesticides** affect the nervous system by disrupting the enzyme that regulates acetylcholine, a neurotransmitter. The enzyme effects are usually reversible. There are several subgroups within the carbamates.

**Pyrethroid pesticides** are a synthetic version of the naturally-occurring pesticide pyrethrin, which is found in chrysanthemums. They have been modified to increase their stability in the environment. Some synthetic pyrethroids are toxic to the nervous system.

**Neonicotinoids** affect the central nervous system of insects. They have been associated with some bee kill incidents. Neonicotinoid pesticide products are applied to leaves and are used to treat seeds. They can accumulate in the pollen and nectar of treated plants, which may be a source of exposure to pollinators.

**BOX 2.3 Biopesticides**

Biopesticides include micirobials, botanicals and semi-chemicals. Microbial pesticides consist of micro-organisms (bacteria, viruses, fungi) and their intermediate metabolites as the active agent. The most widely used microbial pesticides are subspecies and strains of Bacillus thuringiensis, or Bt. Each strain of this bacterium produces a different mix of proteins, and specifically kills one or a few related species of insect larvae. Other biopesticides are naturally occurring biochemical substances that control pests by non-toxic mechanisms, such as insect sex pheromones that interfere with mating as well as various scented plant extracts that attract insect pests to traps (Zhang and Pang, 2009).

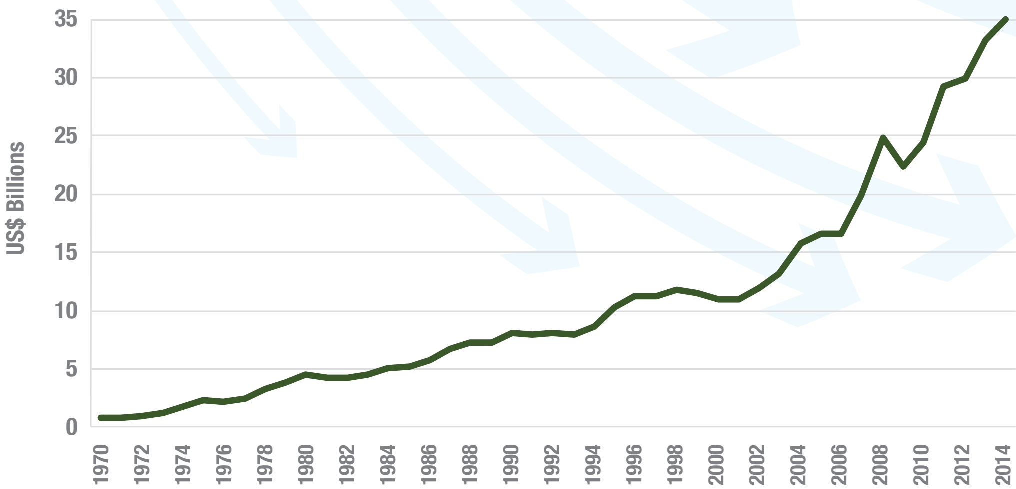
Some advantages of biopesticides, as compared to conventional chemicals, include good control of target pests, with very limited (or unknown) dangers for humans and non- target species. In addition, pest resistance appears to be slow to develop (Yang, 2001).

The biopesticide industry has been developing rapidly in China since the 1990s, with a growth rate of 10% to 20% per year. Hundreds of biopesticides have been registered worldwide, of which more than 30 are manufactured commercially (Xu, 2008). Mexico, the United States and Canada are the biggest users: their consumption of biopesticides accounts for 44% of the world total. Consumption of Europe, Asia, Oceania, Latin America, the Caribbean and Africa accounts for 20%, 13%, 11%, 9% and 3% of world consumption respectively (Qin and Kong, 2006).

Global sales of pesticides have increased dramatically over the past 50 years, with a global market worth more than USD 35 billion per year at current prices (Figure 2.9) (FAO, 2016a). The proportion of herbicides has increased, while the relative proportion of insecticides has declined significantly over recent decades, stabilizing more recently. The proportion of fungicides in use (18-24%) seems to fluctuate from year to year, reflecting variability in climatic conditions and market prices. China, the United States, France, Brazil and Japan are the largest pesticide producers, consumers or traders in the world (FAO, 2016a).

Synthetic pesticides are typically manufactured from petrochemical or inorganic raw materials and thus pesticide prices also track the oil price. It is difficult to obtain current information on pesticide pricing, but it is likely that rising sales exaggerate the growth in the volume of use in recent years as oil prices have risen over the same period. Prices for the herbicide glyphosate across the globe have increased by anywhere between 100% and nearly 500% since 2006, reflecting a number of other factors than the oil price.

**FIGURE 2.9** Value of global pesticide trade, 1970–2014

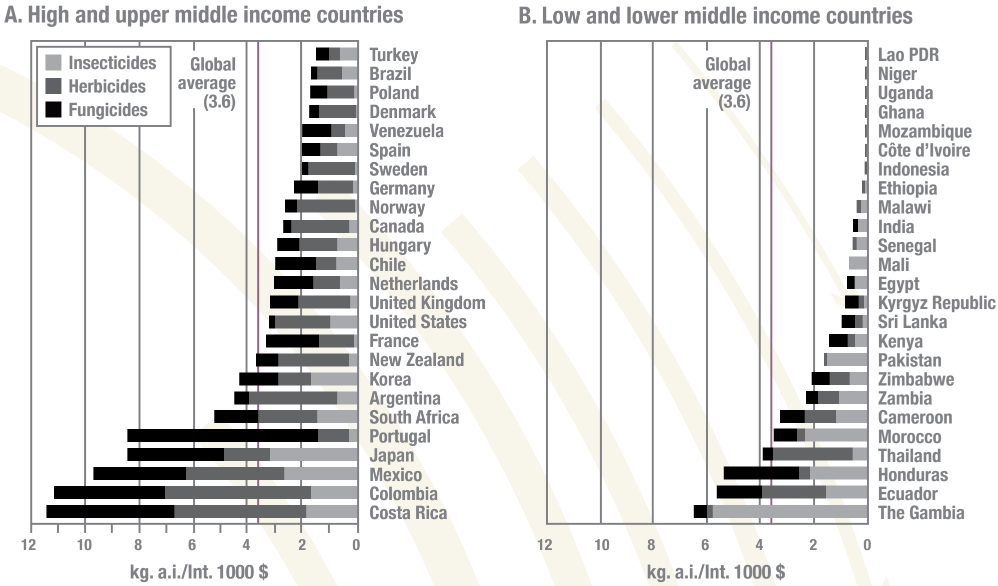



Source: FAO, 2016a.

Recent estimates of pesticide consumption based on FAO data can be seen in Figure 2.10. The figure compares, for a selection of 50 countries, the average intensity of pesticide use in terms of kilograms (kg) of active ingredients (a.i.) per 1 000 international dollars (unit) of crop output. The average country used 3.6 kg per unit of crop output and 3.2 kg of active ingredients per hectare of cropland, but levels vary widely between countries. High and upper middle-income countries (Figure 2.10.A) used much greater quantities of pesticides to produce the same quantity of crop output than did low and lower middle-income countries (Figure 2.10.B). Higher income countries thus had, on average, much lower pesticide productivity. Furthermore, crop output per hectare has generally increased less than pesticide use per hectare, on average a 1.8% increase in pesticide use per hectare has only translated into a 1% increase in crop output per hectare (Schreinemachers and Tipraqsa, 2012).

Future prospects are worrying as climate change is likely to enhance favourable conditions for pests and diseases of agricultural crops with higher temperatures, higher humidity, more variable rainfall and much more variable runoff in the semi-arid and humid tropics (FAO, 2011). Those conditions may further increase the demand for pesticides.

**FIGURE 2.10** Agricultural pesticide use per unit of crop output for a selection of 25 high and upper middle and 25 low and lower middle-income countries




Note: The figure is based on the three most recent years of available data.

Source: Schreinemachers and Tipraqsa, 2012.

In the process of land use intensification, developing countries have increasingly adopted a pest management approach that centres on the use of synthetic pesticides. As a result, several developing countries have undergone double-digit growth in terms of the intensity of pesticide use, though sometimes from a low base level (Schreinemachers and Tipraqsa, 2012). The fast rate of this growth and the reliance on broad-spectrum pesticides in the context of a weak institutional framework, weak rule enforcement and a limited awareness among farmers regarding the use of hazardous chemicals, pose enormous challenges to managing pesticides in a safe and sustainable manner. Indeed, currently millions of tonnes of pesticide's active ingredients are used in agriculture, 25% of which are used in developing countries where 99% of deaths due to pesticides occur (WHO, 2010).

## 2.2.5 Livestock production

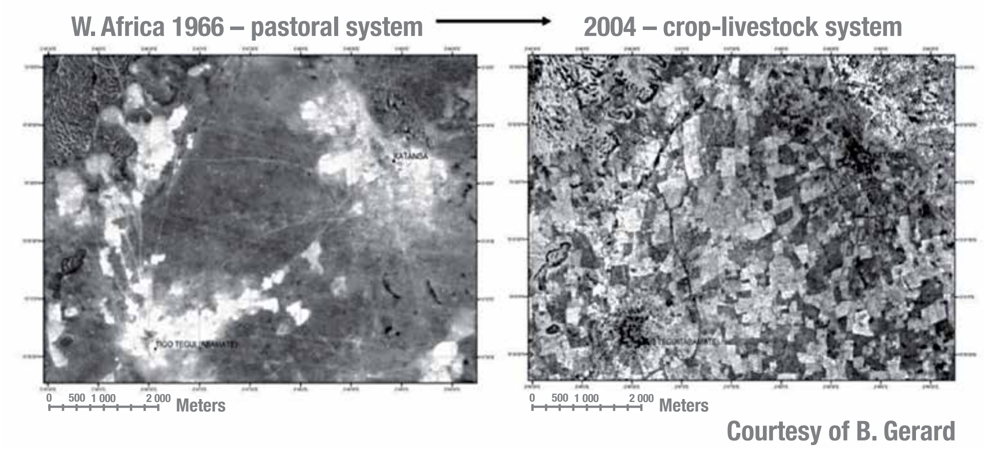
The livestock sector is one of the top three contributors to the most serious environmental problems, including water pollution, at every scale from local to global. Livestock production accounts for 70 percent of all agricultural land and 30 percent of the land surface of the planet (FAO, 2006).

Growing population and urbanization, together with higher incomes and changing diets, are rapidly increasing the demand for meat and dairy products. In response, the global production of meat is projected to more than double from 229 million tonnes in 1999/01 to 465 million tonnes in 2050 (FAO, 2006). Since 1981, global milk production has doubled to 700 million tonnes per year, with 75% of the increase generated in developing countries and 80% generated by smallholders, (McDermott, 2010). Global production is projected to grow to 1 043 million tonnes/year in 2050.

Animal production is changing locations to be closer to urban consumption hubs and to the sources of feedstuff for livestock, be it feed-crop areas, or transport and trade centers where feed is imported. There has also been a shift in species, with production of monogastric species (pigs and poultry, mostly produced in industrial units) growing rapidly, while the growth of ruminant production (cattle, sheep and goats, often raised extensively) is slowing down (FAO, 2006). As a result of these shifts, the livestock sector is entering into more and direct competition for scarce land, water and other natural resources.

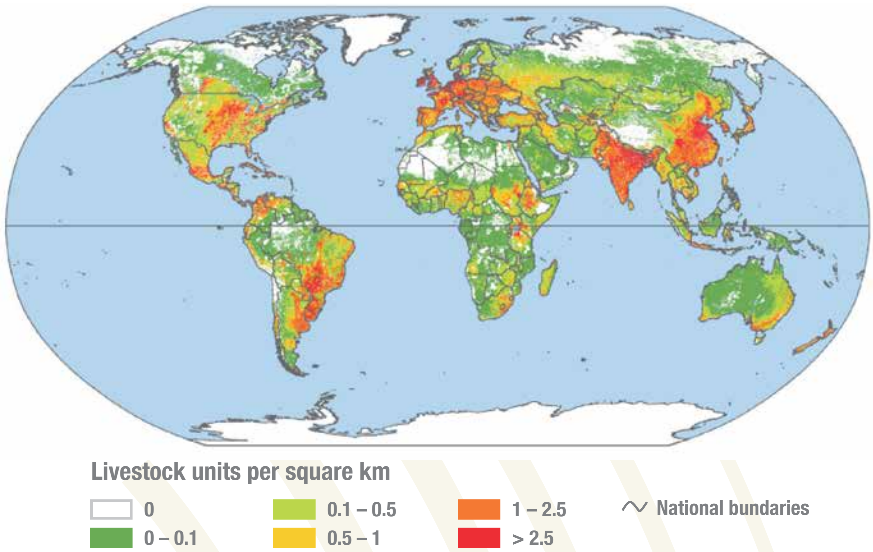
The intensity with which the sector uses land is extremely variable. Of the 3.9 billion hectares used for livestock production, 0.5 are cropped, generally intensively managed; 1.4 are pasture with relatively high productivity; and the remaining 2.0 billion hectares are extensive pastures with relatively low productivity. The trend is to transform extensive pastoral systems into intensive crop-livestock management (Figure 2.11) or industrial livestock production, with a high concentration of animals fed with feed concentrates that are not produced locally (FAO, 2006).

**FIGURE 2.11** | **An example of the changing nature of livestock systems in West Africa**




Source: McDermott, 2010.

**FIGURE 2.12 Estimated aggregated distribution of pigs, poultry, cattle and small ruminants**



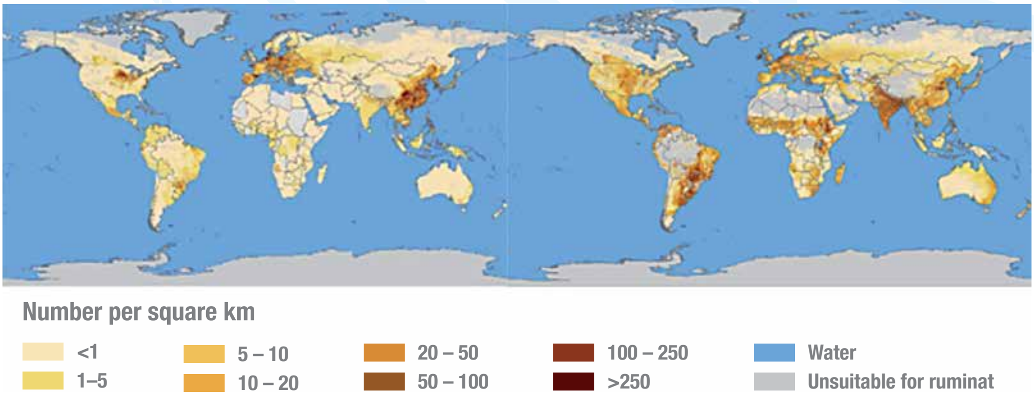

Source: FAO, 2006.

The global geographical distribution of aggregated livestock (pigs, poultry, cattle and small ruminants) is shown in Figure 2.12. There are currently five major areas of livestock concentration: i) central and eastern United States, ii) southern Brazil, Uruguay and northern Argentina, iii) Europe, iv) India and v) China. Other areas with substantial livestock concentration include eastern Africa (e.g. some parts of Ethiopia, Tanzania and Kenya), the eastern part of South Africa, south-eastern Australia and New Zealand (FAO, 2006). Different livestock species have different geographical concentration patterns (Figure 2.13). Pig production is very intense in eastern China, Europe and north-eastern USA, particularly around Iowa and Minnesota, while cattle production concentrates in India, Brazil, Argentina and Uruguay, and to a lesser extent in Europe, USA, China and Central Africa.

There is a strong and well-established relationship between meat consumption and per capita income (Figure 2.14). However, current levels of meat consumption place countries such as China, Brazil, Argentina, Russia or Mexico well above the consumption expected on the basis of per capita income, and other countries like India or Turkey fall well below the expected consumption levels.

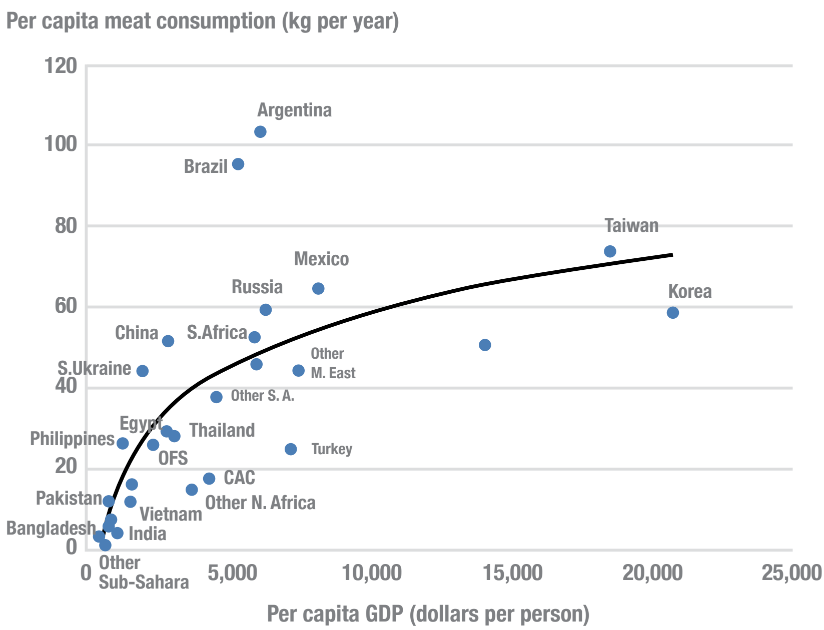
The major structural changes occurring in the livestock sector today are associated with the development of industrial and intensive livestock production systems. These systems often involve concentrating large numbers of animals in relatively small areas.

FIGURE 2.13 Distribution of pigs (left) and cattle (right) density across the world




Source: FAO, 2007.

FIGURE 2.14 Per capita meat consumption and income, in selected developing countries, 3-year average centered on 2010




Source: USDA, 2013.

Traditionally, livestock production was based on locally-available feed resources, such as crop wastes and browse, which had no value as human food. However, as livestock production has grown and intensified, it has come to depend less on locally-available feed resources, and more on feed concentrates that are traded domestically and internationally. It is estimated that around one-third of the global cereal harvest is used to feed livestock (FAO, 2006).

FAO has estimated that 20 to 25 percent of mineral fertilizer use can be ascribed to feed production for the livestock sector. For example, 4.7 million tonnes of N fertilizer is used for feed and pastures in the USA, almost 3 million in China and more than 1.2 million in France and Germany (FAO, 2006).

There is a great deal of variation in the extent and character of livestock sector growth. China and East Asia have experienced the most impressive growth in the consumption and production of livestock. India's livestock sector continues to be dairy-oriented, using traditional feed resources and crop residues. In contrast, Argentina, Brazil and other Latin American countries have successfully expanded their domestic feed base taking advantage of low production costs and an abundance of land.

In summary, the trends in the global livestock sector can be described as follows:

- The demand and production of livestock products are increasing rapidly in developing countries and have outpaced developed countries. A few large countries such as China are taking center stage.
- This increasing demand is associated with important structural changes in livestock sectors, such as the intensification of production, geographic concentration and up-scaling of production units.
- Despite increasing grain prices, there are concomitant shifts towards poultry and pig meat relative to ruminant meat, and towards grain- or concentrate-based diets relative to low-value feed.

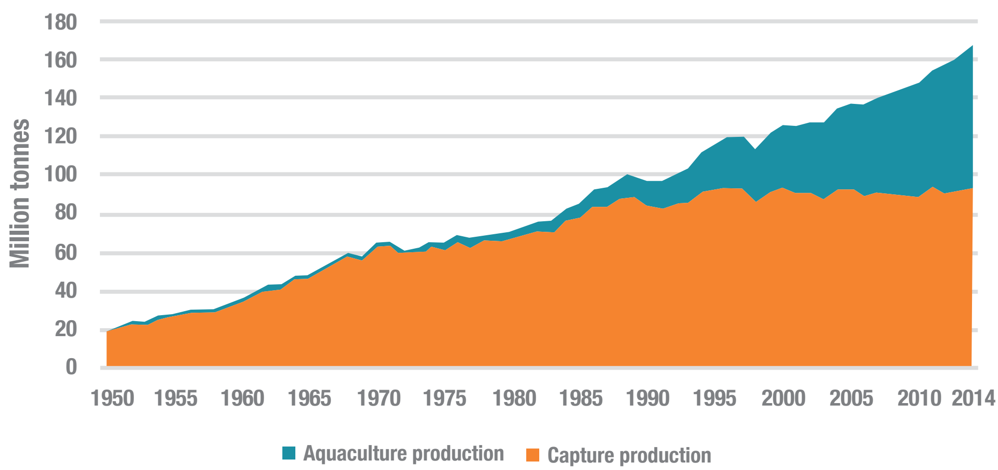
These trends indicate a growing pressure on the environment, and particularly on water quality as more solid and liquid excreta (manure) from livestock, nutrients, BOD, feed additives, hormones, antibiotics and heavy metals, agrochemicals and sediments flow into water as a result of the increased production of livestock and animal feed.

### 2.2.6 Aquaculture production

Over the last several decades, demand for fish and shellfish for food, feed, and other products has risen dramatically. Simultaneously, wild fish catches have plateaued since the 1990s, and the increased demand has been supplied by aquaculture, which has expanded dramatically and is producing now nearly half of all fish consumed (Figure 2.15). Total global aquatic animal production reached 167 million tonnes in 2014 (FAO, 2016b), of which an estimated 146 million tonnes was consumed directly by humans. In the meantime, the global harvest from capture fisheries has remained constant at approximately 90 million tonnes, while aquaculture output rose from 47 to 74 mT between 2006 and 2014. Growth has occurred in marine, brackish water and freshwater environments, and the proportion of output from each sector have remained more or less consistent over this period – with between 50 and 60% of production from freshwater, 30-40% from marine conditions and 10% from brackish water environments. There has been a slight increase in the proportion of freshwater species (heading towards 60%) since 2000, while marine production has tracked down to around 30%.

At the same time, there has been a steady increase in the proportion of fed species that require externally-produced foods, with non-fed species now accounting for 30% of production as compared to 50% in 1980 (Figure 2.16). Fed and intensive aquaculture can result in an excess of faeces, uneaten feed and drugs released into water bodies. Carnivorous species, which have high value, require high inputs of fishmeal and other pelleted feeds. Many types of non-fed aquaculture (e.g. mussel farming) can filter and clean waters, but other types (e.g. intensive caged crab culture) may disrupt natural nutrient cycles and result in water quality degradation.

**FIGURE 2.15** World fish production (million tonnes)



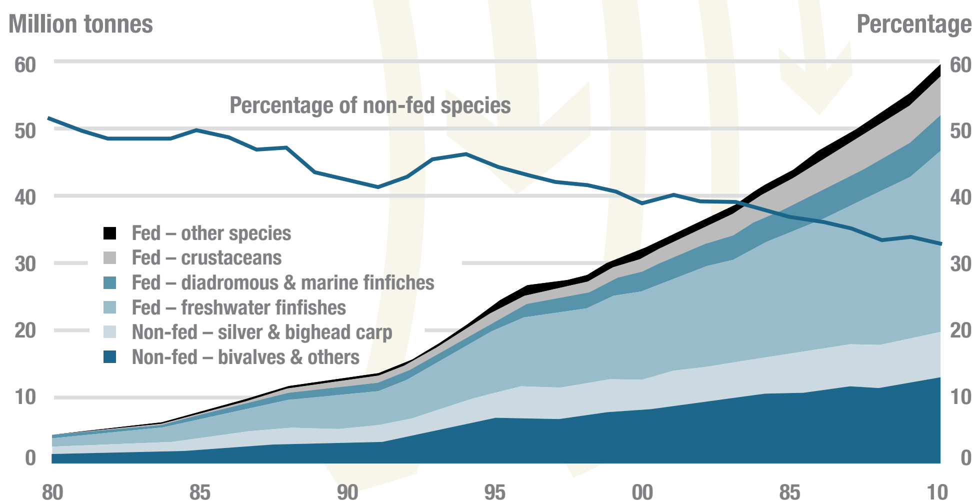

Source: FAO, 2016b.

The growth in aquaculture has overwhelmingly taken place in developing countries, which produce 91% of global output with the greatest concentration in the low-income nations. Globally there is great diversity of fish species. Freshwater species are predominantly cyprinids, tilapia and catfish, whereas diadromous fish (which can live in freshwater, brackish water and saltwater) are predominantly salmonids, milkfish and eels.

Asia generates the highest aquaculture output, representing almost 90 percent of world production, with output from China dominating at 45.5 million tonnes per year (FAO, 2016b).

Economically successful aquaculture demands a high level of water quality. Fish excreta are high in nitrate, nitrite and ammonia and flow rates through production units must be sufficient to control toxic levels and maintain dissolved oxygen levels at 6-9 mg/l. There is thus considerable natural synergy between aquaculture management and the maintenance of good water quality. Market pressure and differentiation are beginning to increase the intensity of production with an increasing concentration on single species. This has resulted in an increase in the use of medicines (antibiotics, fungicides and anti-fouling agents), which in turn pollute downstream ecosystems. Environmental impacts from aquaculture arise from the export and concentration of organic wastes (fish excreta and uneaten feeds) and from medicines. For example, large-scale shrimp culture has resulted in the physical degradation of coastal habitats through, among other factors, the conversion of mangrove forests and destruction of wetlands, salinization of agricultural and drinking water supplies and land subsidence due to groundwater

**FIGURE 2.16 Growth in aquaculture from 1980 to 2010**




Source: FAO, 2012.

abstraction. The discharge of untreated organic waste from salmon production is another concern in countries such as Norway, Scotland, Chile and Canada. However, the impact of this discharge is very localized and is limited to a few hundred metres of sea-bed. The dilution and dispersal of marine and brackish aquaculture effluents are governed by local ocean current patterns, and the nature and extent of impacts on eutrophication and fish stocks are quite variable.

This chapter has provided a summary analysis of how agricultural production systems have responded to growing demands for food over the past decades. Crops, livestock and aquaculture use much more land today than they did fifty years ago (frequently at the expense of forests or grasslands), and the use of land, water and other agricultural inputs is more intense than ever before. Large-scale monocultures in fertilized soils, intensive livestock production and fed aquaculture are becoming the rule rather than the exception in many parts of the world. As will be seen in subsequent chapters, the expansion and intensification of agricultural has contributed through different pathways (Chapter 3) to increased loads of nutrients (Chapter 4), pesticides (Chapter 5), sediments (Chapter 6), salts (Chapter 7), organic matter pathogens and other pollutants of emerging concern to water bodies (Chapter 8), with unprecedented impacts on human health and ecosystems. Nevertheless, as shown in Chapters 10 and 11, there are validated and emerging solutions that can pave the way towards a more sustainable intensification of agriculture to feed the world without further compromising the productivity and safety of agro-ecosystems in the long term.

## 2.3 References

**Alexandratos, N.** 2009. *Proceedings of a Technical Meeting of Experts: How to feed the world in 2050*. Rome: FAO (Food and Agriculture Organization of the United Nations). pp 1-32.

**Alexandratos, N.; Bruinsma, J.** 2012. *World agriculture towards 2030/2050: The 2012 revision*. ESA Working Paper No. 12-03. Rome: FAO.

**Cassidy, E.S.; West, P.C.; Gerber, J.S.; Foley, J.A.** 2013. Redefining agricultural yields: From tonnes to people nourished per hectare. *Environmental Research Letters* 8: 034015. 8p.

**Cordell, D.; Drangert, J.O.; White, S.** 2009. The story of phosphorus: Global food security and food for thought. *Global Environmental Change* 19: 292–305.

**Delgado, C.L.** 2003. Rising consumption of meat and milk in developing countries has created a new food revolution. *The Journal of Nutrition* 133: 3907S–10S.

**FAO (Food and Agriculture Organization of the United Nations)** 2006 *Livestock's long shadow: Environmental issues and options*. Rome.

**FAO.** 2009. *High Level Expert Forum – Global agriculture towards 2050*. Issue brief. Rome: FAO. Available at: www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf. [Cited on February 2017].

**FAO.** 2011. *The State of the World's Land and Water Resources for Food and Agriculture (SOLAW): Managing systems at risk*. Rome and London: FAO and Earthscan.

**FAO.** 2012. *The State of World Fisheries and Aquaculture*. Rome.

**FAO.** 2013. *Guidelines to control water pollution from agriculture in China: Decoupling water pollution from agricultural production*. FAO Water Reports 40. Rome.

**FAO** 2016a. FAOSTAT. Database. Available at http://faostat3.fao.org/browse/R/RP/E [Cited on February 2016]. Rome.

**FAO.** 2016b. *The State of World Fisheries and Aquaculture: Contributing to food security and nutrition for all*. Rome.

**FAO.** 2017. FAOSTAT Available at: http://www.fao.org/faostat/en/ [Cited on February 2017]. Rome.

**FAO.** 2018. *Nitrogen inputs to agricultural soils from livestock manure: New statistics*. Rome.

**Grizzetti, B.; Pretato, U.; Lassaletta, L.; Billen, G.; Garnier, J.** 2013. The contribution of food waste to global and European nitrogen pollution, *Environmental Science & Policy* 33: 186–195.

**Grunert, G.; Hieke, S.; Wills, J.** 2014. Sustainability labels on food products: Consumer motivation, understanding and use. *Food Policy 44: 177–189*.

**Hazell, P.; Wood, S.** 2008. Drivers of change in global agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences, 363*(1491): 495–515.

**Heffer, P.** 2013. by Heffer, P. *Assessment of fertilizer use by crop at the global level*. Paris: IFA (International Fertilizer Industry Association).

**Kummu, M.H.; de Moel, H.; Porkkaa, M.; Siebert, S.; Varis;, Ward, P.J.** 2012. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertilizer use. *Science of The Total Environment* Volume 438: 477–489.

**McDermott, J.** 2010. Global livestock trends – The past may not always predict the future. *Presentation to the US National Academy of Sciences, Board of Agriculture and Natural Resources Meeting, May 12, 2010*. Nairobi: ILRI (International Livestock Research Institute).

**van der Mensbrugghe, D.** 2009. *The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model*. Mimeo. Washington, DC: The World Bank.

**Menzel, P.; D'Aluisio, F.** 2007. *Hungry planet: What the world eats*. Napa, CA: Material World Press.

**Metson G S, Bennett E M and Elser J. J.** 2012. The role of diet in phosphorus demand. *Environmental Research Letters* 7 (2012) 044043 (10pp).

**Rockström, J. Steffen, W, Noone, K. *et al.*** 2009. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society* 14(2): 32.

**Sun, B.; Zhang, L.; Yang, L.; Zhang, F.; Norse, D.; Zhu, Z.** 2012. Agricultural non-point source pollution in China: Causes and mitigation measures. *Ambio* 41(4): 370-379.

**Sutton, M.A.; Bleeker, A.; Howard, C.M.; Bekunda, M.; Grizzetti, B.; de Vries, W.; van Grinsven, H.J.M.; *et al.*** 2013. *Our nutrient world: The challenge to produce more food and energy with less pollution. Global overview of nutrient management*. Edinburgh: Centre for Ecology and Hydrology on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

**Tilman, D.; Balzer C.; Hill, J.; Befort, B.L.** 2011. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Science USA 108(50): 20260–20264.

**UNEP (United Nations Environment Programme).** 2016. *A snapshot of the world's water quality: Towards a global assessment*. Nairobi.

**UNDESA (United Nations, Department of Economic and Social Affairs, Population Division).** 2017. *World population prospects: The 2017 revision, key findings and advance tables*. Working Paper No. ESA/P/WP/248. United Nations New York.

**USDA (United Sates Department of Agriculture)** 2013. *Developing Countries Dominate World Demand for Agricultural Products.* Available at: https://www.ers.usda.gov/amber-waves/2013/august/developing-countries-dominate-world-demand-for-agricultural-products/ [Cited on January 2018]

**Vitousek, P.M.; Naylor, R.; Crews, T.; David, M.B.; Drinkwater, L.E.; Holland, E.; Zhang, F.S.** 2009. Nutrient imbalances in agricultural development. Science, 324(5934), 1519-20.

**Wint, G.R.W.; Robinson, T.P.** 2007. *Gridded livestock of the world 2007*. Rome: FAO. 131 p.

**World Bank.** 2013. *World Development Indicators: Agricultural irrigated land (% of total agricultural land)*. Available at http://data.worldbank.org/indicator/AG.LND.IRIG.AG.ZS (accessed on 05-17-2016).

**Xu, Y.Z.** 2008. The application of biological pesticides and industrial development measures. *Chinese Agricultural Science Bulletin* 24(8): 402-404

**Yan, X.; Jin J.Y.; He, P.; Liang, M.Z.** 2008. Recent advances and prospects on the technology to increase fertilizer use efficiency. *Scientia Agricultura Sinica* 41(2):450-45.

**Yang, J.L.** 2001. *Green chemistry and technology*. Beijing: Beijing University of Posts and Telecommunications. pp. 176-180

**Zhang, W.J.; Pang, Y.** 2009. Impact of IPM and transgenics in the Chinese agriculture. In: R Peshin, R.; Dhawan, A.K. (eds) *Integrated pest management: Dissemination and impact*. Springer. pp. 525 - 553