Pesticides in agriculture

Introduction
The first part of this article explored the history and use of agricultural pesticides and focused on two important classes: herbicides and insecticides. Attention is given here to other pesticides of importance to farmers, as well as issues associated with their use - principally environmental sustainability and human health. In the production of agricultural food materials, herbicides are ubiquitous in the management and control of undesirable plant species that compete with crops and insecticides are important to both crop and farmed animal protection. Other biotic threats of importance to agricultural food production are various fungal species, which can be problematic in crop production, nematodes, which threaten plants and animals, and common rodents.

Farmers seek to gain advantage over the variety of pests that threaten crops and animals. Failure to do so can result in product losses and reductions in yield, quality and profit as well as, in certain instances, food safety hazards. Although farmers constantly seek to control the environment in which they produce agricultural foodstuffs through the management of pests, they must also remain cognisant of the possible negative impacts that pest control measures may have on local ecology and biodiversity as well as the capacity to sustain food production resources for future use.

As the agricultural pesticide industry developed through the 20th century and became an integral part of the mid-century Green Revolution, modern farmers, particularly in Europe and North America, embraced the technology and profited from huge increases in yield. However, with the benefit of hindsight, we are now beginning to understand that while synthetic pesticides offer immediate benefits for farmers and consumers, they also bring longer-term concerns about negative effects on ecosystems and wild biodiversity.

In the second of a two-part article (part one was published in the December issue of FS&T), Ralph Early describes the control of fungal, nematode and rodent pests and discusses the future of synthetic pesticides in agriculture.

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Fungicides
Fungi are ubiquitous in most ecosystems and are generally familiar as edible macro-fungi, such as meadow mushrooms (Agaricus campestris), which produce large fruiting structures. They are a kingdom of eukaryotic organisms that includes many species beneficial to human endeavour, for instance bakers’ yeast (Saccharomyces cerevisiae) used in the production of bread and Penicillium roqueforti, the mould used in the production of blue cheeses. Fungi are also represented by the numerous organisms responsible for creating the mycorrhizae essential to the maintenance of healthy soils and the growth of many plant species. Indeed, fungi are nature’s biodegraders.
involved in the breakdown and recycling of organic matter including, significantly, the decomposition of lignin, the structural polymer of vascular plants.

The significance of fungi to agricultural crop production lies in the capacity of some species to damage crops, causing reduced yields and crop failure as well as, in some cases, the production of mycotoxins harmful to both humans and animals. Some fungi of the genus *Fusarium* are prolific cereal pathogens affecting e.g. wheat and maize. They are capable of producing hepatotoxic and nephrotoxic fumonisins, and protein-inhibiting trichothecenes. Various *Aspergillus* and *Penicillium* species infect crops, such as maize and peanuts, producing carcinogenic and nephrotoxic ochratoxins, while others can produce the genotoxic mycotoxin, patulin, which is why many farmers rely on specialist agronomists for advice. Some fungicides, such as products containing fuberidazole (C17H17N3OS), are used as seed treatments, while others are applied to crops during growth, for instance products containing the active agent difenoconazole (C19H17Cl2N3O3), are used as treatment agents fenamidone (C17H17N3OS) and propamocarb (C9H20H2O2) in potatoes, with the former being effective against foliar infection, while the latter controls soil, root and leaf disease. Fenamidone-based fungicides are also used on grapes, tomatoes, tobacco and ornamental plants.

**Nematodes**

Nematodes – commonly termed roundworms – inhabit virtually all ecosystems. The exact number of species is unknown but estimates suggest around 40,000, with authors frequently describing and classifying new ones. Nematodes vary in size, some are microscopic, typically 0.1 mm in length, while other species are a few millimetres long and up to 1m in length.

In Britain the potato cyst nematode (PCN) represents a particular problem for farmers. The twelve species of PCN belong to the genus *Globodera* and frequent the roots of the Solanaceae family, e.g. potatoes and tomatoes. As natives of the Andes, PCNs were not originally present in British fields, but since they were introduced they have become a nuisance.

Apples grown in the Inn Valley, Austria, are treated with minimal use of pesticides although fungicides are important to achieving quality produce. Nets are fixed over the apples to prevent damage from hail stones.
states that PCNs are the most important potato pests in Britain capable of causing substantial yield losses, with two species, *Globodera rostochiensis* and *Globodera pallida*, being of particular concern. *G. pallida* is now more widespread due to a prolonged hatching period and selection pressure provided by the cultivation of potato varieties resistant to *G. rostochiensis*.

The carbamate insecticide, aldicarb (C$_7$H$_6$N$_2$O), which functions as a cholinesterase inhibitor, was widely used to control nematodes. However, it is extremely toxic and environmentally persistent, having been implicated in the collapse of ecosystems and the irreversible poisoning of farmland. It is also considered to be carcinogenic to humans and has been banned in some countries, although it is permitted in others, such as the USA, where commercial formulations are used in the production of cotton, beans, peanuts, soybeans, sugar beet and sweet potatoes. Biological methods of nematode control in crop production are now of increasing interest as an alternative to synthetics. Matthews[17] describes use of the bacterium, *Pasteuria nisizawae*, a cyst nematode parasite, as a means of such control. He also reports the use of biopesticides derived from fungi, such as *Paecilomyces lilacinus*, which is one of a number of nematophagous fungi producing toxins able to immobilise nematodes.

A variety of parasitic nematode species affect farmed animals, such as cattle, sheep and pigs, for example the large roundworm, *Ascaris suum*, causes ascariasis in pigs. Roundworm treatments include piperazine (C$_{11}$H$_{10}$N$_2$), anthelmintics, such as benzimidazoles (C$_7$H$_6$N$_2$) and *aldrin* (C$_{12}$H$_{7}$Cl$_2$N$_2$O), which are both Ecological by Design and Ethical by Design[5,6]. Aldicarb is a cholinesterase inhibitor, was widely used to control nematodes. However, it is extremely toxic and environmentally persistent, having been implicated in the collapse of ecosystems and the irreversible poisoning of farmland. It is also considered to be carcinogenic to humans and has been banned in some countries, although it is permitted in others, such as the USA, where commercial formulations are used in the production of cotton, beans, peanuts, soybeans, sugar beet and sweet potatoes. Biological methods of nematode control in crop production are now of increasing interest as an alternative to synthetics. Matthews[17] describes use of the bacterium, *Pasteuria nisizawae*, a cyst nematode parasite, as a means of such control. He also reports the use of biopesticides derived from fungi, such as *Paecilomyces lilacinus*, which is one of a number of nematophagous fungi producing toxins able to immobilise nematodes.

Rodents

Rodents as pests in agriculture are also familiar to those who work in the food industry. One of the key methods of control is the pest-proofing of buildings and produce storage facilities in order to prevent structural damage and, importantly, the contamination of products with urine and faeces as well as *cross-contamination* with spoilage and pathogenic microorganisms. The common mouse (*Mus musculus*) and brown rat (*Rattus norvegicus*) are associated with farms and together carry a range of rodent-borne diseases, such as Salmonellosis, Trichinellosis, Leptospirosis and Weil’s disease (a more serious form of leptospirosis).

Anticoagulant, coumarin-based poisons have long been used to control rodents in domestic and industrial situations, including farms. Warfarin, a first generation anticoagulant, has commonly been used and disrupts vitamin-K metabolism and the synthesis of various proteins including some necessary for blood clotting[6]. A number of more toxic, second generation anticoagulants are now available, including difenacoum, brodifacoum and flocoumafen, all based on 4-hydroxycoumarin. The use of rodenticides on farms is tightly controlled under the UK Rodenticide Stewardship Regime.

Future directions

As a tactical instrument of control, agricultural pesticides offer benefits to farmers and society in the management of pests in crop and animal production. However, increasing concerns about long-term strategic use and their negative effects on the environment, ecosystem stability and human health are causing environmentalists, public health authorities and policy makers to review rationales for continued use. It is clear that industrial agriculture, of which synthetic pesticides are an integral part, is not sustainable. The need to develop global food systems that are both Ecological by Design and Ethical by Design[7,8] is now understood by many authorities and the part that pesticides might play in such systems will be increasingly scrutinised. Indeed, for many years approaches to reducing and eliminating pesticides have been explored, principally because of environmental concerns, but now also because of concerns about human health.

Organic farming methods are well documented as an approach to food production that limits the use of pesticides, although some traditionally used compounds, such as copper sulphate, are extremely toxic. Agroecology, as detailed by Rosset and Altieri[9,10], is gaining ground worldwide as a form of agricultural food production that excludes synthetic pesticides and various governments are exploring its potential. Integrated pest management (IPM) as an approach to pest control in crop production has been under...
development since the 19th century. It aims at reducing the use of pesticides through a combination of biological, cultural, mechanical and chemical pest control methods, thereby minimising negative effects on wild biodiversity. However, concerns have been raised that although pesticide use is permitted within IPM, the prophylactic use of pesticides, such as neonicotinoids, challenges the spirit and practice of the technique.

Precision agriculture using a range of technologies, including satellite imaging and remote sensors feeding data to artificial intelligence (AI) systems controlling drones or UAVs (unmanned aerial vehicles) and robotic tractors, are taking agricultural food production in new directions. Bongiovanni and Lowenberg-Deboer suggest that precision agriculture can contribute to long-term sustainability by enabling the targeted application of off-farm inputs, such as pesticides, thereby reducing use. Interestingly, the rationale for precision agriculture appears to challenge assertions by the agro-chemical industry that agriculture based on the intensive use of chemical inputs can be sustainable. This may explain why some corporations are investing in precision farming technologies as they may sense that for moral and environmental reasons the sun is setting on the market for synthetic agricultural pesticides.

Environmental advocacy groups assert that genetically modified (GM) crops were originally developed as a strategic means of sustaining the market for pesticides whose patents were expiring and, at the same time, exercising commercial control over food systems. A quarter of a century ago GM crops were promoted as an ethically sound technology aimed at reducing pesticide use. A utilitarian ethical justification claimed that glyphosate-tolerant crops would limit to one the number of pesticides applied to a crop as well as reducing quantities used. Environmental groups opposed GM crops on deontological ethical grounds expressing concerns, for example, about the eventual occurrence of glyphosate resistant weeds. Such weeds have, in fact, become a problem in the USA, where GM crops have been extensively grown.

To address this problem new GM crops have been developed that tolerate glyphosate and dicamba (3,6-dichloro-2-methoxybenzoic acid), the latter being effective against resistant weeds. However, dicamba is controversial as it drifts onto non-target crops, trees and other plants causing severe environmental and economic damage. Consequently lawsuits associated with dicamba are being filed in the USA and linked to GM crop production. Some American food companies are being sued over glyphosate found in food products, with claims made that residues may be harmful to human health.

Conclusions
We may think of food as simply a matter of energy replenishment, nutrition and hedonic pleasure. But it is inescapably also a political issue concerning not least the means by which farmers produce raw materials for transformation into saleable food products.

Feeding a growing global population is frequently cited as the key challenge of the 21st century, with the prospect of world population reaching some 10bn by 2050. However, biodiversity loss and global climate change are rationally the priority issues for our time and both are impacted negatively by the world’s industrial food system, which is controlled by global corporations to feed mainly urban populations. Indeed, if the problems of biodiversity loss and global climate change are not resolved quickly, the question of feeding an expanded world population remains purely academic.

Agricultural pesticide use is now intrinsic to the industrial food system and in many ways has become synonymous with it, as has the use of synthetic fertilisers. The work of organisations, such as the Stockholm Resilience Centre, illustrates the need to reduce significantly synthetic pesticide use globally. It is becoming increasingly clear that we must learn to develop ways of farming with nature and not against it.

It is in the interests of pesticide manufacturers to transition from old-school 20th century pest control solutions and to explore the development of products that are consistent with sustainable food production and the protection and proliferation of wild biodiversity.

There is potential to develop new biological pesticides, perhaps based on microorganisms and their derivatives and possibly using GM technology, and macro-organisms, such as arachnids, insects and nematodes, that allow pest control without being ecologically catastrophic.

Indeed, we can be sure that the political dimensions associated with agriculture and food production will demand this as social and political concerns about mankind’s effects on the planet increase and take centre stage in national and international policy making.