Johann G. Zaller

Daily Poison

Pesticides - an Underestimated Danger

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The truth is reasonable for people.

Ingeborg Bachmann

Foreword

Why writing a book on pesticides? According to the advocates of pesticide-based agriculture, pesticides are among best studied substances in the world that specifically target weeds, pests or diseases and after fulfilling their duties, are broken down into harmless substances. Should traces of pesticides nevertheless be detected in food, the environment or the human body, this is said to be primarily due to the refined analytical methods. Usually, we consumers are comforted that pesticide residue levels in food are always below legal limits. In addition, everyone knows the century-old principle according to which only the dosage makes the poison, and one can even die from excessive water consumption! Consequently, anyone who speaks out against the use of pesticides is considered a dreamy environmentalist who denies the reality of modern food production and in doing so risking the starving of millions of people. This is the rough outline of the public presentation on the subject of pesticides. With this book I would like to shed some light on these and other statements about pesticides and challenge the truthfulness of the above-mentioned statements. This seems more important than ever, especially in our times of ubiquitous influence of politics through various interest groups, fake news and alternative facts.

You are only marginally interested in this topic, since you are neither a farmer nor a hobby gardener, and as a city-dweller you feel that you are not confronted with pesticides whatsoever? Well, let's consider you treat yourself with a pizza with mixed salad, a glass of wine or apple juice and a banana for dessert. Perhaps you will be surprised that for the production of the main ingredients, wheat for the pizza dough, tomatoes, corn, peppers, herbs, salad, wine and apple production, more than 1000 different pesticides are permitted in Europe, the USA or other countries (EPA 2019b; European Commission

2019)! Of course, all these pesticides will not be used at the same time, but they are theoretically available in the pesticide arsenal of conventional, pesticide-intensive agriculture. This pesticide number is conservative and does not include chemical substances that are allowed for further food processing, preservation, storage, taste improvement, cellar technology and so on. I hope that this example has convinced you that you are most likely also affected by pesticides, whether you like it or not!

I started with the research on the effects of pesticides on non-target organisms several years ago. In the hindsight I was quite naive when I started with this. Before that I spent almost 15 years studying the effects of elevated-CO_2, ultraviolet-B radiation and other environmental and climatic factors on ecological interactions between plants and animals. As many ecologists I preferred to investigate native ecosystems that are close to nature, because they usually inhabit interesting and rare species in great diversity. By contrast agricultural or other human-influenced ecosystems are often treated somewhat pejoratively by ecologists because the factors driving ecological interactions are simpler than in native ecosystems.

My curiosity on the pesticide topic rose after moving into a very nice region in Austria dominated by viticulture. Raised in a mountainous area with dominating grassland farming and no pesticide use I found it bizarre to spray pesticides on crops we would later consume or feed to livestock animals. Back then, of course, also the general media turmoil around glyphosate caught my attention. A first orientation on the topic in the scientific literature was eye-opening, because despite thousands of scientific studies published there were still many gaps in our knowledge. Just as most non-scientists and also many fellow scientists do, I believed that the pesticides that are used every day were, of course, rigorously tested before they could be applied to the environment in order to control pests and weeds. Of course, I remembered reading the famous *Silent spring* of Rachel Carson (Carson 1962) dealing with the devastating effects of pesticides on our environment but this was almost 60 years ago and things surely have changed. Well, after just a brief immersion into the matter, I concluded that many of these pesticide-related standard phrases were myths spread by pesticide manufacturers and various interest groups (Leu 2014). This eye-opener and what I experienced in the course of our relevant work at the University of Natural Resources and Life Sciences in Vienna inspired me to write this book. Most of what I compiled here is already published in various scientific papers, but who other than fellow scientists or a few science journalists reads and understands these articles often presented in very technical language?

The following aspects prompted me to write this book:

- The contamination even of newborn babies with traces of pesticides in their bodies.
- Parkinson's disease is a recognized occupational disease for winegrowers in France.
- The steady increase in legal limits for pesticide exposure and residue levels in recent years.
- The inadequacy for many modern synthetic pesticides of the much-used quotation from Paracelsus, according to which the dosage makes the poison.
- The many pesticide counterfeits with unknown ingredients which make up to 25% in some countries (UNEP 2018).
- Agrochemical companies pay several million Euros on compensation to Italian winegrowers because treatment with a recommended pesticide product led to complete crop failures.
- Toxic waste landfills of agrochemical industries are ticking time bombs especially in the event of natural disasters.
- Scientists who take a critical look at pesticides are quickly denounced in internet forums aiming to undermine their integrity?

Nobody can seriously say how the well over 100,000 chemicals that are currently in use affect our health and nature, as their side effects are insufficiently investigated. Theoretically, in Europe the precautionary principle is stipulated in the European Treaties. However, this principle is widely ignored also when it comes to free trade agreements (TTIP, Mercosur etc.). In my assessment of the situation I am strongly guided by this precautionary principle, which calls for restrictions in marketing a substance when there is a suspected risk to human health or the environment even when scientific evidence is not completely clear.

The first part of this book begins by outlining the problems regarding our use of pesticides, the quantities applied and where pesticides are mainly used. The second part gives an insight into the everyday scientific research of pesticide effects and their results. It also discusses how scientific results are disseminated and received in the public. If you now ask yourself how we can feed the growing world population without modern pesticide-intensive agriculture, then you have apparently been taken in by the marketing machinery of the agricultural lobbyists! The third part shows that pesticide-intensive agriculture is actually a quite unsustainable business model that causes tremendous costs for our economies and societies. The supposed benefits in crop yields by no means outweighs this. Fortunately, there are many practical alternative concepts that work without synthetic pesticides and even representatives of conventional agriculture admit that it would be possible to save half of the pesticides without causing drops in yields. An outlook chapter summarizes what is urgently needed for a transformation of pesticide-intensive agriculture and what policymakers need to contribute.

This book is based on a German popular science book (Zaller 2018). Although the German book already addresses international topics, I further expanded the scope of this English version in order to interest more international readers and updated the references with relevant studies. There remains a bias towards the pesticide situation in Europe, but that simply reflects my main sphere of activity. All statements in the text are supported by scientific studies that can easily be found in the internet. However, because of the broadness of the scope of the book I could only include a small part of the available studies—apologies if I forgot some important contributions. If the reader gets the impression that pesticides exclusively have detrimental effects on humans and the environment it is important to emphasize that there are of course studies out there that show only little effects. However, for my look at this matter both the precautionary principle and also some pragmatism is decisive. Why should we take unnecessary risks when there is scientific evidence on the harmfulness of certain substances and beyond, many alternative methods successfully demonstrate that there are pesticide-free measures to deal with pests, diseases and weeds? Additional information is knitted-in from numerous discussions with pesticide experts and practitioners.

Good scientific practice is characterized by the fact that studies are reviewed by other scientists (usually anonymously) and then published in international journals. In many modern journals, the studies, the underlying raw data and the reports of the reviewers are now made freely accessible for everybody. If studies on the approval of pesticides are still kept confidential by manufacturers or approval authorities, then this is scientifically suspicious and gives room for speculations that not everything might have been performed correctly. This secrecy is justified by manufacturers and authorities by protecting business secrets.

Readers who have not yet dealt with the pesticide topic will find some aspects simply unbelievable. However, it can be safely assumed that the real situation may well be even more serious than described in this book.

What I certainly don't want to do with this book is denouncing farmers that apply pesticides. My aim is rather to sensitize the farmers, other pesticide applicators and the wider public for this topic and perhaps ultimately also make it clear to politicians that there is an acute need for action for the benefit of our environment and our health. Moreover, often the farmers are ill-advised by people with unilateral economic interests. The mechanisms and entanglements between the agrochemical industry and spokespersons of the farm industry that lead to recommendations for such excessive use of pesticides must also be addressed in this context.

When I talk about pesticides in this book, I am referring to the substances—herbicides, insecticides, fungicides and others—that are sometimes called plant protection products. They are used in agriculture, forestry, by road-keepers, municipalities, railway companies and private persons in their gardens or at home. I personally refuse to use the term plant protection product because it is misleading and euphemistic. The absurdity of the term becomes clear when herbicides, i.e. substances that are made to kill plants, are also called plant protection products.

This book will not deal with biocides which are chemical substances that are used to control organisms that are harmful to human or animal health or that cause damage to natural or manufactured products. It is a very diverse group of poisonous substances including wood preservatives, insecticides, disinfectants, and rodenticides mainly used in non-agricultural applications. The terms "biocides", "pesticides" and "plant protection products" are often used interchangeably, the split up in different categories has mainly legal reasons. In Germany alone about 25,000 biocide products are known (UBA 2019), they are used outside of agricultural land in many areas of private or professional life such as in the building industry. Effects of these biocides on the environment and humans are particularly poorly studied and would fill another book. Biocides are approved throughout the EU, and are recorded in a positive list. Substances that are categorized both as a pesticide and a biocide are termed "Dual-Use" substances. Maximum residue levels for food also apply to these substances.

Already in this preface I mentioned the terms pests or weeds. Generally, both words are taboo words in an ecological perspective. In an ecosystem there are actually no unwanted organisms, since each species plays a specific role in the entire system. If an organism becomes harmful, then only if a certain population level is present. A few potato beetles, or thistles, have important functions in ecosystems; only if they occur in masses that harm our crops we see them as problematic and worth controlling. Since these terms for animals and plants, which occur at the wrong place in too large quantities, are so widely used in general language, I will use them also throughout the book.

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1

What Is the Problem? Pesticides in Our Everyday Life

Literally, pesticides are substances that kill pestiferous organisms. In practice, they include insecticides against insect pests, herbicides against weeds, fungicides against fungal pathogens, acaricides against spiders and mites, molluscicides against pest slugs, and so on. The widespread use of these toxins in agriculture is being justified by securing higher yields that are considered more important to human society than potential side effects of these pesticides. We will later see that there is actually quite little scientific evidence that more pesticides secure higher yields. Pesticide manufacturers and regulators are reassuring critics that everything is alright as long as pesticides are used correctly with proper application equipment and protective clothing. In this context, the term "application according to good agricultural practice" is often used. What sounds like a standard only means the farming practice common in a given region. It is actually a rather empty phrase without clear rules of applications, quantitative requirements, or any legal significance. Nevertheless, the term is often used to reassure consumers that food production is well-controlled and environmentally friendly. One wonders, however, why reports are mounting that, despite this good practice, pesticide residues are so widespread in our environment and food.

For about 60 years, conventional agriculture has relied on the intensive use of synthetic chemical pesticides. In order to safeguard agricultural yields, around 466 active substances are currently approved in the European Union; among them are also about 25% microorganisms, insect pheromones, and plant extracts which are not synthetic chemicals (EC 2019c). These active ingredients are mixed or formulated with so-called adjuvants or co-formulants to a great variety of pesticide products. This sums up to more than 1700

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pesticides approved alone in Germany (BVL 2019). It is not easy to get official numbers of approved pesticides for other important agricultural countries such as the USA or China, but numbers mentioned in studies indicate that it is substantially higher. There is still much to be said in later chapters about the role of these adjuvants, which are commonly considered chemically inert and ineffective.

In Europe, around 374,000 tons of active substances of pesticides are sold annually on average between 2011 and 2016 (Eurostat 2019). The demand for pesticides is increasing worldwide, and the amount of pesticide use has risen 50-fold since 1950. Figure 1.1 provides an overview of pesticide use in different world regions based on the United Nations Food and Agricultural Organization (FAO, www.fao.org/faostats). The database contains national data collected from 205 countries and territories via a questionnaire filled out by national statistical offices, ministries of agriculture, or other relevant agencies. Since 1990 the amount of total pesticides used in the world has increased by 80% until 2017. The only region with decreasing pesticide amount during this time was Europe, while all other world regions showed enormous increases by 218% in Oceania, 116% in the Americas, and 97% in Asia.

Many pesticides are produced and sold by European, US, and Chinese chemical companies. The whole pesticide business is gigantic and accounts for

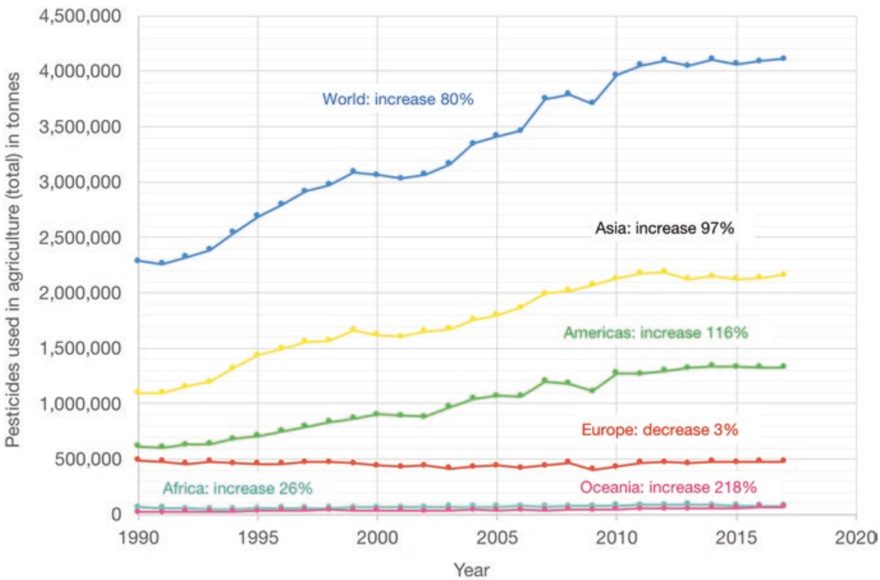

Fig. 1.1 Pesticide use in different world regions between 1990 and 2017. Graph drawn based on data from FAOSTATS 2019

an estimated 49 billion € worldwide (EPA 2017). Only four agrochemical companies control around 75% of the global pesticides business: two of them have their headquarters in Europe (BASF, Bayer/Monsanto), one in China (ChemChina/Syngenta), and one in the USA (Dow/DuPont now called Corteva Agriscience). The Chinese-Swiss company ChemChina/Syngenta is the world's largest pesticide manufacturer with a share of approximately 23% (MultiWatch 2016). The fact that the majority of research into the effects and side effects of pesticides is carried out or commissioned by these companies themselves is also notable.

It sounds unbelievable, but cautious estimates indicate that at most 10% of pesticides used are actually effective against the pests or diseases they are intended to control (Pimentel et al. 1998). Over 90% of the pesticides used affect areas not meant to be treated or impact so-called nontarget organisms, i.e., organisms that were not supposed to be controlled. Anyone who has ever observed pesticide sprayers on land, or worse, pesticide spraying via planes (so-called crop duster), can easily acknowledge this estimate of pesticide wastage. The consequences are inevitably a worldwide loss of biodiversity which is increasingly linked to pesticide use (Brühl and Zaller 2019). Furthermore, the pesticides, their degradation products, and co-formulants accumulate in the soil and impair nutrient cycles and the natural interaction between beneficial organisms and pests in nature. Sooner or later, these pesticides will also be found in drinking water or in our food and impair our health. Pesticides are now held responsible for neurological and hormonal dysfunctions, miscarriages, cancer, and other chronic diseases. These topics will also be elaborated further in later chapters.

Even though direct links between pesticide exposure and our health are difficult to prove, some health-related side effects are now legally recognized. Parkinson's disease caused by pesticides is officially accepted as an occupational disease for French winegrowers (agrarheute 2012; Gunnarsson and Bodin 2017). In order to be entitled to a retirement pension, winegrowers or farm worker must prove to have come into contact with the pesticides for at least 10 years and the disease must have broken out no later than 1 year after use. In Germany, too, several farmers and gardeners have already been granted pensions for occupational disease after developing Parkinson's. When I mention this aspect in public talks, it regularly leaves the audience in disbelief, consternation, and anger. Indeed, it is unbelievable that our farmers deal with such products. Sometimes it feels as if farmers are meant to sacrifice their health for the sake of cheap food. But even the agricultural chambers and extension services are silent about this and leave their members out in the pesticide rain. This is a taboo subject in many countries. Politicians responsible for agriculture, the environment, or health, or even representatives of farmers, seem to have more important issues on their agendas. But perhaps they are simply in a dilemma, since many of them sit in governing boards of agrochemical companies and are therefore in a conflict of interest if they would have to advocate for stricter regulations. This is at least documented for Germany (Balser et al. 2019; Nischwitz et al. 2019) and the USA (UCS 2018).

Agriculture, along with mining and construction, is one of the three most dangerous professions in the world. Of the many millions of accidents at work every year, at least 170,000 are fatal. The main causes for these fatalities are accidents involving machinery, poisoning with pesticides and other agrochemicals, physical overload, noise, dust, allergies, and animal-borne diseases (IAASTD 2009).

Pragmatics may now reply that pests and diseases need to be combated, because food production is at stake and farmers have to make a living from yields. It is assured that pesticides are only sprayed when there is acute danger and the harvest is threatened by pests, weeds, or fungal diseases. Unfortunately, this is not really the case. In many situations, pesticides are not only used when diseases or pests occur, but also as a preventive measure. This inevitably leads to some agricultural crops being treated with pesticides several times in the course of a vegetation period, for example because certain weather conditions increase the probability of fungal diseases according to computer models. Modern farmers are nowadays informed with text messages on their smartphones about the necessary pesticide treatments. This handy spraying advice is often provided free of charge by pesticide manufacturers. One might see a clear conflict of interest here as these advisors after all of course aim at selling their pesticides. I have also been told that unnecessary pesticide applications are also recommended by agricultural warehouses because salespersons do not want to risk any recourse claims from farmers in the event of crop failures (Zaller 2018).

Agricultural crops are differently affected by pests and diseases and treated with pesticides at different intensities. Generally, it is difficult to get hard data on the number, times, and frequency of applied pesticides. However, fortunately, we have published information from Germany (JKI 2019). These data include around 100 farms for each of the following crops: covering winter wheat, winter rye, winter oilseed rape, sugar beet, maize, potatoes, apples, and grapes, and 80 farms cultivating hops (Fig. 1.2).

Of course, these farms applied pesticides according to good agricultural practice. The most doubtful leader in the use of pesticides is apple cultivation with an average of 31 pesticide treatments per growing season, followed by viticulture with 18 and potatoes with 12 applications per season. Considering that the apple growing season lasts only 24 weeks (6 months), this is more

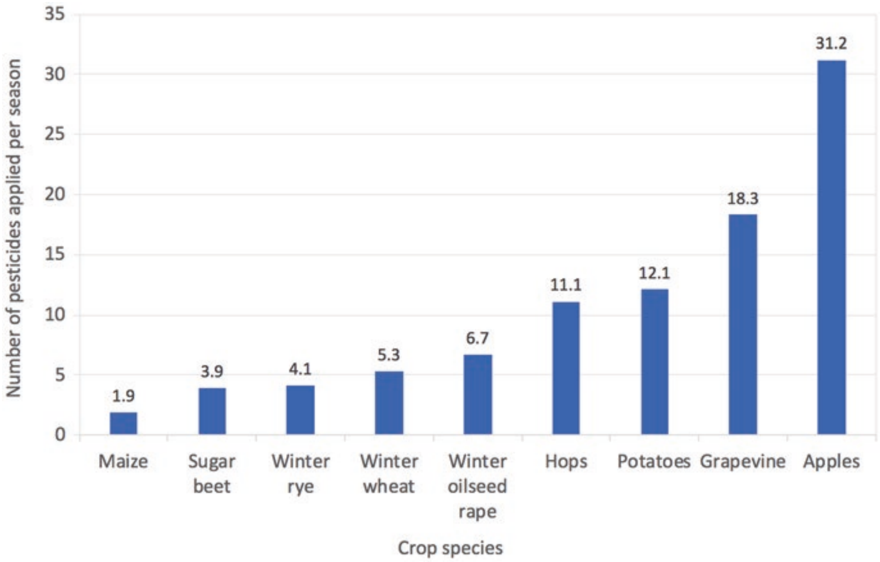

Fig. 1.2 Average number of pesticides applied in different crops assessed between 2011 and 2018 throughout Germany. Note that pesticides used for seed dressings are not included. Graph drawn based on data from JKI (2019)

than one pesticide treatment per week. In contrast, hops with an average of 11, wheat with five, or maize with two pesticide applications per season appear like near-natural forms of cultivation. Especially for the arable crops these numbers are too low as pesticides used in seed treatments are not considered. Also, pesticides used to store fruits are not included.

Comparisons with other countries are difficult because very little data is available for the public. However, it appears that the pesticide usage might be even heavier in other countries. As an indication the average number of pesticide treatments applied to crops in the UK increased dramatically (PAN UK 2017): for wheat from averaged 1.7 applications in 1974 to 20.7 in 2014, for potatoes from 5.3 applications in 1975 to 32 in 2016, and for onions and leeks from 1.8 applications in 1966 to 32.6 in 2015. Different time spans are mentioned due to the availability of data. An illustration of the available pesticides for different crops in the UK is also quite astonishing: there are 62 approved active ingredients with 633 approved products for potato production, and 93 active ingredients and 1432 products approved for wheat production (FERA 2020).

The figure makes clear that fruit and wine growing is very pesticide intensive. So, parental advice to children to wash fruits before eating was obviously well meant. However, unfortunately, many pesticides contain active substances that act systemically within the treated plant that means that they not only adhere to the outside of the plants or fruits but are distributed throughout the entire plant. Researchers actually tested a few different ways (water, bleach, baking soda) to get rid of pesticide residues from apples (Yang et al. 2017). Holding an apple under running water for a couple of seconds is not enough to get rid of the pesticides on its skin. However, almost all pesticides were gone from the apple surface after soaking the apples in a baking soda solution for 12–15 min! Still, about 20% of the fungicide and 4% of the insecticide used had soaked through the apple's skin and could not be washed off. Of course, the residue amounts found on fruits are usually low; however, depending on the type of pesticides and the amount you eat we will later see that certain pesticides may do harm to our health in the tiniest concentrations. So, the safest way is perhaps peeling your non-organic apples or buying organic ones.

But fortunately, as we read in the specialist books, modern pesticides are among the best tested chemical substances, comparable only to medicines (Hallmann et al. 2009). It is also constantly claimed that modern pesticides, in contrast to the older ones, are easily biodegradable and they quickly decompose into harmless components. Surprisingly, we regularly find pesticide residues in our food and every year pesticides are being banned because of their burden on the environment and human health. I do not want to sound polemical, but these are often the arguments in debates about pesticides.

The excessive use of pesticides is leading to another problem, which is now spreading around the globe. More and more animal pests or plant diseases become resistant against pesticides and weeds develop to so-called superweeds. It would be unfair to suggest that there is a business model behind this, since resistances ultimately lead to the development and sale of ever new pesticides. In any case, basic evolution in school biology already teaches us that organisms react to chronic stressors—and regular pesticide administration is nothing else—with evolutionary adaptations. Experts also warned very early on of the danger of resistance formation, but were ignored by the agrochemical industry. The situation is now so serious that even pesticide manufacturers are advising their farmers to switch to products of their competitors or apply more traditional methods of mechanical weed control (UCS 2013). With the logic of agrochemical companies, conventional research is now moving toward developing pesticides with several active ingredients or the development of genetically modified organisms (GMOs) that are resistant to several herbicides.

So far, we also contoured the problem area of this book. The following questions will be addressed further:

- How well do we actually know the substances that are applied in these large quantities?
- How rigorously are these products tested before they are marketed?
- What side effects do these pesticides have on our environment and on humans?
- Are the risks of pesticides outweighed by their benefits?
- What role does and should critical science and policy-makers play?
- Can we feed the growing world population without using pesticides?

But first we will briefly take a look on how the so-called conventional agriculture became so dependent on agrochemicals.

1.1 Agriculture in the Pesticide Treadmill

The history of pesticide use is almost as old as the history of agriculture itself because pestiferous organisms and plant diseases were always attacking crops. In Mesopotamia, elemental sulfur was used to combat pests on agricultural crops as early as 2500 BC. In the fifteenth century, the use of arsenic, mercury, or lead was widespread. In China during the Ming Dynasty (1368–1644), a number of plants and minerals were used as pesticides such as veratridine, flavescens, arsenolite, realgar, orpiment, and lime (Zhang et al. 2011). The voyages of discovery in the eighteenth century then brought to light the fact that plant-active substances can also be used against pests—nicotine from tobacco plants or pyrethrin from chrysanthemums plants. The widespread use of pesticides in the field began in the second half of the nineteenth century. The decisive trigger was probably the introduction of various pests around the globe with the upcoming of international trade, leading to catastrophic crop failures.

Back in 1845 Irish people based their diet largely on potatoes imported from the New World. Consequently, it was devastating when the potato blight (*Phytophthora infestans*), a fungal pathogen that is favored by moist, cool environments infected potato crops. In Ireland about one million people died and at least as many emigrated to the USA and other places; also, thousands left the Highlands of Scotland. The rest of Europe had more diverse crops and were not hit as hard. The disease is still around in our days and damaging potato crops and other crops of the Solanaceae family such as tomatoes. Around 1878, the highly aggressive fungus-like organism downy mildew of the family Peronosporaceae was introduced with seed potatoes from America to French vineyards. These are just a few examples of diseases that today's agriculture is still fighting against particularly when growing potatoes, grapes, tobacco, and cucurbits. In addition, worldwide trade flows constantly bring new potential pests or diseases to regions where they have no natural counterparts.

The first synthetic insecticide was developed as early as 1892 by the German agrochemical company Bayer. But the era of modern pesticides did really begin in the 1930s with organochlorine insecticides, including active ingredients such as the notorious DDT (dichlorodiphenyltrichloroethane) and lindane (gamma-hexachlorocyclohexane). It was in the 1940s that the first synthetic herbicide called 2,4-D (2,4-dichlorophenoxyacetic acid) was developed. All these substances are still around in our environment. We will see later that 2,4-D even celebrates a renaissance nowadays in the fight against glyphosate-resistant superweeds. Many pesticide-active substances, especially organophosphates, were used as combat gases during World War II or even in Iraq War in 2003. They were easy and cheap to produce and shown to be effective against a wide range of insect pests.

In many parts of the world, agricultural yields increased after the application of pesticides; therefore, their use was increasingly popular. In 1957, the first factory producing organophosphorus pesticides was built in China. Meanwhile, China has become the largest producer and user of pesticides in the world (Zhang et al. 2011).

Soon it turned out that many pesticides also have side effects on humans and the environment and that they were persistent and accumulated in the food chain.

In contrast to small-scale, traditional, and subsistence agriculture, modern conventional agriculture is characterized by specialization, monocultures, and maximum efficiency. At least that is how it is communicated to the public. Monocultures, i.e., the cultivation of an agricultural crop over huge areas, promote the development and spread of plant diseases and pests. The trend toward specialization is mainly found in conventional farming and to a lesser degree in organic farming.

Agriculture has undergone enormous changes in recent decades which heavily affected rural populations. In Europe in the 1950s more than half of the population was still employed in agriculture, whereas nowadays only 2.8% of Europe's working population is employed in agriculture (Eurostat 2018). Still we have about 10.5 million agricultural holdings in the EU in 2016, two-thirds of which were less than 5 ha in size. EU farms cultivated 173 million hectares of land in 2016, 39% of the total land area of the EU. The number of farms in the EU has been in steep decline, but the amount of land used for production has remained steady. Similar declines can be seen in all industrial nations.

Perhaps because of this decline in the labor force, the importance of agriculture compared with other branches of the economy is also notoriously underestimated by politics. However, a representative survey across Germany reveals that the importance of agriculture is still appreciated (TNS Emnid 2012). According to this survey most Germans think that a well-functioning agriculture is a basic prerequisite for the quality of life and viability of the country and that rural life is an important component of German culture. The survey also showed that ecological aspects are becoming increasingly important for people and that the production of renewable energies and climate protection are increasingly linked to agriculture. Compared with a similar survey 5 years earlier, the interest of the public in agricultural issues has increased significantly, but changed from a focus on the production of sufficient food to product quality and compliance with animal welfare standards. Now, almost 10 years later we are in the midst of the discussion how a transition of our societies toward more sustainability could be achieved. The keyword for agriculture is multifunctionality, i.e., not only the pure production of food, but also the creation of an attractive landscape, a healthy environment, and other agroecosystem services. I will look at this aspect in more detail later.

The basic principle of agriculture is actually to use solar energy as efficiently as possible through the cultivation of crops in order to produce food. It uses one of the oldest biological processes on earth: photosynthesis. Every plant utilizes solar energy, takes up the greenhouse gas CO_2, water, and nutrients, and builds up biomass, wood or fruits, which we can then use in a variety of ways. Fortunately for us, the waste product of photosynthesis is oxygen, which in turn is vital for most living beings (there are actually some viruses, single-celled microbes, and even multicellular animals that live without oxygen). The challenge for humans is to use this fascinating cycle in the most sustainable way possible.

Usually, we think that modern agriculture, with all its great machinery and sophisticated production facilities, is much better and more efficient at taking advantage of this solar energy link than old-fashioned, traditional agriculture. But this is not necessarily true. Around 1830, every unit of energy input in agriculture resulted in an output of five units in the form of food and harvested biomass. By 1910, this ratio even increased to 1:9, for energy input *versus* energy output. This was possible by better seed material and better equipment for field cultivation and smarter cultivation techniques. However, in the year 2000, the ratio between energy input and output in agriculture was only about 1:1, and some production methods now require more energy than can be extracted of the system (Krausmann 2001). Similar ratios apply for individual agricultural crops: the input/output ratio for maize was 1:10 in 1700 and 1:2.5 in 1980; traditional rice cultivation in the Philippines has a ratio of 1:108, but only 1:5 in the USA (Nentwig 2005). This means that modern agriculture, as the central supplier of human nutrition, is getting further and further away from being sustainable (Pimentel et al. 2005).

What are the reasons for this high energy consumption in agriculture? For US farmers, it has been calculated that almost 29% of energy costs are used for fertilizers, almost 6% for pesticides, and the remaining 65% for electricity and fuels (Schnepf 2004). If only fertilizers and pesticides are considered, then the fertilizer has an energy share of 77% of the crop product, followed by 23% for pesticides and seeds (FAO 2000). Synthetically produced fertilizers and pesticides used in agriculture have increased food production, but both fertilizers and pesticides also demand a lot of energy in production. Especially pesticide use and its energy demand are hardly addressed in the climate change debate. Nitrogen is the most important plant nutrient contained in fertilizers in terms of quantity. The production, transport, and application of one ton of nitrogen fertilizer corresponds to the energy content of about two tons of crude oil. Nitrogen fertilizer production uses large amounts of natural gas and coal and can account for more than 50% of total energy use in some sectors in conventional agriculture. Petrol accounts for between 30% and 75% of energy inputs of UK agriculture, depending on the cropping system (Woods et al. 2010).

Also, synthetic pesticides are made of fossil fuels and their production is very energy-intensive. For UK farming, it is estimated that pesticide manufacture accounts for less than 10% of energy input (Woods et al. 2010). Due to the great variety of pesticides and different production methods, there is a great variety on estimates on the energy intensity of its production. One can only estimate that the demand must be huge when seeing the great oil depots of agrochemical companies; also, many of those agrochemical companies are located near oil refineries. Estimates of carbon emissions, a measure for energy consumption, are in the range between 0.9–1.8 kg carbon per kg of nitrogen fertilizer. In comparison, average emission of carbon per kg of active ingredient is 6.3 kg for herbicides, 5.1 kg for insecticides, and 3.9 kg for fungicides (Lal 2004). The energy input devoted to pesticides of course depends on the agricultural sector. Fruit producers who treat their crops with pesticides 30 times per season have a higher proportion of their energy balance devoted to pesticides than cereal farmers who apply pesticides only four times per season. Despite the high energy costs of fertilizers and pesticides, farm machines are great diesel guzzlers. For example, in viticulture with about 25 pesticide applications during the season a diesel consumption of more than 250 liters/ha was estimated. Converted to 100 km, this corresponds to an incredible 300 l of diesel, or 0.8 miles per gallon (Moitzi 2005). Perhaps, this explains better why many farmers have their own filling station and why farmers fiercely fight for tax cuts on agricultural diesel.

Compared with that in 1950, the amount of pesticides used has increased about 50-fold (Tilman et al. 2002). If one projects pesticide production, which in the past has been constantly increasing, into the future, then pesticide production would almost double again by 2020, and almost quintuple by 2050. The exposure of nature and humans to pesticides will therefore also increase in the future.

There is little official information on the most commonly used pesticides used in different agricultural sectors in different countries. Of course, this would also be dependent on the agricultural sectors, actually be prevalent in different countries. As an example, the situation in the USA is shown in Table 1.1.

Of the 10 most commonly used active ingredients half of them are herbicides, with glyphosate, atrazine, and metolachlor-S being in the top three, and five are fumigants mainly used as fungicides or nematicides. Insecticides do not make it under the top ten of most commonly used pesticides in the USA.

It would be unfair to deny at this point the enormous achievements of agriculture in recent decades. During the first 35 years of the so-called *Green Revolution*, grain production doubled, thus satisfying the growing world population's demand for grain. The *Green Revolution* was proclaimed by the US Development Aid Organization as a countermovement to the violent Red Revolution in the Soviet Union. The American agronomist Norman E. Borlaug really pushed this concept forward in several regions of the world and even received the Nobel Peace Prize in 1970 for his work. The result was what we

Table 1.1 Most commonly used active ingredients of synthetic pesticides in the agricultural market sector in the USA in 2012. Data according to EPA (2017)

Active ingredient	Type	Amount applied (million kgs act. ingred.)	Rank
Glyphosate	Herbicide	122.5–131.5	1
Atrazine	Herbicide	29.0–33.6	2
Metolachlor-S	Herbicide	15.4–20.0	3
Dichloropropene	Fumigant	14.5–19.1	4
2,4-D	Herbicide	13.6–18.1	5
Metam	Fumigant	13.6–18.1	6
Acetochlor	Herbicide	12.7–17.2	7
Metam potassium	Fumigant	7.3–11.8	8
Chloropicrin	Fumigant	3.6–8.2	9
Chlorothalonil	Fungicide	2.7–7.3	10

call conventional, industrial-style agriculture that is characterized by large monocultures, large machines, chemical inputs in the form of fertilizers and pesticides, specialization, and a focus on a few high-performance crops. Since we have heard before how energy-intensive and machinery-intensive this type of agriculture is, it was probably not just a coincidence that it was mainly the oil giant Rockefeller and the agricultural machinery manufacturer Ford that supported this type of agriculture all over the world (Brown 2016).

Despite these achievements, almost 821 million people are still starving on our planet. Accordingly, the food industry and big agrocorporations agree unequivocally that we must press ahead with intensification in order to combat hunger in the world (WHO 2019). The fact that about 1.1 billion adults and children suffer from overweight and pathological obesity at the same time is deliberately overlooked in this discussion. The conclusion to be drawn is that enough food is actually produced worldwide, but that it is just unfairly distributed. In any case, never before have so much cereals been produced as today, but less than half of this amount actually serves as a direct food source. The rest is used as animal feed for meat production and as so-called agro-fuel mixed with fossil fuel or processed as industrial raw material.

Another example is palm oil. The EU is the second largest importer of crude palm oil in the world and more than half of it (around four million tons) is currently used to make "green" fuel. A study revealed that biodiesel made from palm oil is three times worse for the climate than regular diesel while soy oil diesel is two times worse (EC 2019a). This is because growing demand for these biofuels increases pressure on agricultural land leading to deforestation in tropical regions. A rapidly growing share of global agricultural areas is devoted to the production of biomass for nonfood purposes; yet, this sector has attained little critical attention in midst the type of bioeconomy. The European Union is a major processor and the biggest consumer of cropland-based nonfood products, while at the same time relying heavily on imports (Bruckner et al. 2019). Two-thirds of the cropland required to satisfy the EU's nonfood biomass consumption are located in other world regions, particularly in China, the USA, and Indonesia, giving rise to potential impacts on distant ecosystems (Bruckner et al. 2019). This example also raises the question of whether the agro-industry, with their plea for pesticide-intensive agriculture, is really primarily concerned with food security or rather devoted to nonfood products.

With this form of industrial agriculture, however, we are now in a conflicting situation. Agriculture is the source of more than a third of the world's population's income and livelihood, and food industry is still the world's most important economic sector. Yet, the agricultural sector is itself becoming one of the most important contributors to climate change, species extinction, environmental poisoning, and water scarcity. It is estimated that up to 40% of all greenhouse gas emissions are caused directly or indirectly by our agriculture and food production, its processing, transport, consumption, and disposal (Tubiello 2019).

Excessive pesticide use usually goes hand in hand with huge monocultures and agriculture on an industrial scale. Less well acknowledged is, however, that many small farms and part-time farmers often also use pesticides. Even quite aesthetical, diverse, and richly structured landscapes where rice, tea, apples, or grapevine is cultivated could receive a heavy load of pesticides. In Europe alone, several hundred pesticides are permitted for treating grapevines; many of them are applied before a pest or disease is making problems. Incidences in Italy and other regions suggest that winegrowers are also unwittingly serving as guinea pigs for agrochemical industry. The German agrochemical giant Bayer paid Italian winegrowers two million € in compensation because the treatment with a recommended fungicide against the *Botrytis* fungus resulted in a total loss of yields (ORF 2016b). Around 800 Italian winegrowers treated their grapes with this fungicide, and noticed enormous damage to the vine blossoms and many crop failures. The producer then published an official recommendation not to use the fungicide in viticulture "for precautionary reasons." So much for now regarding the myth that pesticides are the best investigated chemical substances.

In earlier years, pesticide application was perhaps more ruthless. Back then many pesticides were persistent and accumulated in the fatty tissue of animals and humans. Whether the newer pesticides are really better cannot be answered seriously, since we simply lack experience with them. A scientific textbook from the USA in 1974, for example, states that a mixture of 10–20 gallons of diesel oil, two to three pints of the herbicide dinitrophenol, and 100 gallons of water is recommended as a good herbicide for weed control in vineyards (Winkler et al. 1974). Note the exact specifications for the dosages of the various ingredients. This mixture should then be used four times a season. This pesticide was patented as an insecticide at the end of the nineteenth century, but also as a fungicide and in the 1970s as an herbicide. Sounds more like a trial and error approach than a targeted development of special preparations. The same book also refers to a new very promising and environmentally friendly active ingredient that is completely degraded into harmless components: glyphosate!

Worth reporting in this respect is also an episode with a student, whose father is a jute farmer in Bangladesh. Asked what pesticides they use on their jute farms, the agricultural science student told me that everything was organic and no synthetic pesticides were used. At my skeptical request as to what would be used against pests if necessary, the student explained that they only use kerosene (Zaller 2018). Kerosene, also known as aviation fuel, is not produced by agrochemical companies and therefore not considered a synthetic pesticide in his definition.

1.2 Pesticides Are Also Used Beyond Agriculture

Farmers, who feel wrongly criticized because of their pesticide use, often reply that railway companies are actually much bigger users of pesticides. The argue that nobody is talking about these users because they have a better lobby and are often state-owned. Let us look into the matter.

Fact is that herbicides are used by railway companies to keep the tracks free of weeds, as otherwise there could be derailments or an increased risk of fire. A parliamentary questionnaire about the use of herbicides on the rail network of the German Railways (Deutsche Bahn) showed that around 70 tons of glyphosate were used per year on a rail network of around 34,000 km (Bundestag 2009). This makes the German Railway not the largest, but by far the second largest consumer of herbicides in Germany after agriculture, which uses about 4000 tons annually. The herbicide is applied with a special spray train that travels at night, recognizing and selectively spraying the vegetation instead of applying the herbicide over a large area. In Austria, this has allegedly saved 75% of the original amount of herbicide applied. Herbicides are also used on track lines that lead through nature reserves. Public relations people have been careful in the wording calling the former "weed killer" an "anti-growth agent" and the applied glyphosate a biologically effective agent.

Pesticides are also used for so-called game deterrence, to ward off wildlife browsing in forests or birds feeding on agricultural crops. The substances used there are not harmless either and can be toxic to earthworms and aquatic organisms, toxic when inhaled, and suspected of triggering Parkinson's disease in the doses used (Wang et al. 2011).

Pesticides are used in a wide range of fields outside agriculture such as aquacultures, i.e., farms in which fish and seafood are produced. Random tests of salmon, trout, gilthead, and sea bass from aquacultures also revealed that a pesticide (ethoxy quinine) was found to be above the permitted limit (Weiland 2016). Due to possible carcinogenesis, genotoxicity, and alterations of the liver metabolism, this pesticide has been off the market in the European Union since 2011; however, hardly understandable, the chemical is still allowed as a feed additive. The problem has disappeared from European markets, but not from European plates. In a consumer market study, the chemical was found in 44–54 fish products; a salmon sample exceeded the maximum permissible quantity by the factor 17. Fish meal producers from all over the world use ethoxyquin to preserve their product for transport.

Pesticides are also used, for example, to decimate naturally occurring shrimps in commercial shrimp farms (Pisa et al. 2015). It sounds strange, but pesticides are used in shrimp farms to combat fish, crabs, snails, fungi, algae, and climbing plants (Gräslund and Bengtsson 2001). Furthermore, large quantities of disinfectants are used to prevent the formation of pathogens at the bottom of the sea, which could endanger farming, due to shrimp excrements. As in all intensive animal breeding operations, also antibiotics are used in large quantities in aquacultures, but this will not be further elaborated here.

Following the devastating floods caused by Hurricane Harvey in Texas in the fall of 2017, insecticides against mosquitoes were extensively applied over several weeks via C-130 Hercules military aircrafts (Kumar 2017). Within a few days, around 7500 km^2 of flood area was treated aiming at preventing the outbreak of diseases transmitted by mosquitoes such as West Nile fever or the Zika virus. Although authorities applying insecticides admitted that most mosquito species, which occur after flooding, do not act as disease vectors, but it is feared that mosquitoes will primarily molest inhabitants and helpers. Such actions have already been performed after the hurricanes Katrina, Rita, and Gustav the years before. Mainly naled, an insecticide manufactured by a partner of Monsanto, is used for this purpose (Webb 2017). In Europe, this insecticide is banned because of "unacceptable risks" to humans. Pesticide flights during hurricane season take place day and night; at least residents are warned to be cautious and beekeepers are asked to cover their hives during insecticide applications.

Insect repellents against mosquitoes, ticks, fleas, chiggers, and leeches often contain the active ingredients diethyltoluamide (DEET) and icaridin. The substances were also used by the military in World War II, Vietnam, and Southeast Asia. Besides its high mortality to salamanders (Almeida et al. 2018), it can also be found in wild mushrooms from Russia, Belarus, Poland, and Bulgaria or teas and tea-like products from Tanzania (Scherbaum and Marks 2019). But also in Europe the control of mosquitoes from helicopters along the great rivers such as the Rhine, the Danube, or also the Lake Chiemsee in Bavaria has been in use for decades (Nazarewska 2013). Insecticides from the group of pyrethroids or, more recently, a bacterium (*Bacillus thuringiensis israelensis*, Bti) is used. Pyrethroids are used against adult insects but are also toxic for many nontarget insects and are also classified as hormonally active substances. Mosquito control based on Bti is regarded as an environmentally friendly alternative. However, it is only effective against mosquito larvae that still live in water and not against adult insects; moreover, it can also affect nontarget chironomid midges that are recognized as a central resource in wetland food webs (Kästel et al. 2017). This shows the dilemma when humans intervene in nature even without the use of synthetic pesticides.

Insecticides are also used on a large scale in landscape gardening. A dramatic incident is reported from the USA where a landscaping company decided to treat some lime trees with an insecticide (Statesman Journal 2014). The trees stood on a parking lot and had infestation with aphids, which occur regularly in lime trees. The "danger" was that cars parked below the trees would be covered by sticky honeydew secreted by the aphids. A few days after spraying the trees with insecticides (neonicotinoid dinotefuran) the parking lot was littered with at least 50,000 dead bumblebees, the biggest reported bumblebee death in history. Probably many more died unnoticed elsewhere. Pesticide use in agriculture could at least be justified by the fact that it is intended to ensure food production, because after all we all need something to eat. But do we really have to spray highly toxic substances into the environment only to meet an exaggerated requirement for tidiness?

It might sound strange, but pesticides are also applied in nature conservation areas around the world (SNH 2017). Some plants and animals, so-called invasive alien species, neophytes (plants), neozoa (animals), or generally neobiota (all organisms), might pose a threat to the conservation interest of protected areas. Where the protected habitats and species may be threatened by these fewer desirable species, it is often accepted even among the conservation community that pesticides could be used as a component of management. Unfortunately, these pesticide applications are little monitored regarding their effects on nontarget species and are rarely made public either.

Pesticides are also used where it is not suspected at first: in fine arts museums, for example, where wooden picture frames or canvases of invaluable art works are threatened by wood-eating insects or fungi. In natural history museums all over the world, the exhibitions containing organic material are or have been heavily treated with pesticides. The use of pesticides in museums began in the 18th century (Ornstein 2010). Decades of pesticide use have resulted in a great deal of toxic cultural property being stored in the museum depots. The pesticides used in the twentieth century comprised arsenic, the insecticides DDT, lindane, and PCP (pentachlorophenol). Many of them are banned nowadays, but the art objects are still contaminated with these very persistent substances. It is estimated that around two-thirds of the collection in the well-known Ethnological Museum Berlin-Dahlem, Germany, is contaminated with pesticide residues. The topic is regarded as delicate, one speaks only carefully about the contamination of the archives and possible health problems of the people working in museums. Restorers and depot staff told me about dizziness, extreme fatigue, respiratory problems, and skin rashes after working with contaminated objects for a couple of hours (Zaller 2018). The danger for museum visitors is considered to be low, as affected objects are often presented in glass showcases in public exhibitions. In the meantime, even scientific conferences debate this subject (Wetzenkircher and Llubic Tobisch 2014).

Objects contaminated with pesticides have been returned to Native American tribes raising concerns about the risks posed to human health (Ornstein 2010). A survey of the American Association of Museums revealed that some of the most common pesticides found in collections were arsenic especially prevalent in taxidermy preservation, mercury on botanical specimens, naphthalene, and paradichlorobenzene (PDB) commonly known as "mothballs," DDT until the 1970s applied as a insecticide or disinfectant to biological and animal specimens as well as library materials. Many museums are aware of this problem and have guidelines for the handling of pesticides. The situation in tropical regions is even more serious. A colleague working on pest control in museums showed me pictures from museums in Southeast Asia, where termites not only eat away the picture frames of art objects, but also all the furniture, including the museum door frames.

Instead of pesticides, museum staff in modern museums increasingly rely on pest monitoring and ideal climate conditions to prevent pest development. As alternatives to poison, for example, insect traps are used in the Vienna Wagenburg, a museum with lots of wooden carriages, that emit nontoxic sexual attractants for wood pest species. This attracts the animals and keep them away from the valuable objects. If, despite all prevention, objects are affected by pest infestation, the objects are fumigated in chambers with a high nitrogen content for a couple of weeks. During this time both the animals and their eggs are killed. This procedure is efficient and not hazardous for the workers dealing with it.

An environmental physician told me that residues of the insecticide DDT are still detected in blood samples taken from actors (Zaller 2018). Although DDT has been banned for decades, it is assumed that the former treatment of historical costumes and wigs with DDT-containing moth powder was responsible for this contamination of the actors.

This is how people come into contact with pesticides at their working place, as farmers and gardeners, in museums or theaters. However, it is also very likely that you get in contact with pesticides during vacation, for example, in intercontinental flights. Especially on flights to Australia, New Zealand, India, the Seychelles, Mauritius, or South Africa, chances are good of getting in contact with pesticides (ORF 2010). In order to comply with the regulations