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Problems caused by the contamination of agricultural land and woodlands by toxic chemicals

Edwards, Clive A.

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Clive A. Edwards

Abstract

Toxic chemicals affecting the soil biota of agricultural land and woodlands are mainly pesticides, heavy metals from waste materials and industrial effluents.

Chemicals do not accumulate greatly in soil and affect surface-living organisms most, either directly or indirectly. They decrease species diversity, affect invertebrates more than the microflora and sometimes lead to poor soil structure and fertility.

Kurzfassung

Giftige Chemikalien, die das Leben in landwirtschaftlichen Böden und in Waldböden beeinflussen, sind vorwiegend Pestizide, Schwermetalle von Abfallmaterial und industrieller Ausfluß.

Chemikalien reichern sich im Boden nicht sehr an, sie beeinflussen vielmehr meist die an der Oberfläche lebenden Organismen, entweder direkt oder indirekt. Die Chemikalien mindern die Artendiversität, sie beeinflussen die wirbellosen Tiere mehr als die Mikroflora und führen manchmal zu sehr armer Bodenstruktur und -fruchtbarkeit.

1. Introduction

Although, pollution of air, freshwater and the oceans by toxic chemicals has been the subject of many publications, the scientific literature on pollution of soil by such materials is relatively sparse. To a large extent, this is because we know much less about the biological functioning of soil systems, but also because it is much more difficult to establish the degree of contamination of land by such chemicals and to do so requires complex sampling techniques and extensive surveys.

Historically, contamination of soil by toxic chemicals is a relatively recent phenomenon and dates back to the use of inorganic pesticides such as copper sulphate, introduced as a fungicide in 1882, lead arsenate which was first used as an insecticide in 1892, the arsenical herbicides produced in 1900, the organic mercurial fungicides marketed in 1913, and copper silicate which was first tested as a foliar fungicidal spray in 1936. All of these pesticides, which are based on heavy metals, tend to be extremely persistent in soils and some orchard soils have become very heavily contaminated as a result of repeated annual treatments made over many years.

The second group of relatively persistent chemicals with potentially toxic effects on soil organisms is the organochlorine insecticides, the first of which was DDT introduced in 1939, BHC in 1942, chlordane in 1945 and a range of other related chemicals from 1948 onwards. Most soil contamination resulted from the deliberate application of such chemicals to agricultural and horticultural land, with the aim of controlling pests.

More recently, contamination by toxic chemicals has been extended to natural environments. It has occurred by the aerial drift of pesticidal spray particles or dusts or by the volatilization of pesticides into the atmosphere, (from where they may be washed out in precipitation and fall on the soil). Secondly, chemicals emitted from many industrial factories e.g. brick or smelting works such as sulphur dioxide, and the lead given off from car exhausts can be washed out of the atmosphere and contaminate nearby land. Finally, the increasingly common practice of depositing different forms of processed human sewage, that may contain many contaminants especially heavy metals, on to agricultural land has led to wide-spread pollution of some soils. Fields that have been treated regularly in this way since before the Second World War, can carry very large amounts of certain heavy metals, which may be transmitted into crops grown on them.

2. Methods of assessment of the effects of toxic chemicals in soil

The primary problem is to assess the extent and amount of soil contamination. This has to be done by surveys involving sampling, residue analysis and some assessment of ecological effects. Such surveys, which can be on local, national, or international levels, are extremely

expensive to do in terms of both resources and manpower required and because of this there have been few large scale surveys to date.

Fortunately, once a suitable sampling programme has been designed there are few major problems in assessing the degree of contamination by residue analyses other than resources required, because analytical methods for most pesticides and heavy metals, are available due to the requirements of most governments for the availability of suitable chemical methodology before they will register a toxic chemical for general use.

However, such surveys do no more than establish the degree and distribution of soil contamination by toxic chemicals. The assessment of the overall effects of any chemical contaminant on populations of soil organisms and on soil metabolic processes raises many more problems. It is not difficult to devize laboratory bioassay techniques which will give some indication of the toxicity of different chemicals on certain readily identifiable soil organisms, but it is much harder to interpret such toxicological data in meaningful ecological terms. Even more complex, is the design of experiments which can assess accurately the effects of toxic chemicals on the total fauna and flora of the soil (EDWARDS & THOMPSON 1973). Such studies are laborious and time-consuming and require not only a thorough taxonomic knowledge of the broad range of such organisms, but also the availability of efficient methods of adequately sampling populations of such organisms. For general purposes, the usual approach is to assess the effect of the chemicals on a range of dominant and representative key indicator species in carefully replicated field experiments. These experiments are sampled periodically after the test chemicals have been applied and populations of such organisms assessed by methods that have been fully summarised elsewhere (EDWARDS & FLETCHER 1970).

There are also alternative methods of investigating the broader impact of toxic chemicals on soil systems: these involve studying the effects of these chemicals on soil metabolic processes, such as organic matter breakdown, respiration or mineralization of nitrogen, phosphorus and possibly sulphur. Such studies, which can be made either in the laboratory or field, give a more general idea of the overall effects of toxic chemicals on important soil processes (EDWARDS 1979).

3. Contamination of agricultural land with toxic chemicals

The most important contamination of agricultural soils is by pesticides and this can occur, either as a result of direct application of chemicals to the soil to control pests and diseases or, when chemical sprays applied to the foliage of crops fall on to the soil surface. As much as one half of the crop spray applied to a crop can miss its target and reach the soil surface.

3.1. Arable land

When arable land is treated with pesticides to control soil-inhabiting pests, the chemicals are mixed into the soil as carefully as possible so that the pest comes into contact with the pesticide as it moves through the soil. This means that a wide range of non-pest organisms that live in soil are also exposed to the chemicals, but for the same reason it tends to diminish the overall effects on these organisms because the chemicals are diluted with a large quantity of soil and the degree of exposure of is therefore less.

Certain organisms are exposed to pesticides, particularly those which fall on to the soil surface and are left there as a surface residue not cultivated into the soil. Animals moving over contaminated soil surfaces, such as the common earthworm, *Lumbricus terrestris,* can pick up large doses of toxic chemicals in this way.

The practice of direct drilling or zero cultivation, which may involve growing crops for a number of years with no cultivation of the soil, creates an extreme situation of this kind because repeated treatments with persistent chemicals without any soil disturbance can lead to a gradual build up of residues on the soil surface. This is especially serious because, under these conditions, soil invertebrates play an important role in maintaining soil structure and fertility (EDWARDS & LOFTY 1978).

Another important source of contamination of agricultural land is when materials such as sewage products containing heavy metals are disposed of primarily on to grassland but also on arable fields. In England up to 46% of sewage is disposed of in this way so there is a serious potential for contamination.

3.2. Orchards and Plantations

Fruit trees and bushes seem to be especially susceptible to pests and diseases, particularly because the public demands unblemished fruit. In attempts to control these organisms, during the last century, a wide range of toxic chemicals have been used. The great variety of pest and disease organisms has meant frequent applications of relatively persistent chemicals to orchards and plantations every growing season. As a result, orchards treated regularly with such persistent chemicals as lead arsenate and copper fungicides for many years before the Second World War still have large residues of such chemicals. These can kill many soil-inhabiting invertebrates, especially earthworms, and some soils treated in this way have a very poor structure with a thick mat of undecayed organic matter at the soil surface (RAW & LOFTY 1960).

After the Second World War, synthetic organic pesticides became used widely and of these the organic organochlorine insecticide DDT was the chemical applied most commonly to orchards. Fortunately, this chemical did not have drastic effects on soil organisms, However, from 1970 onwards, the use of DDT was severely restricted in most countries and it has been replaced by other pesticides particularly carbamate insecticides such as carbaryl. These have had much more drastic effects on soil organisms, especially earthworms.

During recent years, herbicides have been used increasingly in orchards and some of these especially simazine and quintozene are very persistent. They can affect soil organisms either directly, through toxic action, or indirectly by lessening the supplies of organic matter derived from weeds in soil. Finally, the use of fungicides, especially the carbendazim fungicides, has increased rapidly in the last decade. Some of these, particularly benomyl and thiophanate methyl, are quite persistent and very toxic to soil invertebrates especially earthworms.

An interesting aspect of the use of benomyl to control apple scab („Apfelschorf", *Venturia inaequalis*) in orchards is that this disease is transmitted from year to year in fallen leaf litter. A good earthworm population will remove most of the fallen leaves in autumn and winter but earthworms are most susceptible to benomyl residues so that the natural control agent is destroyed (EDWARDS 1976).

Thus, there is a long history of use of chemicals toxic to soil organisms in orchards, and unless care is taken there is the danger of long-term effects on soil structure and fertility.

4. Contamination of natural Woodlands

Forests and woodlands are exposed to toxic chemicals in two main ways: either by direct application of pesticides or by fallout from the atmosphere of toxic chemicals contained in industrial atmospheric contaminants. Fortunately, neither of these is serious.

Trees are susceptible to many pests and, for about twenty years after the Second World War, aerial spraying of forests with insecticides such as DDT to control pests was common. With widespread governmental restrictions on DDT, this practice has become much less common but less persistent chemicals such as fenitrothion are still used in this way. However, there seems to be little evidence of any major ecological problems arising from these practices.

5. Overall effects of toxic chemicals on soil systems

Although every chemical tends to have specific effects on soil organisms and systems, it is possible to generalize about these effects and the different problems that result from contamination of land with toxic chemicals.

5.1. Differential effects

The different elements of the soil flora and fauna vary considerably in their susceptibilities to toxic chemicals. In general, the more mobile and active an organism is then the more susceptible it is to chemicals probably because it is in greater contact with the contaminant.

Moreover, those organisms with a high rate of metabolic activity are usually affected most. The decreasing susceptibility of different organisms is summarized in Table 1.

Microorganisms	↑
Nematodes (Nematoda)	|
Molluscs (Mollusca)	|
Earthworms (Oligochaeta)	|
Springtails (Collembola)	increasing
Woodlice (Isopoda)	susceptibility
Symphyla	|
Most mites (Acarina)	|
Millipedes (Diplopoda)	|
Centipedes (Chilopoda)	|
Other insects (Insecta)	|
Other insects (Insecta)	|
Predatory Insects	|
Predatory Mites	|
Pauropoda	↓

Table 1. Relative susceptibility of soil invertebrates to chemicals

Tabelle 1. Relative Empfindlichkeit von bodenbewohnenden Wirbellosen gegenüber Umweltchemikalien geordnet nach Zunahme der Empfindlichkeit.

To some extent this is related to size and quite clearly, microorganisms are much less susceptible than the smaller invertebrates such as nematodes, which in turn are affected less than the larger invertebrates.

5.2. Zonal effects

Most toxic chemicals remain as a layer on the soil surface upon which they fall and hence exert a much greater effect on organisms, such as staphylinid and carabid beetles and certain millipedes and centipedes, that spend most of their life near the surface and do not penetrate far into the soil. The deeper an organism lives the less likely it is to be affected by toxic chemicals.

5.3. Effects on species diversity

Almost invariably there are certain species of soil-inhabiting organisms that are especially susceptible to a particular toxic chemical. These tend to be eliminated so that the range of species in soil decreases. Such effects are seldom severe and those species that are unaffected may actually increase in numbers, sometimes quite dramatically.

5.4. Selection of organisms

Certain organisms are either tolerant of chemicals or, when continually exposed to residues of particular toxic chemicals, gradually lose their susceptibility, due to selection of the more resistant strains. There are few well-documented instances of this among soil organisms but there is a large amount of circumstantial evidence for its occurrence.

An interesting aspect is that some soil organisms have the ability to detoxify and/or break down toxic chemicals. Microorganisms are the main agents of degradation of many pesticides that reach soil. Thus, successive soil contaminations with a particular chemical may have progressively less effects on the respective soil system and result in its more rapid breakdown.

5.5. Direct and indirect effects

Soil systems are exceedingly complex, with very much interdependence between the organisms that live in it. Thus, any toxic chemical may affect certain organisms directly through toxic action but also have a considerable effect on other organisms, that are not susceptible to the toxic chemical but depend upon the susceptible organisms for food or some symbiotic or other relationship.

5.6. Uptake of chemicals into organisms

Some toxic chemicals are absorbed readily into the tissues of soil organisms. When these are eaten by other organisms the residues are passed on and there is a tendency for predators and organisms in the higher trophic levels to accumulate chemicals.

Earthworms and molluscs can accumulate extremely large amounts of certain toxic chemicals such as the organochlorine insecticides and heavy metals, and when these invertebrates are eaten by birds and mammals the residues are taken up by these animals. Hence, soil contamination with toxic chemicals can be transmitted into organisms that do not live in soil and cause other environmental problems.

5.7. Dose/effect relationship

Usually, the relationship between the dose of a toxic chemical that an organism is exposed to and the toxicity of a chemical is not a linear one. It is most often expressed as a log probit relationship, which is nearer to a logarithmic relationship than a linear one. This aspect is often forgotten by some ecologists who postulate that the greater the degree of contamination of soil with toxic chemicals the greater the effect on soil organisms.

5.8. The relationship between toxicity and persistence

It is often assumed that the most harmful chemicals are those that are most persistent in soil. This may sometimes be so but only when the chemical is also toxic to most soil organisms. An extremely toxic chemical such as a soil fumigant, that persists for only a short period in soil, can have much more drastic and long-lived effects than a relatively non-toxic but persistent chemical. An example of this is soil contamination with heavy metals which does not kill many soil-inhabiting organisms except at high dose levels.

Moreover, most chemicals are gradually degraded in soil and only the most persistent ones that are applied to or reach soil frequently tend to accumulate.

6. Synopsis

Contamination of soil with toxic chemicals is mainly by pesticides and heavy metals or from atmospheric fallout of industrial effluents. These can affect either the fauna or flora, the greatest effects being on earthworms und surface-active arthropods. Agricultural land is contaminated mainly by pesticides and heavy metals contained in organic wastes (particularly sewage), whereas woodlands (other than orchards) are polluted most by chemicals in atmospheric fall-out, although some can be affected by aerial sprays of pesticides.

Assessments of the effects of these chemicals can be made by field population studies of organisms before and after contamination, in controlled field and laboratory experiments, and by investigations into the effects of toxic chemicals on metabolic processes, particularly organic matter breakdown, soil respiration and nutrient cycles.

The more serious effects of toxic chemicals included those of pesticides on organisms in zero or minimally-cultivated (direct drilled) land, possible contamination of arable land with heavy metals and contamination of orchard soils with heavy metals and pesticides, which sometimes results in few living organisms and poor soil structure and fertility.

In general, effects of toxic chemicals are:

(1) less on soil microorganisms than on certain elements of the fauna and flora;
(2) greatest on organisms living close to the soil surface and most exposed;
(3) to decrease the species diversity of soil organisms;
(4) to result in selection of organisms resistant to or that can break down toxic chemicals and build up in numbers of those organisms that can tolerate large amounts of a contaminating chemicals in their tissues and environment;
(5) either direct or indirect;
(6) often important when the chemicals are taken up in large quantities into soil organisms and thence into food chains;
(7) not usually a linear dose/effect relationship
(8) not usually due to accumulations of these chemicals in soil unless exposure is relatively continuous.

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Address of author: Dr. Clive A. Edwards, Rothamsted Experimental Station, Harpenden, Herts, England.