HANDLING TOXIC CHEMICALS — ENVIRONMENTAL CONSIDERATIONS*

I Introducing a New Agricultural Chemical

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Agricultural chemicals, like the more traditional implements of agriculture, are designed to produce biological effects, usually by killing insects, or fungi, or higher plants. While, from the human point of view, the distinction between insect and pest, fungus and disease, or plant and weed is often very clear, the physiological distinction may be much less clear, and it is evident that an agricultural chemical may well produce some effects upon living things other than the pests, diseases, and weeds at which it is aimed. While quite remarkable progress has been made in chemicals having selective activity, such as the hormone weed-killers, which will destroy broad-leaved weeds in a cereal or grass crop, it is broadly true that the introduction of more effective pesticides, and in particular more persistent pesticides, has intensified the environmental problems.

It is clear that no new biologically active chemical should be introduced without intensive experimental work to establish its likely impact upon the environment. This is demanded by public opinion, recognized by the chemical industry, and ensured by the increasing weight of regulatory law relating to the registration of pesticides. The types of technical problems involved are well illustrated by a consideration of environmental effects of two types of agricultural chemicals which have been in use for many years.

The organochlorine insecticide DDT was introduced into agriculture in the 1940s, following earlier and spectacularly successful use in the control of insect disease vectors during the war years. Understandably, this development had gone on with minimal attention to possible environmental effects. DDT is a new chemical addition to the environment, in that it did not exist until it was synthesized in a laboratory. DDT can now be found practically everywhere, in soil, in water, in air, and in living things. The levels of DDT in these places are generally low and without physiological significance, and the fact that they can be determined with precision is a tribute to the advances in analytical methods. This situation arises from the chemical and physical properties of

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DDT. It is chemically stable, so that when applied to the soil it may take between 10 and 20 years for 95% of the applied dose to disappear. Its relatively low solubility in water, of the order of 0.001 p.p.m., together with a ready solubility in oils and fats, makes it possible for animal life to accumulate higher residue loads of DDT from a relatively low contamination level in the environment. This effect can be particularly marked in animals which have specialized feeding habits, such as small birds specializing in earthworms in sprayed orchards. While DDT is not a particularly poisonous substance, in the acute sense, to higher animals, there is evidence that high residue levels in some birds can produce indirect effects in enzyme systems, causing the birds to lay thin-shelled eggs and so decreasing their reproductive capacity. It is probably true that DDT became widely distributed in the environment before we had any idea of what constituted an ecologically acceptable level, and while all the indications are that a tolerable level has not been exceeded, the experience of the problems which have arisen in 30 years of DDT usage must be taken into account in the design of environmental research work on new chemicals before their introduction.

Useful information also arises from a consideration of the use of mercury compounds as agricultural fungicides. While the use of mercury as a preservative has long been known, the most important agricultural use today is as a seed-dressing on cereal and other seeds for the control of seed- and soil-borne diseases. This became possible with the discovery of suitable organic mercury compounds early in this century. The use of, for example, a phenylmercury acetate dressing on cereal seed, at a rate of about 5 g of mercury per hectare, will give complete protection from diseases formerly very damaging. Unlike DDT, mercury compounds are not new additions to the environment. Mercury occurs naturally in the rocks of the earth's crust. Erosion and evaporation from such natural resources and subsequent distribution by water and air movements ensure that mercury is present everywhere in Nature, although generally in minute concentration. Some organic mercury compounds can accumulate into animals, and such compounds can be formed in Nature by microbiological methylation of inorganic mercury. Any additional mercury introduced into the environment through human activities must therefore be considered against this background. If the quantity introduced is small in relation to natural background levels, it is reasonable to believe that the situation is satisfactory. While the ingestion of any mercury is probably not beneficial, there is little point in avoiding a modest use of mercury in pesticides if they are beneficial in crop protection.

The development of a new agricultural chemical starts from the synthesis of a few grams in the laboratory and proceeds eventually to the design and erection of a chemical plant to produce many tons of it per year. The initial step of synthesis is relatively inexpensive, while the final stage is extremely costly. From the point of view of the manufacturer it is of the greatest importance to know of any adverse environmental effects which may limit the application of the chemical, and to know of these effects at as early a stage as possible, and certainly prior to undertaking any major development expenditure. In favourable circumstances the time from point of discovery to point of sale is likely to be a minimum of five years. Such a time scale may pose problems for the environmental scientists concerned with amassing sufficient information on the probable environmental impact of the chemical. Such matters as the accumulation of the chemical into large predatory animals, and possible effects upon the reproductive efficacy of slow-breeding forms of life, cannot be studied in the field on a small scale, since such information could only rise from the treatment of large areas of land with correspondingly large amounts of chemical. Decisions are needed, however, at a time in the early part of the development period when only small quantities of chemical are available and when large-scale field treatments would not in any event be desirable. The problem which the industrial ecologist has to face is that of devising small-scale experiments from the results of which reasonable deductions may be made of the large-scale environmental behaviour of the chemical.

An approach to this in the Environmental Science Group at Jealott's Hill has involved the treatment of 6 m × 6 m field plots, some at application rates near to those likely to be used in commercial practice, and others at grossly excessive rates, perhaps 100 times the expected rates. Observations are then made of the behaviour of the pesticide residue in the soil, in terms of penetration down the soil profile and rate of decomposition, and careful and detailed observations are made on the effects of the treatments upon various small forms of life in and on the soil.

Effects upon microbiological activity in the soil are investigated by taking soil samples from the field plots and setting them up in the laboratory to measure such things as the total respiration (as a measure of overall activity), the rate of conversion of ammonia into nitrate (a function of some importance in agriculture), and the rate of breakdown of soil organic matter. Organic matter breakdown is measured by adding ^{14}C-labelled organic matter, and, to separate soil samples, ^{14}C-labelled organic fractions such as sucrose, starch, cellulose, urea, and fatty acids, and then trapping the evolved $^{14}CO_2$ over a period of several weeks. Measurements are also made of total microbiological biomass in the soil, by estimates of the ATP content by a luminscent biometer and of the DNA content by a specific staining reaction in soil dispersions in an agar film.

The microarthropod soil fauna in the plots is sampled by taking soil cores to various depths and extracting the arthropods by a wet-sieving and differential-wetting technique. The arthropod fauna, principally mites and Collembola, are identified to species and counted, and the information is used to monitor changes in populations and species diversity at various times after application of the pesticide.

The earthworm fauna is sampled by a combination of digging and expelling them by the use of a 0.2% formaldehyde solution applied to the soil. In appropriate temperature and humidity conditions, particularly in spring and autumn, reasonable earthworm population estimates are attainable. In addition to information on earthworm populations and species diversity, pesticide residue measurements can be made. The earthworms may be dissected and residue analyses done on the gut content and on the remaining tissues. Since the earthworms feed on soil organic matter, or, in the case of some species, on surface organic matter, and are themselves an important source of food for birds and small mammals, the earthworm is an important link in food chains from the soil. Worms are particularly useful, therefore, as a means of obtaining an early warning of the possibility of an accumulation effect in a food chain.

Biological work involving small plots uses small areas of land and little chemical, and can therefore be done early in the research and development programme, and yet it can provide a lot of information on the likely biological impact. If, after a year of such work, no major environmental hazards have become apparent, development may reasonably proceed to larger areas of land. When areas of 5—10 ha of crops are treated, ecological investigations can proceed to studies of the effects upon larger forms of surface invertebrate life, such as beetles and spiders. These forms are sampled by trapping techniques, using a grid of 20 small pitfall traps set into the ground, each with a small depth of preservative liquid in the bottom. The catch of small animals may then be collected at intervals of a few days. While such traps do not give absolute population estimates, and, owing to differences in trapping efficiency, cannot be used to compare populations of different species, they can give useful information on the effects on the populations of the same species of different pesticide treatments in the same crop. Insects able to fly are better sampled by other methods of trapping, such as liquid or sticky traps, or by the use of a mechanical suction trap.

The measurement of effects in the field on vertebrate animals, and particularly on birds, necessitates the use of even larger areas of treated land. This work is of particular importance when a chemical is to be used as a seed-dressing. A seed-dressing is one of the most economical ways of using a pesticide, in that the chemical is placed in close proximity to the seedling, where it can provide the maximum protective effect in the vulnerable young state of the plant, and yet the whole bulk of the soil is not unnecessarily contaminated. Seed-eating birds and mammals, however, may collect the seed and so acquire a relatively large dose of the pesticide. For work on small birds a treated area of about 50 ha is desirable. The fields in this area are drilled with the treated seed and observations are made upon the number and extent of the territories occupied by the breeding pairs of birds, using the census techniques employed by ornithologists. This involves regular visits to the area by a skilled bird observer over a period of several weeks in the spring. Nests may be found and a measure obtained of breeding success. Samples of common seed-eating birds may be taken, under appropriate licence, and analyses made to determine pesticide residue levels in the birds. This information may then be compared with that obtained in laboratory toxicological tests, in which birds are fed known quantities of pesticide, so that it becomes clear if, in the field situation, the birds acquire a level of pesticide which might do them harm.

By the application of these procedures, together with the related work on toxicology and on the persistence and ultimate fate of chemical residues in soil, in water, and in plants and animals, it is possible to build up a body of knowledge on the likely environmental behaviour of a new agricultural chemical before it goes into commercial use. In experimental work, however, it is clearly not possible to cover all living species and so to recognize all specific peculiarities and susceptibilities. For this reason, it is desirable that ecological observations should continue for some years as a new material goes into increasing commercial use.

The primary aim of environmental investigations during the development period is to provide the necessary information to meet the requirements of the various national registration schemes. In recent years, requirements have multiplied in various countries, with rather little international collaboration. Since the cost of environmental investigations is a substantial part of the total research and development cost, it is important that registration requirements should be reasonably related to the proposed uses of the chemical, so that new materials are developed not only for widespread, major, crop uses but also for small and specialized applications where different environmental considerations might apply.