Chemicals for agriculture

by J.R. Plimmer*

Agricultural production relies heavily on man-made chemicals used as fertilizers and pesticides, and to regulate plant growth. Pesticides are released intentionally into the environment to control insects, weeds, plant diseases and other pests that affect crop or animal production, as well as to control insects that spread human diseases. Pesticides have a well-established rôle in agriculture and public health. The benefits of their use in terms of economic returns and of improved human health and well-being have led to the rapid world-wide adoption of this chemical technology. However, their use in advanced countries is often regulated and monitored because of potential problems associated with their injudicious use. Unfortunately, many developing countries lack the experience and expertise necessary to solve such problems.

The quantities of pesticides that do not reach the target organism are of concern because of their potential impact on man and his environment. For that reason, pesticide regulations require submission of data that concern the potential fate of any given pesticide in the environment as well as its toxicity to a variety of non-target species. Pesticide residues on crops or in other foods present special problems; their presence is important not only in human terms, but also in international trade. The term "residues" denotes not only the original pesticide, but also those compounds that may derive from it by metabolism, chemical change, or other processes. Extensive regulations in developed countries deal with the problem of residues, and limits for maximum acceptable quantities of residues in food have been defined. Elsewhere, guidelines developed by the FAO and World Health Organization (WHO) are generally followed.

The WHO has proposed an "acceptable daily intake" of pesticide residues in food, the amount of a pesticide "which during an entire lifetime appears to be without appreciable risk on the basis of all known facts at the time" (WHO Technical Report Series 391, World Health Organization, Geneva, Switzerland, (1968) p.22).

Pesticides may enter man's diet in many ways, but it is not only man that is at risk. There is also considerable concern for the environment. Natural resources such as soil and water must be considered. Non-target species must be protected from the adverse effects of pesticide residues.

It is therefore important to detect pesticides and measure their quantities in food, crops, water, soils, air, animals, fish, and other components of the environment. A range of analytical techniques for detection and quantitative analysis of residues is available. That there may be analytical difficulties, however, becomes apparent when it is realized that in October 1977 the US Environmental Protection Agency listed 1850 substances and more than 40 000 pesticide products. About 1.6 billion pounds (727 000 tonnes) of pesticides were produced in the USA in 1975.

Analytical procedures capable of detecting low concentrations (0.1 to 0.01 parts per million or even lower) are used. Methods must be selective, and the analyst is often pressed to achieve even greater sensitivity and selectivity as the concern for long-term, low-level effects increases.

For registration of a pesticide, studies of metabolism in plants, birds, fish, mammals, and the environment are often required. It is usual for the manufacturer to synthesize isotopically- (^{14}C, ^{3}H or other radioactive atom) labelled molecules for these studies. Incorporation of such markers has become the accepted technique for investigating the fate of complex molecules in biological tissues, soil or other complex matrices. The use of labelled molecules gives unequivocal answers in questions of quantitative or qualitative analyses.

The development of residue data by the manufacturer is necessary to ensure safety for the consumer. However, from the user's standpoint, the manufacturer must also demonstrate that the material is effective, and provide instructions for its use. Rates of application must be prescribed and the recommended methods of use should ensure that harmful residues are not left on the crop.

Pesticide efficacy and safety are thus closely linked. Efficacious use also implies economical use. Pesticides are expensive. Excess pesticide use is not only uneconomical, but may hasten the development of pesticide resistance in insects or weeds, or reduce the number of beneficial organisms.

Safety and efficacy can only be ensured through continuous efforts to monitor and improve the way in which pesticides are used. The programme of the Agrochemicals and Residues Section of the Joint FAO/IAEA Division is concerned with the examination of pesticide residues in a number of commodities, with the way in which pesticides behave in the environment, and with the formulation or delivery of pesticides to the target.

* Mr Plimmer is Head of the Agrochemicals and Residues Section of the Joint FAO/IAEA Division.

The needs of developing countries

The intensification of agriculture in many developing countries is accompanied by increased imports and use of pesticides. In Venezuela, for example, the annual import of active ingredients increased from just over 4657 tonnes in 1967 to 15 710 tonnes in 1976, and reached 26 600 tonnes in 1982. The Venezuelan experience is typical, as many nations strive for self-sufficiency in food production.

The majority of pesticides were developed in Europe, North America or Japan. The cost of development of a new pesticide, now about US$ 20 million per compound in the USA, makes it unlikely that new chemicals will become available other than for the world's major crops. Therefore, it will be necessary to rely heavily on currently available compounds. The use of such compounds in tropical agriculture systems is increasing. Because efficacy is potentially affected by climate and other environmental factors, it is essential to develop patterns of use suited to crops, climates, and pests of many different regions of the world. The factors that affect efficacy will also influence residue patterns. Rates of loss of residues will be affected by temperature, rainfall, and sunlight as well as the nature of crops and soils.

Unfortunately, many developing countries have not had sufficient experience of the use of synthetic organic pesticides to be able to solve potential problems associated with their use. Personnel trained to conduct quality control analyses and to monitor crops, soils, and so on for pesticide residues are few, and their facilities are often limited. FAO has recognized this problem, and in 1961 recommended the expansion of its pesticides programme to encompass an effective international approach and to provide governments with appropriate guidance.

Since that time, FAO has become increasingly involved in providing expert advice on pesticide questions, particularly in connection with pesticide registration (including safety activities and control). In addition to these activities, FAO has also sought to provide technical backing for many projects in developing countries that have safer and more efficient use of pesticides as their objective. These programmes include increasing the availability of national personnel trained in various aspects of pesticide use and control and the establishment of laboratory facilities to control the quality of pesticides as well as to measure residues in food and the environment.

A variety of techniques is required to solve pesticide problems. The ability to apply nuclear methods powerfully extends the capabilities of a routine pesticide laboratory. Radioisotopically-labelled molecules are frequently used in analytical studies, in studies of pesticide metabolism, and in investigations of problems of pesticide behaviour in the environment. The Joint FAO/IAEA Division has assisted a number of developing Member States to initiate and conduct pesticide projects that involve the use of nuclear techniques.

The activities of the Agrochemicals and Residues Section are wide-ranging. Projects in Member countries have as their major objectives the improvement of pesticide safety and efficacy, but there are also programmes concerning utilization of agricultural wastes.

Pesticide residues

Radioisotope-aided studies of pesticides in stored products were among the earliest such studies. The pioneering work of F.P.W. Winteringham and his colleagues in the 1950s demonstrated the types of residue which resulted from the use of halogenated hydrocarbon fumigants, and their effects on wheat flour quality. The use of ^{14}C-labelled compounds provided a model for many similar studies.

Stored grains, especially in times of plentiful harvests, represent a large investment, but losses caused by pests may be substantial, especially in tropical areas.

Fumigants are used to control heavy infestations of pests, and insecticides may be used to prevent pests becoming established. Residues depend on methods of application, the time interval between application and consumption, conditions of storage, the nature of the stored product, and the nature of the active ingredients. Because radioisotope techniques are ideal for such studies, the Agrochemicals and Residues Section has established a co-ordinated research programme to study pesticide residues in grain. This aims to measure the type and magnitude of residues, and to demonstrate how terminal residues could be minimized by changes in operating procedures.

The use of pesticides in animal production is routine. Animal feed and the environment may be contaminated with pesticide residues. To study pesticide levels in meat or milk, a co-ordinated programme has brought together a number of studies including several on residues of chlorinated hydrocarbons and organophosphate insecticides, as well as naturally occurring aflatoxins.

Some uses present minor or no problems. In Egypt, for example, residues of methomyl in milk were found to be at such a low level that they were unlikely to be hazardous to the consumer.

The behaviour of pesticides is affected by the environment, and it has been suggested that some pesticides, although not readily degraded in temperate climates, may undergo much more rapid degradation and detoxication in tropical environments. Such considerations are particularly important in developing countries because many of them lie in the world's tropical zones, and many pesticides that can no longer be used in temperate zones may be quite satisfactory under tropical conditions. Their time of residence in the environment or "persistence" may be significantly lower in the latter case. Because many of these pesticides are inexpensive and effective, there seems to be little reason for discarding them if environmental risks are low. Since radiotracers are an ideal tool for measuring rates of degradation and dissipation in tropical (or other) environments, such a study is now being conducted as a co-ordinated research programme.

Bound and conjugated residues

A major breakthrough in techniques of pesticide analysis was made possible by the use of radioisotopically-labelled pesticides. Conventional analysis based on solvent extraction gives quantitative data on the pesticide and its degradation products. It was assumed that the fraction that could not be extracted had been degraded or metabolized and lay beyond scientific concern. Such residues are said to be "bound". However, the issue of their reversibility began to be debated in the 1970's. In this context, "bound" residues appear to be intimately associated with a substrate such as soil, whereas "conjugated" residues are formed by a chemical bonding of a pesticide to a compound of biological origin, such as an amino acid or sugar molecule. The question of their toxicological significance was raised, and regulatory agencies were pressed to take action on this potential problem. To investigate the nature of bound and conjugated residues, sophisticated analytical methodology must be used and the use of radiolabelled pesticides is essential.

Sometimes, "bound" residues constitute a considerable fraction of the total residue, but would escape detection using current analytical procedures. The binding may be due to unusually strong adsorption forces, or to the formation of chemical bonds between the pesticide and components of tissues or soils. The Agrochemicals and Residues Section is conducting a co-ordinated research programme to study some selected bound residue problems in order to determine their nature and quantity and to improve methods for measurement and identification.

Studies with ^{14}C-labelled pesticides indicated the extent of the problem. For example, 38% of the applied radioactivity remained bound 12 days after malathion was applied to soil. With paraquat, a herbicide, there was no loss of radioactivity from soil after one year in the laboratory, whereas 26% was lost in the field after 15 months. Paraquat represents an extreme case, but a significant percentage of radioactivity remained in a number of cases.

The programme is attempting to improve the methodology and to compare the performance of methods by investigating common chemicals in a number of co-operating nations. The value of specific techniques, such as high temperature distillation, has been demonstrated clearly in comparative studies.

The major issue is that of the toxicological effects of "bound"pesticide residues and their biological availability. The programme provides the essential foundation for the acquisition of quantitative and qualitative data, without which any discussion of the toxicological issues becomes mere speculation.

Pesticide formulation

The fraction of a pesticide reaching a target organism may be an extremely small fraction of that applied. The active ingredients of a pesticide are formulated to make application easier and to ensure that an effective dose is transferred to the target. The effective dose need usually be only very small, but much of the applied material is dissipated before it reaches the target. A substantial proportion reaches soils or non-target organisms where it represents an "economic" loss and a potential environmental contaminant.

Better formulation improves efficacy and may also improve safety in shipping or handling. Recently, there has been considerable progress in the technology of controlled-release formulations. In these, the pesticide is contained in a reservoir and is released to maintain a predetermined concentration level for a specific period of time. The reservoir serves to protect the active ingredient from loss by volatilization or degradation by environmental forces, and limits its movement from the site of application.

A variety of matrices or controlled-release devices are available; the suitability of a particular technology depends on its effectiveness in a specific situation and on its economics.

Several co-operators in a co-ordinated research programme are evaluating different types of polymer matrix. Radiolabelled pesticides are used for studying the behaviour of the active ingredient, its rate of release and its environmental fate. At the Agricultural Biotechnology Laboratory in Seibersdorf, alginate formulations are being tested because natural polymers appear to offer promise for economical formulation. In Indonesia, for example, natural latex is being used to prepare herbicide formulations and the problem of vulcanization has been solved by irradiation of the latex.

More sophisticated formulation techniques are being examined by co-operators at Neuherberg, in the Federal Republic of Germany, where polymer formulations based on polyethylene or ethylene vinyl acetate copolymers can be moulded or extruded as ropes suitable for aquatic weed control.

A number of formulations have been evaluated in preliminary laboratory studies. Formulations such as that of endosulfan in an alginate matrix will now be tested in the field against cotton insects. Efforts will then continue, through laboratory experiments with radiolabelled materials, to optimize the performance of the new formulations.

Trypanocidal drugs

About 10 million square kilometres of the African continent are infested by the tsetse fly, which transmits trypanosomiasis, a parasitic disease of cattle and humans. This disease reduces livestock production and the suitability of substantial areas for agricultural development.

Control of the tsetse fly and the production of suitable vaccines are approaches to amelioration of the problem. However, neither approach is technically feasible at present and chemotherapy is the only practical solution to the problem of animal trypanosomiasis. It has been estimated that more than 25 million doses of trypanocidal drugs are used annually in Africa. However, no new drugs have been introduced in the last 25 years and there must be heavy reliance on the limited number of drugs available.

Although these drugs continue to be used, experts agree that their mode of action is unknown and that their use could be optimized if the relationship between drug dosage and curative or protective effect were clearly understood.

To obtain the necessary information, radiolabelled drugs are to be used in animal studies at the Kenya Trypanosomiasis Research Institute. Information on the drug level in tissue will be obtained for correlation with biological effects of drug administration. Sensitive methods of analysis for trypanocidal drugs have been developed in the Agricultural Biotechnology Laboratory and will be used in the practical investigation in Kenya.

Utilization of biomass — agricultural wastes

The energy derived from fossil fuel sources is a major factor in agricultural production and distribution. Modern agricultural practices are highly dependent on sources of energy and the increasing cost of energy is a major constraint on agricultural production in both developed and developing countries. Considerable research and development work is now in progress to exploit new sources of energy. In particular, the utilization of renewable resources (manure, crop residues, "energy" crops, and so on) for production of energy, animal or plant nutrients is a field of research in which nuclear techniques can play a valuable rôle.

Energy as methane or ethanol can be produced from cellulosic wastes by fermentation. Fermentation processes are also widely used for production of food, feed and beverages, and a major endeavour in the expanding field of biotechnology is the extension and improvement of fermentation processes using "tailored" biological catalysts.

A lack of basic understanding of the processes involved limits current techniques for energy production. Generation of methane by fermentation (biogas) is a relatively recent approach to energy production from wastes such as animal manure. Although the scientific background is rudimentary, many constraints have been identified, such as the limited ability of micro-organisms to digest lignocellulosic substrates (wood, straw, and so on). Fermentation may be slowed or prevented by the presence of certain micro-organisms or by the excess of certain intermediates in the breakdown process. Also, fermentation processes occur only within narrow ranges of pH or temperature.

Energy-production processes and their limitations are therefore being investigated in numerous laboratories throughout the world. Nuclear techniques are being utilized in this research, and the Joint FAO/IAEA Division is supporting a number of research projects. Studies of the processes occurring in methane generators in rural areas and the influence of operating conditions on the efficiency of production of methane are being investigated by the addition of isotopically-labelled substrates to the waste in the fermenting.

It may be possible to enhance the rate of lignocellulose breakdown and the rate of fermentation at lower temperatures by using new strains of micro-organisms. Radiation-induced mutants have been produced in the quest for enhanced capability to degrade agricultural wastes, such as bagasse from sugar-cane production or fruit wastes remaining after fermentation and distillation of spirits.

The observation that African termites can utilize woody materials as a food source suggests that the microfauna present in the gut of termites possess unique capabilities for degrading lignocellulose. A research programme in the Agricultural Biotechnology Laboratory is in progress to isolate, identify and exploit such organisms. Organisms that degrade cellulose have been isolated for mutation studies, and scientists in Nairobi, Kenya, are co-operating with scientist of the Joint FAO/IAEA Division in this project.