THE CONTRIBUTION OF THE UNIVERSITIES AND COLLEGES

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Crop losses due to diseases, disorders, animal pests and weeds are often far greater than either scientists or farmers realise. Surveys by the Food and Agricultural Organisation constantly confirm the startling fact that even today more than one-third of the potential annual world harvest is destroyed by harmful organisms. This is a shocking waste of human effort and energy resources and obviously there is ample scope for improvement. But it is quite impossible to estimate the value of crops which are saved from destruction by the application of appropriate control measures. In many parts of the world economic production of basic crops could not be sustained without adequate crop protection. Hence the need for advanced and specialized training in crop protection technology.

1. TRAINING FACILITIES

Broadbent (1974) summarized existing higher education facilities in crop protection and allied sciences in the U.K. He showed that education and training in the sciences and their application relevant to crop or plant protection were offered at three levels as follows:

(a) several colleges included the subjects in courses for the Ordinary or Higher National Certificates and Diplomas (O.N.C., O.N.D., H.N.C., and H.N.D.)

(b) courses designed for technologists were offered usually at honours degree level in universities and polytechnics for B.Sc., B.A., or B.Tech. qualifications, and in a few colleges for Membership of the Institute of Biology (M.I. Biol.) which is equivalent to an honours degree.

(c) post-graduate courses for a diploma or a Master's degree were offered by a few establishments, some covering the subject widely as crop protection but most offering a study in depth of one aspect, for example pathology or entomology or weed biology.

The basic training facilities outlined above have continued, virtually unchanged, since 1974. At that time it was agreed that both general and specialist crop protectionists would be needed in increasing numbers to cope with the food supply for the expanding world population. It was also felt that there was a need for a broad education prior to specialization since, in future, personnel would need to be more adaptable to change than in the past.

Syllabuses and Course Content for crop protection courses were reviewed and discussed in detail at the British Crop Protection Council Symposium at Stirling in 1976. It was recommended at the end of the Symposium that there should be an integrated approach to crop problems in crop protection course syllabuses, and attention was drawn to the shortage of studentships in the U.K. in the broad field of crop protection. It was stressed that agriculture including horticulture and forestry, was Britain's most important industry, yet the number of taught course and research studentships available was strictly limited, and they were few compared with those available in the pure sciences, social and environmental sciences.

2. TRAINING REQUIREMENT

The syllabus and programme of work should be designed to provide a realistic balance between theory and practice to educate and train students to:

(a) develop ability to apply scientific principles and technology logically to solve problems.

(b) use scientific and technical literature critically and effectively.

(c) evaluate the scope and limitations of a range of technical and economic developments from investigational work, observation and literature.

(d) assess crop protection techniques and developments in financial benefit/cost terms.

(e) communicate ideas and make practical recommendations on crop protection.

Because of the rapid scientific and technological development in, and the increasing practical importance of crop protection there is a need to provide independent vocational training in crop protection as an essential service to the agricultural industry. Vocational training is concerned with technology designed to equip students with sound knowledge and experience of the skills required in their future occupation. The course of training must not only be relevant; it must be seen by students to be relevant. Crops are grown in fields and both the agrochemical industry and farmers need trained personnel with a feel for the job. It may be a gross exaggeration to say that, 'a gram of practice is worth a tonne of theory', but it is a meaningful expression. Nevertheless, in advanced training, the question 'why' is often more pertinent and difficult to answer than the question 'how', so that our technologist must comprehend the principles of and reasons for crop protection as well as the practice.

The need for broad-based education prior to specialization is widely recognised and accepted within the agricultural industry. It has become impossible to provide more than a superficial study of crop protection and its components at honours degree level in universities and polytechnics for B.Sc., B.A., or equivalent qualifications. Similarly courses for Ordinary or Higher National Diplomas provide insufficient coverage of crop protection technology in their crowded syllabuses and timetables. At best the course referred to previously under Training Facilities (a) and (b) provide a sound broad-based education with an introduction to some aspects of crop protection technology. For example, in a B.Sc. Hons, course in Agriculture or Agricultural Science, or in an H.N.D. course in Agriculture, agronomy may account for only about 20 per cent of the total syllabus, and crop protection in turn only about 10 per cent of the agronomy syllabus. It follows that only about 2 per cent of the total course will then be devoted to a study of crop protection technology.

Specialized courses in plant pathology or entomology usually follow basic studies in botany or zoology. Such courses may provide appropriate training for important but numerically restricted research and development posts in agrochemical manufacturing companies. Research chemists required by similar companies usually receive their basic training at universities or polytechnics. But employment opportunities in these sectors are limited and at present the supply of graduates exceeds demand, so that highly specialized scientists may feel unwanted and frustrated.

There appears to be a much greater need and demand in the Agrochemical Industry for crop protection technologists than for science specialists, for technical sales, advisory and development work. Post-graduate training for a diploma or a Master's degree in crop protection technology is therefore more relevant and important in a quantitative sense than specialist science training for the Agrochemical Industry of the future. Because of this, training requirements for these type of courses will be outlined in detail in the next section, and some of the associated education and training problems will be discussed.

3. POST-GRADUATE TRAINING IN CROP PROTECTION

The course syllabus should be designed, after close consultation with scientific and commercial authorities on crop protection, to provide a realistic and meaningful balance between theory and practice as illustrated in Table 1.

TABLE 1 Crop Protection Course Syllabus

Subject

1. Evolution and role of crop protection.
2. Agronomy.
3. Pesticides and the environment.
4. Chemistry of pesticides.
5. Application of pesticides.
6. Biology and control of weeds.
7. Crop diseases and their control.
8. Crop pests and their control.
9. Plant growth regulation.
10. Non-parasite disorders.
11. Crop management economics.
12. Design and analysis of experiments.

Major Projects (a) Investigational work,
(b) Review of Literature.

Minor Projects (a) Field and Laboratory studies.
(b) Official and Commercial Literature.

Outside Visits and Visiting Speakers

Supplementary science and technical subjects as required

The duration of this type of post-graduate course will usually be one academic year.

3.1 PROJECT WORK

3.1.1 MAJOR PROJECTS

Each student should undertake, preferably, two major projects, from a provided list of subjects, each related to some aspect of crop protection. The first major project should consist of investigational work to provide the student with practical knowledge and experience of research and development work. The completed project could be presented in the form of a scientific paper. The second major project should consist of a review of literature of up to 5,000 words.

This type of work will provide students with opportunities to use their initiative and develop their ability to identify and solve problems. Experience in organising information and presenting reports will be most useful.

3.1.2 MINOR PROJECTS AND PRACTICAL WORK

Minor projects and practical investigations provide an essential link between the theory and practice of crop protection. An intensive, regular programme of work should be followed throughout the course and the projects and practicals should be written-up, submitted, assessed and discussed. This type of work forms the basis of continuous assessment of the progress of students and demands regular work and commitment.

Some examples of minor projects and practical work are given in Table 2.

TABLE 2 Minor Projects and Practical Work

Minor projects	Reviews of scientific and technical literature.
	Specific problems on the biology and control of weeds, diseases and pests.
	Crop protection in commercial practice.
	Financial aspects of crop protection.
	Design of field experiments, analysis and interpretation of data, and presentation of results.
Practical work	Determination of fresh and dry matter yields of crops.
	Calibration and use of crop sprayers.
	Design and lay-out of field experiments and demonstration plots.
	Application of treatments for the control of weeds, diseases and pests.

Monitoring and recording effects of treatments.

Collation and analysis of experimental data.

Studies of the growth and development of crops.

A progressive vocational crop protection course, catering for training in a rapidly developing technological subject, must be supported by adequate facilities for training in applied research and development. Students must have access to field development work and so become familiar with progress and problems in crop production.

Objective studies may be carried out on modern and well equipped University or College farms to evaluate scientific and technical developments in crop protection in major field crops like cereals, potatoes, sugar beet, grass, forage maize and brassica crops.

A crop demonstration area of about 1 ha may be most useful to establish and grow a wide range of minor field crops including beans, brassica vegetables, carrots, linseed, maize, onions, peas, rye, soyabeans and sunflowers. This additional range of crops could provide useful opportunities to extend crop protection work.

Field laboratory and glasshouse facilities should be available for investigational and teaching purposes.

Initially, minor projects and practical work may be designed and used to provide training and experience. Later, students may take on responsibility for designing and carrying out crop protection programmes. For example, small teams of 2 - 4 students may be required to investigate potential crop protection problems in a particular crop such as a winter cereal, beans, carrots, maize, onions or peas. The students are responsible for identifying crop protection problems, suggesting and when appropriate, carrying out remedial treatment. Progress reports on their work may then be given by individual students in tutorial sessions to provide experience in presenting reports to an audience and answering questions.

The need to be able to communicate technical information clearly and objectively cannot be overemphasised. Regular practice and guidance is necessary during training.

3.2 OUTSIDE VISITS AND VISITING SPEAKERS

The importance of access by staff and students to applied research and development in crop protection cannot be overstressed. Apart from the basic need to acquire knowledge and understanding of the principles and practices of crop protection, students need the impact and stimulus of contact with the main sections of the industry. This experience may be provided by a regular series of outside visits to, and talks by visiting speakers from agricultural research and development institutes, official and commercial development and advisory services, university science departments, agrochemical manufacturing and servicing industries, agrochemical merchanting organisations, farmers and farming organisations, and commercial business and marketing organisations. At least one day per week of teaching time should be allocated to this important section.

Arrangements should also be made for students and staff to attend National, Regional and Local conferences and demonstrations on crop protection and related subjects. Details of typical programmes of Outside Visits and Visiting Speakers were given by Eddowes (1976).

Outside visits and talks by authoritative visiting speakers not only effectively stimulate interest and awareness of students in important aspects of crop protection but also provide them with an appreciation of the size, and employment opportunites within the industry. Experience at Harper Adams College has shown that students consider that visits and visiting speakers make an outstanding contribution to their course.

4. SOME PROBLEMS ASSOCIATED WITH A ONE-YEAR VOCATIONAL COURSE

Several problems are likely to arise in teaching a one-year post-graduate course in crop protection and the most important ones are summarized below:

a) the subject of crop protection covers a huge area of applied science and technology. In the limited time available teaching has to be selective and it may be difficult to cover the syllabus adequately

b) students may be enrolled from Britain and Overseas. Their academic background and practical experience may be very diverse making it difficult to set and maintain standards appropriate to them all

c) the academic year does not coincide with the main cropping season in this country. Useful field work in crop protection may be restricted to about 2 months because of vacations and examination commitments

d) there may be difficulties in striking the right balance between theory and practice in a one-year vocational course, to allow sufficient time for study.

Another important problem is that of students financing the cost of post-graduate training. In recent years chronic inflation and consequent severe restrictions on grants by Local Authorities have prevented many well qualified and keen potential students from taking crop protection courses. The present cost for tuition is likely to be £600-£800 per student and a similar amount is needed for board and residence. Whilst the main source of grant for post-graduate training will continue to be National and Local Government, there is a need for more direct financial help from the Agrochemical Industry.

Experience suggests that more opportunities are needed by students for pre-entry and vacational practical experience in crop protection in the Agrochemical Industry and on commercial farms. Such opportunities provide a valuable supplement to course training.

5. EMPLOYMENT OPPORTUNITIES IN THE AGROCHEMICAL INDUSTRY

The type of course outlined above is designed to train future crop protection specialists in applied science and technology. In Britain, and on the continent of Europe, crop protection specialists are employed mainly by Agrochemical Manufacturing, Distribution, Service and Supply Industries. There appears to be an increasing demand for independent vocational training in crop protection to serve the agricultural and food industries in Europe.

6. CONCLUSIONS

It is concluded that Universities and Colleges have an important role to play in providing independent scientific and vocational training in crop protection as an essential contribution to future training requirements of the Agrochemical Industry.

This training may be complementary to specialist in-service training schemes already operated by many agrochemical manufacturing and servicing organisations.

Since there appears to be a much greater need and demand in the Agrochemical Industry for vocationally trained crop protection technologists than for science specialists, for technical sales, advisory and development work, it is concluded that priority should be given to post-graduate training in crop protection, and undergraduate courses which include sandwich training periods in crop protection.

Maintaining the independent nature of the training is most important, but this does not mean that students should be isolated from commercial reality. Whilst it is difficult and unconvincing to provide effective sales training at a teaching establishment suitable opportunities may occur during sandwich training periods, and students of crop protection should be constantly aware of the needs of the Agrochemical Industry to evaluate, market and service commercial products.

The type of post-graduate course described in this paper has useful potential for training students from developing countries especially in relation to temperate crops.

References

Broadbent, L. (1974) Higher education in crop protection and allied sciences in the U.K. Br. Crop Counc. Monogr. No.13, 60-62.

Eddowes, M. (1976) Crop protection syllabus content. Vocational agricultural course. Br. Crop Prot. Counc. Monogr. No.20, 66-76½

NOTES

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RECENT ADVANCES IN THE STUDY OF EFFECTS OF PESTICIDES ON THE POPULATION DYNAMICS OF NON-TARGET MICROORGANISMS

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Summary Increasing concern for man and his environment has resulted in increasing importance of studies on side effects of crop protection chemicals concerning non-target soil microorganisms. Therefore, the present state of knowledge and recent advances in the study of such effects are reviewed. The connections of microorganisms and their activities with soil fertility and plant production are highlighted. Potential side effects are discussed, particularly with regard to their influence on soil fertility, and interactions of environmental and soil conditions with side effects are indicated. Criteria and tests suggested by researchers working on the subject of pesticide -microbe-interactions are presented which should permit the monitoring and quantification of pesticidal side effects on the soil microflora. Problems and possibilities of interpreting of results obtained with the tests are discussed. It is concluded that compulsory and rigid regulatory guidelines cannot, and should not, be established yet, since too little is known about the importance and practical relevance of microbial processes for soil fertility. Instead, a plea is made for increased efforts in basic research on soil microbial activities and side effects of pesticides.

Pesticides are widely used in agriculture to minimise the often considerable losses in food production caused by competition of weeds, pest insects and fungal and bacterial diseases. These pre- and post-harvest crop losses are estimated by FAO to amount to about 30 percent of the potential production, with losses being greatest in the developing countries (Furtick, 1976). These losses are in direct contrast to the needs of the growing world population. It is estimated that crop production has to be doubled during the next 10-20 years in order to meet the most urgent demand of the world population (Bommer, 1976, Gray, 1976). Despite considerable progress in biological pest control it was recognised by the leading plant protection experts called together by FAO after the World Food Conference that pesticides will, during the forseeable future, remain a primary means for reducing losses (Furtick, 1976) and thus enhance crop production. In addition to that, chemical crop protection has gained considerable importance in the rationalisation and mechanisation of modern agriculture and is increasingly becoming an integrated part of farming systems. As a consequence, a more extensive use of pesticides will be made and demand for new chemicals will increase.

In addition to their expected effects, the past has shown that pesticides can produce undesirable side effects. These may cause hazard to man and his environment in the widest sense of the word, particularly if pesticides are applied indiscriminately and in large quantities. Recognition of this danger has led to the introduction of registration of pesticides with Regulatory Authorities prior to their large scale production and use. The registration schemes currently in force in many countries all over the world, though different in many details, have the common goal of ensuring the registration of efficacious compounds the proper use of which does not pose any undue risk to user, consumer and the environment. The development of the registration requirement during the last 2 decades has been described by Waitt (1975). The tests currently needed to assess toxicological and environmental 'safety' of pesticides are shown in Table 1.

In this context, ecological studies have gained considerable importance with Registration Authorities in recent years. Initially, the interest concentrated on above-ground macroorganisms. Subsequently, it extended to below-ground macroscopic organisms and finally during the last few years to microorganisms. Contrary to widespread and popular belief, the agrochemical industry recognised that pesticides might create environmental problems and developed techniques to study such effects well before legislation and regulations were introduced. Ecological studies at ICI Plant Protection Division started in the late 1950s and a special unit to study ecological effects of pesticides was set up in 1963. Intensive research concerned with effects of pesticides on microorganisms was started by PPD's Ecology Section during the second half of the 1960s and has resulted in important contributions to the development of relevant tests and methodology (Anderson, 1973, Johnen and Drew, 1977). Similar developments have taken place in most parts of the crop protection industry.

Table 1 : Toxicological and environmental data required for registration

ENVIRONMENTAL DATA

Active ingredient and/or degradation products

I Fate in Plants

- a) metabolism and degradation
- b) analytical residue method
- c) residues
- d) taint
- e) special studies (eg rotational crop studies)

II Fate in animals

- a) Metabolism) in: poultry, large
- b) Excretion) animals, fish
- c) Accumulation) (eggs, meat, milk)

III Soil) metabolism and degradation
) leaching, analytical
Water) methods, residues, micro-ecology

TOXICOLOGICAL DATA

I Acute toxicity - active ingredient (and formulations)

- a) oral LD_{50} (4 species)
- b) dermal LD_{50} (2 species)
- c) intraperitoneal LD_{50}
- d) eye irritation
- e) inhalation
- f) skin irritation
- g) skin sensitisation

II Subacute Toxicity

- a) 14 day, oral
- b) 21 day, dermal
- c) 21 day, inhalation
- d) 90 day feeding - rat
- e) 6-12 months feeding - dog

III Chronic Toxicity

- a) Life span carcinogenic and no effect level study - rat
- b) Life span carcinogenic study-mouse
- c) Multigeneration reproductive study
- d) Teratogenic studies
- e) Mutagenicity studies - predictive, short term *in vivo* lethal study

IV Special Studies

- a) Metabolism, Accumulation, Excretion
- b) Mode of Action (including Antidote)
- c) Neurotoxicity
- d) Potentiation
- e) Probably studies on Metabolites

The growing interest in soil organisms and particularly soil microorganisms is probably based upon two important aspects of microbial activity. Dependent on their use, pesticides or their metabolites eventually arrive in soil in one way or another in varying quantities. Microorganisms play by far the most important part in their degradation to biologically inactive products. It is widely accepted that microorganisms also play an important part in the wider aspects of maintenance of soil fertility and long term crop production, however little may be known about the exact mode of action by which they exert their influence. It is therefore important that the benefit of pesticides as pest combatants and weed control agents is not outweighed by detrimental effects on soil microorganisms, and hence soil fertility and crop production.

Although latest editions of regulatory guidelines such as those drafted by the U S Environmental Protection Agency (EPA), the U K Pesticide Safety Precaution Scheme (PSPS) and the Commission of the European Economic Community (EEC) require studies on the effect of pesticides on microorganisms to be included in the registration package, virtually no guidance is being given as to how such effects could be evaluated.

Initiated by the Biologische Bundesanstalt and Bundesforschungsanstalt für Landwirtschaft in the Federal Republic of Germany, 4 International Symposia[1] with participants from Regulatory Authorities, Research Institutes and Industry in Western Europe, were held during 1974-1977 to discuss the role of microorganisms in soil, how pesticides may interfere with their population dynamics and how potential effects could be evaluated and interpreted. This last aspect, of course, is of particular importance.

STATE OF RESEARCH

Hundreds of papers have been published over the last 20 years concerned with potential non-target or side effects of pesticides on microorganisms. Many reviews were also written during this period (Newman and Downing, 1958, Fletcher, 1960, Domsch, 1963, Audus, 1964, 1970a, 1970b, Alexander, 1969, Helling et al, 1971, Greaves et al, 1976, Anderson, 1978). However, our knowledge and understanding of the interactions between pesticides and microorganisms have made very little progress (Domsch, 1972). This may be due to the fact that tests were carried out in pure culture. Such tests can be carried out relatively easily and may often produce valuable biochemical information. Their results can, however, not be extrapolated to the natural soil environment. In more recent years, such experiments have been therefore less frequently employed as a means of evaluating side effects in soil (Anderson, 1978). Another reason may be that purely descriptive methods were used or isolated aspects of microbial activity studied, the results of which did not elucidate the dynamics of functional relationships in the ecosystem. A methodology has therefore to be developed for uncovering interactions in the soil ecosystem which quantifies microbial activities, but is not restricted to isolated aspects (Alexander, 1969). Results obtained by various authors investigating the same pesticide may also be contradictory. This is usually due to our present insufficient knowledge of ecological relations and disregard of differences in soil types. Considerable diversity in the choice of methods used to investigate side effects on microorganisms, incomparable experimental conditions and pesticide application are further reasons. A certain degree of standardisation of tests, methods and experimental conditions including pesticide application is therefore desirable and needed as far as is possible in the current state of knowledge (Grossbard, 1975, Johnen and Drew, 1977).

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[1] International Symposia on Side Effects of Pesticides on Soil Microorganisms, Braunschweig, February 12-13th, 1974, December 13th, 1976, Münster, October 12th, 1977.

IMPORTANCE OF MICROORGANISMS IN SOIL

Microorganisms gain their importance because of the vast numbers present in soil. 10^9-10^{10} cells per g in the root-free soil are normal. Numbers may be several orders of magnitude higher in the rhizosphere and rhizoplane. Thus, considerable amounts of carbon and nutrients can be stored in the microbial biomass making it a potentially valuable nutrient supply for plants and other higher organisms. Microorganisms are also important because of the part they play in mineralisation and recycling of essential plant nutrients (C, N, P, S), decomposition of all kinds of organic debris and formation of humus; they aid the formation of the soil structure and maintenance of aggregate stability and release nutrients from minerals; microbial N-fixation can result in a considerable contribution to the nitrogen supply of plants; saprophytes help to suppress pathogens; the total microflora or some of its specific groups are responsible for the detoxification of most pesticides. The efficient functioning of these processes is the result of a dynamic equilibrium between microorganisms, soil and plants, which is influenced and maintained by many environmental factors. The balance of these factors and processes is usually called 'soil fertility' (Greaves et al, 1976). Plant production and thus feeding of mankind are dependent on its maintenance and furtherance.

POTENTIAL SIDE EFFECTS OF PESTICIDES ON SOIL MICROFLORA

The influence of pesticides on the living microbial system can be exerted on two dimensions, the individual cell and the population. Too little is known about the effects of pesticide compounds on the cell per se, its components and functions. Consequently, virtually nothing is known about the mechanisms by which pesticides may affect microorganisms. It is therefore not possible to group compounds in a scheme like: probable - potential - unlikely side effects and, at the current state of knowledge, no pesticide or group of pesticides can be assumed to have no potential for side effects on microorganisms.

Potential side effects on the microbial population are shown in Table 2. They can directly affect microbial functions (catabolic, anabolic, energy producing and biogeochemical processes) or associations and antagonists (plant parasites, predators, micro parasites, symbionts), or indirectly affect soil fertility, since soil physiological (eg maintenance of nutrient cycles, physical soil properties, nutrient supply and microbiological synthesis) and soil ecological (eg maintenance of equilibrium between organisms and of food chains) contributions of the microflora in support of the soil fertility are inhibited, interrupted or eliminated.

Table 2 : Potential side effects of pesticides on microbial populations (after Domsch, 1972)

Decrease in total number of microorganisms
Decrease in groups of microorganisms
Decrease in microbial species
Inhibition of total activity
Inhibition of metabolic activity
Inhibition of biomass production
Inhibition of enzymic activities
Interruption of nutrient cycles
Disintegration of ecological associations
Elimination of ecological antagonists

It is obviously possible to identify the potential side effects of pesticides theoretically and relate them to the physiological and ecological processes which maintain soil fertility. However, it is not possible - at least to the same degree - to rank these functions with regard to their contribution to soil fertility; nor to decide whether functions such as decomposition of organic debris, microbial contribution to stability of soil structure and sorption properties, formation of humus, degradation of toxic substances and maintenance of nutrient supply can be dispensed with. With some exceptions the importance for plant growth and development of antagonists and associations such as predatory fungi - nematodes, insect pathogenic microorganisms - insects, mycorrhiza, non-symbiotic N-fixation and rhizosphere associations is almost completely unclear.

The extent of side effects of pesticides on soil microorganisms is dependent, apart from the properties of the active ingredient and the formulation additives, on a variety of factors which can be combined in 4 groups:

1 physico-chemical properties,
2 original biological conditions in soil,
3 climatological influences, and
4 agro-technical actions and cropping systems.

The physico-chemical properties such as clay mineral content, cation exchange capacity, pH, soil moisture and humus content combined with the properties of the pesticide influence adsorption, leaching, volatility and biological inactivation of the pesticide and may thus increase or decrease its potential side effects. The influence of biological factors such as competition between organisms for space and nutrients must not be underestimated. Climate and weather can put microorganisms under considerable stress and may determine the extent of any effect. Agro-technical actions such as ploughing, burning of straw and minimum cultivation as well as crop rotation and fertilisation create a specific microflora of which the reaction to the effect of pesticides may vary dependent on composition and biomass. The interactions between pesticides and microorganisms which are caused by such environmental changes have been discussed in more detail by Greaves et al. (1976).

DETERMINATION OF SIDE EFFECTS

Confronted with such a complex of problems it is obviously very difficult, if not almost impossible, to suggest criteria and a programme of tests and methods for the evaluation and quantification of side effects of pesticides on microflora. The task becomes increasingly difficult if such a test system has to accommodate a degree of standardisation of experimental conditions and pesticide application sufficient to make studies comparable. Whatever criteria and tests may be proposed at this stage, they are open to criticism. Differences in opinion are inevitable since microbial ecology is still rather poorly understood and huge gaps exist in our knowledge of microbial ecosystems, how they function and what the most important functions are.

Consequently, not all the factors influencing soil fertility can be determined. This conclusion is supported by a review of the literature which, disregarding experiments in pure culture, reveals that most studies are concerned with the quantitative and qualitative determination of the microbial population, potential enzyme activities, decomposition of organic matter, measuring of 'soil respiration', nitrogen mineralisation, nitrification and symbiotic nitrogen fixation.

Anabolic and biogeochemical processes, however, are investigated much less frequently. Also comparatively little attention is directed towards studying pesticide effects on plant parasites, predators, micro parasites, mycorrhiza and other interactions between microorganisms and plants in the rhizosphere. The same applies to indirect effects such as oxygenation in paddy fields (Raghu and McRae, 1967). The relatively small number of this latter type of study is mainly caused by a lack of basic research and a convincing methodology suitable for routine investigations. As a result of these considerations the participants of the Symposia, referred to above, decided to select representative factors, which allow the measurement of complete microbiological processes and reveal the extent and the duration of potential pesticide side effects (Table 3).

Table 3 : Proposals for Evaluation of Side Effects of Pesticides on Soil Microorganisms

(1) CO_2-production/O_2-uptake (lab test)
- a) Soil without amendment (basic respiration)
- b) Soil amended with glucose ('activated' respiration = microbial growth).
- c) Soil amended with plant material (decomposition of complex organic matter by a sequence of groups of organisms).

(2) Nitrogen Transformation (lab test)
- a) Ammonification
- b) Nitrification

(3) Symbiotic Nitrogen Fixation - Rhizobia development in pot experiment (if relevant to use of pesticide).
- a) Nodule formation: Number, Weight, Size
- b) Nodule activity
- c) Plant yield

(4) Special Microorganisms and Antagonists
- a) Mycorrhiza of plants
- b) Antagonists
- c) Soil Borne Pathogens

(5) Microbially induced soil structure and crumb stability

(6) Spray Sequences, Spray Mixtures.

Whereas detailed proposals for routine methods could be worked out for items (1)-(3) in Table 3, it was thought to be premature to try to establish routine tests for items (4)-(6). These were deferred until further basic research had established their significance and given indications towards a suitable approach for their evaluation. The tests should be carried out in the laboratory since, besides other advantages (Johnen and Drew, 1977), the laboratory test is less variable. Indirect effects are excluded which may, for example, occur under field conditions as a result of herbicide application and weed control and subsequent changes in soil moisture and temperature. Also the laboratory test is more stringent than a field experiment (Johnen and Drew, 1977). Therefore, if any side effects are experienced, they are more likely to be detected with the former than the latter. Field experiments are, however, required to verify or refute pesticide effects obtained under laboratory conditions, and thus facilitate final conclusions. The soil preparation, experimental conditions, pesticide application and dosing as well as the test methods underwent comparable testing (Johnen and Davies, 1977;

Johnen, Drew and Castle, 1979). They proved to be useful for evaluating pesticide effects and were thus integrated into our routine test system to evaluate pesticide side effects on microorganisms (Johnen and Drew, 1977). A similar approach was adopted by Atlas et al (1978) for studies involving several pesticides which were carried out on behalf of the U S Environmental Protection Agency.

Recently, an International Workshop[1] with participants from all parts of the world discussed the need and possibilities for routine testing of side effects of pesticides on microorganisms. The workshop established the same factors for routine testing as those shown in Table 3 (1)-(3). In addition, studies on non-symbiotic nitrogen fixation, mycorrhiza and soil borne pathogens were suggested, but before these could become routine more research into their importance to the plants and relevance in agriculture was recommended. A steering committee[2] was set up to act as a link between researchers working actively in the field of non-target effects of pesticides on microorganisms and organise further meetings to discuss advances in the field. The ultimate aim is to derive tests which are appropriate to evaluate non-target effects and which are widely accepted and used throughout the world.

INTERPRETATION OF RESULTS

It is of course insufficient to produce data only on side effects of pesticides. It is equally questionable to draw vague conclusions regarding side effects solely based upon a statistically significant difference between treated and untreated samples. Statistically analysed data should rather be used to attempt an interpretation of their practical significance and relevance. To do this, extent and duration of side effects have to be considered. It may also be necessary to carry out additional confirmatory experiments. The criteria employed and the results obtained with the relevant tests have to be assessed in relation to their agronomical implications and the beneficial effects of the pesticide and then be ranked and 'valued' accordingly. Three examples, stated by Domsch (1972), may illustrate this.

1 A high percentage of fungal units is usually eliminated from the soil after fungicide application. The relative importance of fungi as compared to bacteria is, however, still relatively obscure. Consequently, too much emphasis on the reduction of soil fungi in such cases seems inappropriate.

2 It is possible that the total number of microorganisms is drastically reduced by a certain pesticide, while essential soil metabolic activities are still functioning in the same system. Consequently, processes of decomposition, transformation and production must rank higher than numerical shifts.

3 Nitrification is frequently inhibited by pesticides. However, the 'value' of nitrification for plant nutrition is extremely small. Consequently, the rank of the criterion 'nitrification' should be re-evaluated, even if it is probably the most frequently used criterion to evaluate pesticide side effects (Anderson, 1978).

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[1] Pre-Congress (III. ICPP, München, 1978) Workshop on Side Effects of Pesticides on Non-Target Soil Microorganisms, Braunschweig, Aug 14-15th, 1978.

[2] <u>Chairman</u>: Prof G Jagnow, Institute for Soil Biology, Federal Institute for Agriculture, Bundesallee, D-3300 Braunschweig, West Germany.
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To facilitate interpretation it is also vitally important to know when the limit of stress bearable for the microflora is exceeded by side effects of pesticides. That is to say, to what extent can side effects be tolerated and what respective recovery times are permissible, critical and intolerable during which the original population or activity has to reestablish itself? Astonishingly, these questions have been considered very little up to now. Domsch and Jagnow[ø] have therefore suggested using population changes and fluctuations of microbial processes caused by 'natural' events such as freezing and thawing, compression, silting up, flooding, seasonal fluctuations in plant growth and other seasonal influences as a yardstick to evaluate non-target effects of pesticides on the microflora. Extent ("maximal depression") and duration ("phase shift") of side effects are compared with the relevant values resulting from the effect of these natural stress factors. It is suggested that the 'recovery time' (the time needed to recover from maximal depression to the original level of activity or number of organisms) observed after cessation of natural stress factors could be used to derive threshold values for the classification of pesticide-induced side effects into the categories tolerable, critical and intolerable.

This hypothesis is exciting because it provides a conceptual framework for further work. However, it must be realised that any threshold values have, at least for the time being, to be based on a literature survey and hence on sometimes doubtful work, and also that the literature, at the moment, is rather inadequate. Thus, there is a need to generate data which could be used to test, develop and finally, critically analyse the hypothesis forwarded by Domsch and Jagnow. The Weed Research Organisation have already carried out research in this area. Preliminary results of this research will be reported by Marsh later in this Session and it is hoped that a joint publication with Domsch and Jagnow will be possible in 1980. This will be, as far as I know, the first serious attempt to consider experimental results of side effects of pesticides on the soil microflora in an ecological context and evaluate them accordingly.

REGISTRATION ASPECTS

Considering all the problems discussed above it is not surprising that authorities who require testing of pesticides with regard to potential adverse effects on soil microorganisms, give very little, if any, guidance on the kind of tests required and methods to be used. Since research in microbial ecology is still in its infancy there is, at the moment, very little security in the selection of a suitable test programme which would cover all aspects of microbial functions in soil and their contribution to soil fertility. Consequently it would be futile to draw up rigid registration guidelines before a suitable choice of tests can be made. Instead, all efforts in relevant non-industrial and industrial research establishments should continue to be concentrated to deepen the understanding of the pesticide-microorganism-soil-root-relations aiming at "the quantification of specific activities of soil organisms, so that the components of the soil ecosystem can be weighed against each other" (Domsch, 1972) and potential effects on these can be interpreted according to their importance.

It is hoped that the regulatory authorities realise that there is still a considerable amount of basic research to be done and that this research is being actively pursued. This is amply demonstrated by the great number of publications on the subject which have shown that pesticides, at least when applied at normal

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[ø]At the 3rd Symposium at Braunschweig, 1976 and the pre-ICPP Workshop. Braunschweig, 1978.

rates and correctly, do not have any lasting adverse effects on the biomass, composition and activity of the soil microflora. Exceptions are fumigants and some fungicides, which are applied at high rates to kill the microflora or some groups of microorganisms (Alexander, 1969; Helling et al, 1971). In any case, new regulations for the registration of pesticides should be the result of extensive discussion between scientists actively working in the field and the registration authorities, with the aim of arriving at "harmonised" regulations. The foundations for this dialogue have been laid as far as the terrestrial aspect of microbial ecology is concerned. It would be advisable to achieve the same in the area of aquatic microbiology, since first outline regulations are now being proposed by EPA and EEC.

References

ALEXANDER, M. (1969) Soil Biology, Reviews in Research (UNESCO), Natural Resources Research 9, 209-240.

ANDERSON, J. R. (1973) A system for evaluating effects of pesticides on soil microbial activity, Bull. Ecol. Res. Comm (Stockholm), 17, 470-478.

ANDERSON, J. R. (1978) 1978 Microbiology: Microbiological aspects of pesticide behaviour in the environment. Academic Press, London. (in press).

AUDUS, L. J. (1964) The physiology and biochemistry of herbicides. Academic Press, London. 163-206.

AUDUS, L. J. (1970a) The action of herbicides and pesticides on the microflora, Meded. Rijksfac. Landbouwwet. Gent, 35, 465-492.

AUDUS, L. J. (1970b) The action of herbicides on the microflora of the soil, Proc. 10th Brit. Weed Control Conf., 1036-1051.

ATLAS, R. M., Cramer, D. and Bartha, R. (1978) Assessment of pesticide effects on non-target soil microorganisms, Soil Biol. Biochem., 10, 231-239.

BOMMER, D. R. F. (1976) Landbewirtschaftung im internationalen Vergleich, Chemie und Fortschritt, Schriftenreihe Verband der chemischen Industrie, Heft 2, 3-13.

DOMSCH, K. H. (1972) Interactions of soil microbes and pesticides, Symposia Biologica Hungarica, 11, 337-347.

DOMSCH, K. H. (1963) Einflüsse von Pflanzenschutzmitteln auf die Bodenmikroflora, Mitt. Biol. Bundesanstalt Land. Forstwirtsch., Berlin-Dahlem, Heft 107.

FLETCHER, W. W. (1960) Herbicides and the soil. Blackwell, Oxford. 20-62.

FURTICK, W. R. (1976) Pesticides and human welfare. Oxford University Press, Oxford. 3-12.

GRAY, R. H. (1976) Pesticides and human welfare. Oxford University Press, Oxford. 13-27.

GREAVES, M. P., Davies, H. A., Marsh, J. A. P and Wingfield, G. I. (1976) Herbicides and Soil Microorganisms, C.R.C. Critical Reviews in Microbiology, 5, 1-38.

GROSSBARD, E. (1975) Techniques for the assay of effects of herbicides on the soil microflora, Soc. Appl. Bacteriol. Tech., 8, 223-256.

HELLING, C. S., Kearney, P. C. and Alexander, M. (1971) Behaviour of pesticides in soils. Adv. Agron., 23, 147-240.

JOHNEN, B. G. and Davies, P. I. (1977) Standard-tests als Indikatoren für Nebenwirkungen von Pflanzenschutzmitteln auf Bodenmikroorganismen. Mitt. Biol. Bundesanstalt Land, Forstwirtsch., Berlin-Dahlem, 178, 227-228.

JOHNEN, B. G., Drew, E. A. and Castle, D. L. (1979) Studies on the effect of pesticides on symbiotic nitrogen fixation, Proc. of Section Soil-Borne Pathogens of III. ICPP, München, Academic Press, London (in press)

JOHNEN, B. G. and Drew, E. A. (1977) Ecological effects of pesticides on soil microorganisms, Soil Sci., 123, 319-324.

NEWMAN, A. S. et al (1958) Herbicides and the soil, Agricultural and Food Chemistry, 6, 352-353.

RAGHU, K. and McRae, I. C. (1967) The effect of the gamma-isomer of benzene hexachloride upon the microflora of submerged rice soils. 1. Effect upon algae. Canad. J. Microbiol. 13, 173-180.

WAITT, A. W. (1975) Pesticide legislation and industry, Pestic. Sci., 6, 199-208.

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CDA - A REVIEW OF DEVELOPMENTS TO DATE

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Summary An attempt is made to review the development of CDA, the application of pesticides at very low volumes and with a restricted and defined drop size range, covering part of the contents of the BCPC Symposium 1978 and previous publications on the subject.

Initiated by the ARC Weed Research Organisation and in the field trials stage taken up by ADAS and the Agrochemical Industry, most of the published work refers to foliar herbicides in cereals, although the CDA principle can be applied to other product groups and crops.

Conventional spraying performed marginally better than CDA in a majority of trials but as conditions, methods and materials varied considerably, interpretation of results is extremely difficult. Possible reasons for variable CDA performance are discussed, and suggestions made for further work.

Farmers' reaction to CDA and its advantages in terms of reduced drift, better timing and logistics will have a decisive influence on scale and urgency of future developments and a survey following the limited commercial usage in 1978 would be desirable.

Resume La littérature au sujet de la CDA., (pulverisation par gouttelettes contrôlées) y compris une partie du compte rendu du symposium du B.C.P.C. 1978, est passée en revue. La plupart de cette littérature se rapporte à l'emploi d'herbicides d'action foliaire dans les cultures céréalierès, cependant le principe de la CDA est susceptible d'application à d'autres produits dans d'autres cultures. L'idee de la CDA a été amortée à la ARC Weed Research Organisation et, à l'étape des essais de plein champ l'ADAS, de même que l'industrie agrochimique, s'y est interesse.

Dans la plupart des essais, le comportement de la pulvérisation traditionelle a eté legèrement supérieure à celui de la CDA; pourtant l'évaluation de ces résultats reste fort compliqué vu le manque d'uniformité des conditions, des méthodes et du matériel. On propose des explications du comportement variable de la CDA tout en indiquant des possibilités de travaux ultérieurs.

L'échelle et la rapidité de l'évolution ultérieure dépendront de l'attitude des fermiers vis-à-vis des avantages de la CDA, à savoir, la diminution des embruns, époque d'application precise, choix plus avisé du moment de traitement; il serait souhaitable de mener un sondage suivant l'emploi commercial de la CDA en 1978.

INTRODUCTION

Controlled drop application (CDA) - a term coined by Fryer in 1975 - was presented and discussed as a possible alternative to conventional spraying of pesticides at a BCPC Symposium held at Reading University in April 1978.

It adopts two principles from earlier work on ULV (Bals 1969; Matthews 1977) - that of defined drop size in relation to a particular target formed by spinning discs, and that of reduced volume.

The basic thoughts and aims behind this concept are:-

a) Elimination of small drift-prone drops (Taylor et al 1976).

b) Reduced drift hazard increases the number of available spraying days, and improves the chances of better timing of herbicide application in cereals.

c) More predictable and possibly enhanced biological results (Taylor et al 1976).

d) Smaller volume rates improve the logistics of the spraying operation (Byass 1976; Rutherford 1977a & b).

e) Reduced weight of equipment will cause less damage to soil and crops. (Farmery 1975).

One can thus define CDA as 'the application of suitable formulations of pesticides in very low volumes and with a defined and restricted drop size range required to give acceptable biological results and economic responses.'

Much of the fundamental research and subsequent field work on CDA with selective herbicides on cereals with a range of drop sizes and volumes was done at A.R.C. Weed Research Organisation (Taylor & Merritt 1975). This was supplemented by work on certain aspects of CDE at N.I.A.E. Silsoe, Imperial College Field Station, Ascot, Rothamsted Experimental Station, Harpenden, and, in the field in 1976, 1977 and 1978 by ADAS and a number of chemical manufacturers.

Those interested in fundamental work on drop formation by spinning discs, behaviour of drops, details of equipment and the historical background I would refer to the papers presented in the first part of the BCPC Monograph 22 (1978). Several references were made to the development work done by Bals; the spinning discs designed by him form the basic element of CDA field sprayers in the UK at present.

When assessing a new system of pesticide application, biological performance must feature prominently; it is the area where the interests of the farmer, the engineer and equipment designer, the research worker, the ADAS adviser and the manufacturer of agrochemicals coincide.

In reviewing this particular topic I shall concentrate on field work on cereals, although the principle of CDA has also been applied to top fruit (Morgan 1972, 1974) and to protected crops (Jarrett et al 1978; Sylvester 1978).

FIELD PERFORMANCE OF HERBICIDES APPLIED BY CDA ON CEREALS IN THE UK

a) WRO Trials

The work done since 1972 is summarised by Cussans & Taylor (1976); part of it is reported in detail by Ayres (1976, 1978) and Wilson (1976).

Initially the application equipment employed single cupped and toothed plastic discs supplied by Mr Bals of Micron Sprayers Ltd., giving direct drop formation at flow rates lower than 85 ml/minute, thus imposing restrictions on forward speed. To overcome this disadvantage the equipment was modified by Taylor, Merritt & Drinkwater (1976) by stacking discs in groups of five and shrouding them to ensure more uniform distribution of drops. This development resulted in a tractor mounted machine with an integral wind shield capable of treating 3m wide plots at volume rates from 5 l to 100 l/ha; drop sizes could be varied between 150 and 350 microns.

In 1975 two field experiments were done with barban and drop sizes of 150 microns and 250 microns, comparing volume rates of 5, 15, 45 and 175 l/ha. In addition, three trials were conducted with difenzoquat and four with dicamba/MCPA/mecoprop, with the above volumes and with drop sizes of 250 and 350 microns. The results, expressed as a mean of 2 dose rates (one as recommended, one lower) indicate that CDA at 45 l/ha was at least equal to conventional application, 5 l/ha performed poorly and 15 l/ha was not statistically inferior. The effect of drop size was slight.

Further work with the above compounds is published by Ayres (1976, 1978) and Wilson (1976). Ayres (1976) reports on 13 field experiments against broadleaved weeds with herbicide mixtures in Spring barley in 1976. CD application was made by units embodying 2 spinning discs of the type described by Bals (1975) mounted on a vertical shaft and fitted on a Dexion frame held by two operators. Drop size was 225 microns and volumes chosen were 10, 20 and 40 l/ha. Conventional spray treatments were made with a pressurised sprayer using 6502 TEE-jets and a volume of 225 l/ha.

A formulation containing dicamba/MCPA/mecoprop was used in 8 trials and the author concludes that at 6 sites there was no significant difference in herbicidal action between volume rates within single dose rates, measured by total dry weight of surviving weeds; at one site 40 l/ha and at another site 225 l/ha gave significantly better results. A comparison of means of total dry weight of surviving weeds/m^2 shows 220 l/ha as best treatment (4.32g), followed by 20 l/ha (5.14g), 40 l/ha (5.19g) and 10 l/ha falling off to 7.13g.

Five trials were conducted with bromoxynil/ioxynil/dichlorprop; at the recommended dose of 1.4 l/ha (formulated product) conventional spraying at 225 l/ha was superior to CDA when comparing mean values. 40 l/ha gave poorer control than 10 and 20 l/ha.

The results of 16 field trials conducted in 1976 on Spring barley against <u>A.fatua</u> with difenzoquat and barban are reported by Wilson (1976). A comparison was made between conventional application and CDA at 10, 20 and 40 l/ha, using the equipment described by Ayres (1976) at a drop size of 225 microns.

At 4 sites, results with barban (5 trials) at 20 and 40 l/ha were comparable with conventional applications at 175 l/ha, with over 90% control of seed production. At 1 site conventional spraying gave poorer results. At 10 l/ha control was unsatisfactory in most cases, leaving a mean of 4.42 panicles/m^2, compared to 2.62 for 20 l; 3.50 for 40 l, 2.44 for 175 l, and 23.24 in the untreated plots.

Conventional applications of difenzoquat (11 trials) gave over 97% control of panicles and seeds. Control with CDA fell off with decreasing volume levels, as can be seen by comparing mean numbers of panicles m^2 : 225 l - 0.54; 40 l - 2.12; 20 l - 5.27; 10 l - 9.55; untreated - 25.78.

It is suggested that the different response of barban and difenzoquat to volume rates may have been affected by spray timing and crop stage; difenzoquat applications were made late, when the barley was well tillered, thus perhaps impeding crop penetration.

Ayres (1978) reports results of 4 field trials with difenzoquat at 0.5 and 1 kg/ha against A.fatua and A.ludoviciana in Winter wheat. In 1975/76 the equipment described by Ayres (1976) was used, whilst in 1977 CD applications were made with a new machine, built by WRO, ADAS and Cropsafe, incorporating 3 spinning discs. In both years CDA drop size was 225 microns. Applications were made at different crop stages, comparing 15, 30, 45 and 225 l/ha.

Control at 225 l/ha was more consistent than CDA but significant differences in favour of conventional spraying were only established in 8 out of 48 reported assessments of wild oat seeds formed per m^2. Yield responses on the 3 sites harvested varied with the degree of wild oat control achieved and showed no significant differences.

b) ADAS Trials

The results of 54 trials conducted in 1976 and 1977 were reported by R J Bailey et al (1978).

In 1976 application was made by rotating disc units designed by Farmery (1975) mounted on a boom carried by 2 men. Swath width 2.5m; drop size 200-300 microns.

In 1977, most trials were done with 4 CDA machines constructed by WRO and Cropsafe Ltd., with swath width and drop size similar to that in 1976. At one centre a tractor mounted unshrouded single Herbi disc was used and at one site application was made by a tractor mounted Horstine Farmery prototype machine.

Volume rates chosen were 10, 20-25, 40-50 and 225 l/ha. Not every trial contained all 3 CDA volumes. Conventional spraying was mostly done by knapsack spraying. There were many differences between sites with respect to the method of assessment. Different herbicides were used at the various centres including barban, benzoylprop-ethyl, bromoxynil/ioxynil/dichlorprop, dicamba/mecoprop/MCPA, dichlorprop/2,4-D amine, difenzoquat, flamprop methyl, ixoynil/mecoprop, MCPA, MCPA/2,4-D ester and mecoprop.

There were 19 trials against broadleaved weeds in Winter wheat. Conventional spraying was superior to CDA at 20 l/ha at 15 sites, about equal to CDA at 3, whilst CDA gave a better weed control score at 1 site. In 8 trials, CDA at 40 l/ha performed better than at 20 l/ha.

18 trials were done in Spring barley; conventional spraying was more effective on 12 sites, whilst in the remaining 6 trials differences between conventional treatment and CDA at 20 l/ha were marginal and probably not significant. In all 5 trials to control A.fatua in Winter wheat 225 l/ha gave better control than CDA at 20 l/ha; performance of CDA improved at 40 l/ha and was equal to conventional treatment in 2 trials.

11 trials to control A.fatua in Spring barley are reported. In 8 of these conventional spraying was superior - perhaps not significantly so - whilst in the remaining 3, differences are marginal. Variability between the 3 CDA volume rates was considerable.

When calculating overall efficiency of treatments in those trials assessed on a percentage basis the authors, setting conventional spraying at 100, arrive at a relative effectiveness for CDA of 70.7 for 10 l; 71.2 for 20-25 l; 76.1 for 50-60 l.

They conclude that commercially acceptable weed control is more likely to be obtained with conventional spraying, but point out that this was not reflected in yield differences.

c) Reports from Chemical Manufacturers

Lush & Palmer (1976) report on 2 seasons work with CDA applied with Landrover mounted equipment (15-40 l/ha) and a drop size of 250-300 µ using mecoprop, dichlorprop/MCPA, benazolin/dicamba/dichlorprop and difenzoquat; in 1975 and the earlier part of the 1976 trials a double disc unit was used for the CDA application; for the later trials in 1976 a triple disc unit was employed. Conventional spraying was done at 225 l/ha. In 3 out of 8 trials against broadleaved weeds CDA was marginally inferior and in 1 trial the results were strongly in favour of conventional spraying. In the remaining 4 trials differences between CDA and conventional application were small. At 2 sites, severe crop scorch appeared in the CDA plots, probably due to local overdosing. There was no clear volume response pattern within the CDA treatments.

The 2 trials against wild oats using difenzoquat gave very dissimilar results.

Mayes & Blanchard (1978) report on a continuation of this work. A prototype Microdrop sprayer from H. Farmery was used in 1977 on 14 sites with an output of 20 l/ha by travelling at 8 km/hour and 40 l/ha by halving the speed of travelling. Drop size was 250-300 µ. CDA at 20 l/ha gave somewhat poorer weed control on all sites than conventional spraying, but despite the harsh climatic conditions the standard achieved at this volume remained generally acceptable. Inferior control at 20 l/ha frequently coincided with areas of thicker crop growth which shielded the weeds from the spray. Results with 40 l/ha were more uniform and closer to those for conventional treatment.

Lush (1976) states a score of 7 (in a system of 0 to 10) as minimum commercially acceptable effect, whilst Mayes & Blanchard (1978) consider scores from 6-10 as "satisfactory to good", prompting the question, what score would be given for excellent weed control?

Robinson (1978) reports on a trial using ioxynil/bromoxynil and ioxynil/bromoxynil and ioxynil/bromoxynil/dichlorprop in Spring wheat, comparing volumes of 5, 20 and 200 or 300 l/ha. CDA application was made by a small plot Horstine Farmery Microdrop applicator with double disc units producing droplets of 200-300 microns. With the first of these mixtures, control of 4 weed spp. was best at 200 l/ha, and 20 l/ha gave better results than 5 l/ha. CDA application to wet weed foliate improved the results. The second herbicide mixture performed best at 200 l/ha against Polygonum convolvulus and P.rhoeas, whilst there was considerable variation in control levels obtained with the different volumes against P.aviculare and Stellaria media.

Farmery et al (1976) described commercial prototype CDA equipment, pattern correction being achieved by a masking technique thus achieving uniform lateral distribution; 3 spinning discs are employed, producing a drop size of 250 microns, at a volume of 20 l/ha. 5 trials on Winter wheat with mecoprop, dichlorprop/MCPA, mecoprop/2,4-D, and dicamba/mecoprop/MCPA, conducted in 1976 are reported. Conventional spraying was done at 312 l/ha.

In 4 out of 5 trials the CDA technique gave results marginally inferior to those with conventional spraying, perhaps due to decreased crop penetration. At one site, the CDA treatment performed slightly better.

It is likely that the foregoing account of trials work with foliar applied selective herbicides in cereals is not complete and that there is a considerable amount of unpublished information to which I had no access. It is also appreciated that no detailed reference was made to work with other herbicides but it should be noted that glyphosate (Caseley et al 1976; Turner et al 1978) gave promising results with CDA against A.repens, with some variability between different types of formulations tested, and against Calluna vulgaris. May & Ayres (1978) reported on work with sub-optimal rates of linuron, chlorpropham and simazine on organic soils and conclude that agronomically CDA applications are a reasonable proposition, although there was some variability in response of different weed species. Robinson (1978) states that asulam gave markedly better control of bracken with CDA compared to conventional knapsack spraying.

CDA AND ULV WORK WITH INSECTICIDES AND FUNGICIDES

Published work on CDA trials with insecticides and fungicides is still rather limited. Pickin (1978) suggests that Sitobion avenae can be controlled by pirimicarb (5% ULV formulation) with small drops (50-90 microns) but there is no comparison with conventional spraying or with CDA application from tractor mounted machines as used in the herbicide work.

Sylvester (1978) reports ULV work on lettuce under glass. In 2 trials ULV at 5.6 l/ha (drop size not given) performed better against Botrytis cinerea than high volume spraying 1,700 l/ha whilst in 1 trial the HV programme gave marginally better protection. ULV treatment was done with a thiram/dicloran mixture at 0.42 kg a.i./ha (weekly intervals), whilst the HV treatment employed thiram at 5.3 kg a.i./ha at fortnightly intervals.

Jarrett et al (1978) studies distribution of coverage of different application methods on dense AYR chrysanthemum beds, using Bacillus thuringiensis and a fluorescent dye. CDA application with hand held spinning cups producing drops of 40 microns (nmd) wasted less B.thuringiensis but this economy was nullified by uneven distribution of the deposit. Martin (personal communication, 1977) showed that fluotrimazole applied at 187.5 g a.i./ha performed less well against Erysiphe graminis on Spring barley when applied in 20 l/ha by H. Farmery prototype CDA equipment, compared with conventional spraying. Triadimefon applied at 125 g a.i./ha acted slower against E.graminis with CDA application but in later assessments both CDA and conventional spraying achieved high levels (94%) of mildew control.

Harris (1977) reports on a trial against E.graminis on Spring barley, using tridemorph at 0.525 kg/ha in 10, 20, 40 and 340 l/ha. CDA application was made with a hand held Micron Herbi; some difficulty was experienced due to lack of direct flow control and in trying to maintain a standard walking speed. Assessments were made 8 days after treatment determining percentage mildew on leaf 2 with the following results : 340 l/ha, 3.8%; 40 l/ha, 6.6%; 201 l/ha, 9.4%; 10 l/ha, 10.1%; untreated, 20%. Yield responses were low and not consistent with the disease levels recorded, probably due to the over-riding effect of a very dry summer.

DISCUSSION AND OUTLOOK

Interpretation of results is a difficult and almost impossible task bearing in mind that this review covers 126 trials over a four year period, that 4 different types of CDA units, some tractor mounted and some carried by hand, were used, that CDA drop size varied from 150-350 microns and volumes ranged from 5-50 l for CDA, and from 175-312 l/ha for conventional applications. 4 different methods of assessment were used, 12 types of herbicides are involved, statistical analysis of results is available for 33 trials only and information on yield response is even more limited. This variability in methods and materials is not surprising considering the number of parties involved but it restricts comparison very considerably.

The overall impression is that CDA, on the basis of published work so far has performed respectably, but in a majority of reported trials did not quite reach the standard of conventional spraying. This greater variability in response would probably not prove statistically significant in a considerable number of trials, but the results of ADAS would suggest that it can be greater than the word 'marginal' implies. As there is no definition for the word 'marginal' in a biological sense and in relation to pesticide response, this point is of course debatable. ACAS are prepared to cope with the situation and point out (Makepeace 1978) that Approval is not necessarily linked with relative efficiency compared to an approved standard but with actual and consistent field performance which can be adequately described by appropriate label wording.

Several authors state that a slight short-coming of CDA performance would most likely be compensated for by the logistic advantages the system has to offer whilst Norman (1978) points to the need for overall improvement of performance when considering the future development of CDA.

Whatever view one takes, it seems reasonable to look for some theoretical explanations as to why CDA did not come up to expectations in 70 out of 126 trials.

In a review paper one can do no more than ask what hopefully may be relevant questions:

a) To what extent may the use of several and different prototype machines, operator error and lateral displacement of the spray swath (Taylor & Merritt 1975) have contributed to some of the less adequate results obtained?

b) Could results be improved by special formulations? Various research workers refer to this aspect, but there is no clear guidance as to the physical requirements of such formulations.

c) Is there scope for improving crop penetration and retention of microdrops on biological targets by providing greater impact velocity through air assistance or by other means, such as electrostatic charges?

d) Is there a need to improve retention and distribution of pesticide deposits obtained with CDA? If so, could either or both be achieved by a higher volume and a smaller drop size?

Some of these problems have clearly been anticipated (Cussons & Taylor 1976) and published work on and related to these aspects offers some guidance. The studies by Taylor & Merritt (1975) suggest that the variability of deposits on 20mm x 20mm artificial sample areas was highest with rotary atomisers, although there was little difference between CDA and conventional application in terms of crop penetration. Merritt & Taylor (1977) did retention studies on *A.fatua* with 0.5% Agral solution with CDA volumes from 20-100 l/ha and drop sizes of 150 μ, 250 μ, and 350 μ. 150 and 250 μ drops were equally well retained, whilst retention of 350 μ was reduced particularly on indoor plants and at high volume rates. Retention was approximately linear with highest deposits achieved at 100 l/ha and lowest at 20 l/ha.

Lake & Taylor (1974) describe experiments where different forms of deposit of barban were applied to wild oats by varying drop size (110, 220 and 400 µ) and application rate. In 5 out of 6 experiments, there was an effect of drop size at low application rates (approx. 50 l/ha), the smaller drops being most effective.

Lake (1977) studied the effect of drop size on retention, using 2 solutions of different surface tension and treating barley and wild oat leaves from glasshouse and field grown plants with drops of 100, 200, 300 and 600 µ at different angles. In 4 out of 5 experiments the highest deposits were achieved with 100 µ drops. Leaf angle had no significant effect. Separate observations of single drops of about 250 µ showed that they were normally reflected from the surface of barley and wild oat leaves.

Merritt & Taylor (1977) investigated in pot experiments and in the absence of a crop the performance of 7 herbicides on 4 dicotyledonous weed species, comparing CDA at 5 to 45 l/ha, at a constant drop size of 250 µ, with conventional spraying at 200 l/ha and a drop size of 170-600 µ. There were no differences in response to volume rates of TBA and dicamba, and with MCPA and mecoprop on 3 out of 4 weed species used. Conventional spraying performed better with dichlorprop on 3 species, and with ioxonyl/bromoxynil mixture and bentazone on 2 species, and the authors consider it possible that the latter 2 products may require greater dispersion over the plant surface than can be achieved at low volume.

From these basic studies and various field observations one must conclude that an application system involving a restricted drop size range and limited drop numbers is not equally suitable for all types of pesticides, because of differences in their mode of action, up-take and translocation, capacity for re-distribution and therefore in their requirements concerning deposits on target plants. This is also implied by the introductory comments in the paper by Cussons & Taylor (1976). Conventional spraying with its much more heterogenous pattern seems more capable of overcoming such specific requirements. If, as I suspect, density and distribution of herbicide deposits are the main factors responsible for the greater variability of CDA, further work is justified, comparing the performance of the present system with one of a smaller drop size range (150-250 µ) and a volume of 40-50 l/ha. The need for greater flexibility of future CDA equipment in terms of drop size and volume may pose problems for the engineer and designer, but could improve the chances of bringing a wider range of chemicals, including cereal fungicides, within the range of CDA, thus making the system more attractive to the farmer. It is assumed - but requires proof - that a reduction in drop size range will still meet the requirement of reduced drift.

At present, a number of agrochemical manufacturers have shown their commitment to CDA by obtaining PSPS Clearance for recommending certain herbicides through specified CDA equipment in 1978.

Before deciding on future work and committing substantial resources, they will want to know what further basic research is in progress or planned by national organisations, how it is co-ordinated, and how CDA applications performed in 1978 during the limited commercial usage stage and under practical conditions. I hope, therefore, that we shall be given details of farmers' reactions to handling CDA equipment, effectiveness of chemicals used and an analysis of logistics of the operation, showing the advantages of CDA compared with conventional systems.

In planning further work, other factors will have to be considered, such as formulation aspects, ACAS and PSPS requirements (Goulding 1978; Makepeace 1978) in particular for fungicides and insecticides, basic selectivity, to which CDA with its much more concentrated drops make additional demands, and the feasibility and performance of tank mixtures.

In practical terms of field experimentation, a decision has to be made whether to concentrate on commercially available CDA systems or to include also more recent prototypes of CDA equipment, thus complicating trials design and adding to the workload.

An official scheme for testing CDA and other low volume application equipment, its performance in terms of drop size and range, spray pattern and certain mechanical features, should offer guidance in this respect.

Further field work should give greater emphasis to yield determinations and to work with residual herbicides applied to winter cereals in the autumn.

To predict the future of CDA against a background of many imponderables is difficult, but in summing up certain factors and probabilities can be presented :

a) CDA is a new principle of application with several potential advantages which may offset its present shortcomings; these seem related to basic properties of the herbicides tested, do not apply to all of them and could probably be largely overcome by manipulating volumes and drop size range.

b) As CDA develops - probably slowly and step by step as one would expect with a change of such magnitude - we can anticipate modifications of existing equipment and further field testing of new types of atomizers (Bals, 1978).

c) CDA as tested and developed in the UK does not allow a reduction of established and approved rates of use.

d) Not all compounds and formulations are suitable for CDA application in its present form, and CDA will therefore not replace conventional application methods in all areas of crop protection.

e) CDA has stimulated thought and further research in the field of pesticide application. It will in future be compared with alternative methods of low volume application currently under development, using existing equipment and special nozzles.

In the end, farmers' attitudes and judgement will have a decisive influence; scale and urgency of future development work and degree of commercial acceptance of CDA - or any of the other new systems - will be greatly affected by their judgement of biological performance and yield response, handling and maintenance of equipment, special operator training requirements, reduced drift in relation to improved timing of application, logistic advantages and the range of products suitable for CDA application on cereals.

References

AYRES, P. (1976) Control of annual broadleaved weeds in spring barley by controlled drop application : comparisons of the activity of two herbicide mixtures at three doses and four volume rates, Proceedings 13th British Crop Protection Conference - Weeds, 3, 895-904.

AYRES, P. (1978) The influence of application method on the control of wild oats (A.fatua L. and A.ludoviciana Dur.) in winter wheat by difenzoquat applied at a range of growth stages, BCPC Monograph No.22, 163-170.

BAILEY, R. J., KITCHEN, R., SMART, A., O'KEEFFE, M. G. O., HARRIS, P. and PHILLIPS, M. (1978) A review of ADAS results in 1976 and 1977 with the controlled drop application of herbicides in cereals, BCPC Monograph No.22, 1-9.

BALS, E. J., (1969) The principles and new developments in ULV spraying, Proceedings 5th British Insecticide & Fungicide Conference, 1, 189-193.

BALS, E. J., (1975) The development of a CDA herbicide hand sprayer, PANS 21, 345-349.

BALS, E. J., (1975) The importance of controlled drop application (CDA) in pesticide applications, Proceedings 13th British Crop Protection Conference - Weeds, 1, 153-160.

BALS, E. J., (1978) Reduction of active ingredient dosage by selecting appropriate droplet size for the target. BCPC Monograph No.22, 101-106.

BYASS, J. B., and LAWRENCE, D. C., (1976) The scope for the use of controlled drop application (CDA) on large cereal growing farms, Proceedings 13th British Crop Protection Conference - Weeds, 2, 363-368.

CASELEY, J. C., COUPLAND, D., and SIMMONS, R. C., (1976) Effect of formulation, volume rate and application method on performance and rainfastness of glyphosate on Agropyron repens, Proceedings 13th British Crop Protection Conference - Weeds, 2, 407-412.

CUSSANS, G. W., and TAYLOR, W. A., (1976) A review of research on controlled drop application at the ARC Weed Research Organisation, Proceedings 13th British Crop Protection Conference - Weeds, 3, 885-894.

FARMERY, H., (1975) Controlled droplet engineering - an engineers viewpoint, Proceedings 8th British Insecticide & Fungicide Conference, 1, 171-174.

FARMERY, H., PECK, A. G. E., and GROSJEAN, O. (1976) Potential and design of CDA from an Engineer's viewpoint, Proceedings 13th British Crop Protection Conference - Weeds, 2, 369-376.

GOULDING, R. (1978) CDA - a health peril or panacea, BCPC Monograph No.22, 243-247.

HARRIS, P. B., (1977) Mixed results with CDA spraying, Arable Farming, 62-65, (November)

JARRETT, P., BURGES, H. D., and MATTHEWS, G. A. (1978) Penetration of controlled drop spray of Bacillus thuringensis into chrysanthemum beds compared with high volume spray and thermal fog, BCPC Monograph No.22, 75-82.

LAKE, J. R., and TAYLOR, W. A., (1974) Effect on the form of a deposit on activity of barban applied to A.fatua L., Weed Research, 14, 13-18.

LAKE, J. R., (1977) The effect of drop size and velocity on the performance of Agricultural sprays, Pesticide Science, 8, 515-520.

LUSH, G. B., and PALMER, R. A., (1976) Field trials comparing the biological effectiveness of 'Controlled drop application' with conventional hydraulic pressure spraying, Proceedings 13th British Crop Protection Conference - Weeds, 2, 391-398.

MAKEPEACE, R. J., (1978) Pesticide application and efficacy from the approval point of view, BCPC Monograph No.22, 249-258.

MARTIN, T. J., (1977) Personal communication

MATTHEWS, G. A., (1977) C.D.A. - Controlled Droplet Application, PANS, 23, (4), 387-394.

MAY, M. J., and AYRES, P. (1978) A comparison of controlled drop and conventional application of three soil applied herbicides to an organic soil, BCPC Monograph No.22, 157-161.

MAYES, A. J., and BLANCHARD, T. W., (1978) The performance of a prototype microdrop (CDA) sprayer for herbicide application, BCPC Monograph No.22, 171-178.

MERRITT, C.R., and TAYLOR, W. A., (1977) Glasshouse trials with controlled drop application of some foliage applied herbicides, Weed Research, 17, 241-245.

MORGAN, N. G., (1972 and 1973) Small volume and very small volume (ULV) applications, Annual Reports Long Ashton Research Station, 103-105 and 105-106.

MORGAN, N. G., (1974) Some biological requirements in the ULV spraying of top fruit, BCPC Monograph No.11, 59-66.

NORMAN, R. F., (1978) A view of the impact of CDA on the agrochemical industry "Agrochemicals as good as their application", BCPC Monograph No.22, 265-270.

PICKIN, S. R., (1978) A preliminary evaluation of an ultra low dosage of pirimicarb against *Sitobion avenae* on Winter wheat, BCPC Monograph No.22, 237-241.

ROBINSON, R. C., (1978) The field performance of some herbicides applied by rotary atomizer in spray volumes of 5-50 l/ha, BCPC Monograph No.22, 185-191.

RUTHERFORD, I., (1977a) The faults - the utilisation and performance of field crop sprayers, The Agricultural Engineer, 41-44.

RUTHERFORD, I., (1977b) ADAS views of impending farm developments, NIAE Subject Day Paper No.6.

SYLVESTER, N. K., (1978) The relevance of ultra low volume spraying for the application of fungicides to protect winter lettuce under glass against grey mould, BCPC Monograph No.22, 231-235.

TAYLOR, W. A., and MERRITT, C. R., (1975) Some physical aspects of the performance of experimental equipment for controlled drop application with herbicides, Proceedings 8th British Insecticide & Fungicide Conference, 1, 161-170.

TAYLOR, W. A., MERRITT, C. R., and DRINKWATER, J. A., (1976) An experimental tractor mounted, very low volume uniform-drop-size sprayer, Weed Research, 6, 203-208.

TURNER, D. J., and LOADER, M. P. C. (1978) Controlled drop application of glyphosate, difenzoquat and dichlorprop, BCPC Monograph No.22, 179-184.

WILSON, B. J., (1976) Control of *Avena fatua* in Spring barley by controlled drop application : comparisons of the activity of two herbicides at three doses and four volume rates, Proceedings 13th British Crop Protection Conference - Weeds, 3, 905-914.