EDUCATION IN CROP PROTECTION IN BRITISH UNIVERSITIES

L. Broadbent, Bath University of Technology

The demand for crop protection specialists

Specialists in one branch or other of crop protection are employed by the agricultural chemicals industry, the National Agricultural Advisory Service, seeds and agricultural merchants, Agricultural Research Council institutes, and by universities and agricultural and horticultural colleges.

Recent figures compiled by the Institute of Biology and the Department of Education and Science indicate that about 550 graduates are employed as entomologists, nematologists and parasitologists, and about 300 as mycologists, virologists and plant pathologists in Britain. Several of those employed in universities will be working on, and teaching, aspects of entomology, parasitology, mycology and virology that are unrelated to crop protection, but if we add people interested in weeds and herbicides, and microbiologists working on the protection of the harvested crop from fungi and bacteria, we can assume that about 800 graduates are employed in crop protection in Britain. This figure is unlikely to change radically during the next decade, but it is difficult to forecast what the demand will be for our graduates. The Institute of Biology is now trying to arrange for an enquiry into the supply of biologists, including those trained in crop protection, and will then try to forecast how supply will, or will not, meet demand over the next decade. We hope this information will be available in about a year's time. Food production must continue to increase rapidly to keep pace with the increasing world population and newly emergent countries will probably employ more agriculturists and horticulturists to improve crop husbandry during the next few years. As their growing methods become more sophisticated their crop losses from pests and diseases will become more obvious. We can therefore assume that the demand for crop protection experts trained in this country will not diminish and is likely to increase. Presumably other countries will still want to send students here for training. British graduates going abroad to fulfil the demand in developing countries complicate the issue, because we can expect that most of them will wish to return to jobs in Britain later in life.

Undergraduate education

In November 1965, Dr. D.S.H. Drennan circulated the universities in Britain and asked for details of the training they gave in crop protection. He kindly made available the replies, which I have analysed and checked with the Departments concerned (Table 1). The figures given are often only approximate, and in many instances are underestimates, because so many of the courses are integrated and aspects of crop protection are discussed by several lecturers under several headings. This comment applies particularly to the columns on chemical and agricultural aspects, these often being included in the previous columns. Some universities also have several options in a degree scheme, so that it cannot be assumed that all students take crop protection to the same level. Furthermore, universities differ in the extent to which they rely on teaching through lectures or through tutorials and private study. For these reasons it is not possible to contrast the average time spent on crop protection in courses on agriculture, horticulture and different specializations in the fields of agricultural science or biology.

The courses in agriculture and horticulture at the universities, agricultural colleges and institutes invariably include some instruction in crop protection, but this is usually designed to familiarize the students with the principles of control of animal pests, plant pathogens and weeds. It seldom forms an adequate biological or chemical background for specialization in the subject, or provides sufficient practical knowledge to allow safe handling of dangerous chemicals and application machinery. However, of such courses offered at 10 British universities, some of the honours courses at Aberdeen, Bath, London (Wye), Nottingham and Reading, and the general degree courses at Belfast, London (Wye), Nottingham and Reading do treat the subject very thoroughly. Honours degree students at Nottingham can specialize in either Plant Pathology or Economic Entomology, and those at Reading who specialize in Crop Protection spend an extra 85 hours on diseases and their control.

Eight universities offer courses in Agricultural Botany, Zoology or Science. Students reading Agricultural Botany are usually given an adequate training in plant diseases and their control, as at Aberystwyth, Bangor, Belfast, Glasgow and Reading, but except at Reading they receive little on plant pests, and only Bangor and Belfast give more than 25 hr. to weeds and herbicides. In contrast, those students reading Agricultural Zoology at Bangor or Glasgow deal with plant pests, but spend little or no time on diseases or weeds. The Agricultural Science course at London (Wye) seems well balanced, and that at Leeds gives a considerable amount of time to both pests and diseases, but apparently treats weeds in a rather cursory manner. Students of Agricultural Science at Edinburgh can specialize in Crop Pathology and spend almost the whole of their last year studying the subject, confining their attention to fungal and virus diseases, and non-parasitic disorders. Those at Belfast do likewise, and they specialize in either Mycology and Plant Pathology or in Agricultural Zoology (mainly entomology).

Plant diseases are covered in some of the honours Botany courses, most comprehensively at Imperial College, London, and in fair depth at Hull and Manchester, but weeds and herbicides appear to be neglected. Botany students at Bristol study all aspects of crop protection, but the time devoted to each is not stated.

Imperial College is one of the few places where honours Zoology students (those who specialize in Entomology) are given even a short course on plant pests and their control.

Degrees in Applied Biology are offered by some of the newer universities. Students at Brunel can specialize in applied botany and applied entomology during their last year, and Strathclyde students may include entomology and mycology among their specializations. Apart from agricultural students at Aberdeen, Strathclyde students apparently spend more time than those elsewhere on weeds and their control.

The only undergraduate course in Crop Protection in the country is that offered by Bath as one of the options in the 4 year sandwich course for the honours degree in Applied Biology. Students take Part I in general biology, biological chemistry and statistics at the end of their second year, and may then specialize in crop protection during the next two years. They study agricultural entomology and nematology; plant pathology, including diseases caused by fungi, bacteria and viruses; weeds; ecological, chemical and other methods of crop protection, agricultural science, horticultural principles and practices, and economics. In addition they do a research project during their last year, and at least one of their three industrial training periods of 6 months each is spent on some aspect of practical crop protection.

Many, but by no means all, of the universities take their students to visit N.A.A.S. establishments, research institutes and industrial firms concerned with crop protection, but only sandwich courses give students a thorough understanding of the ways in which their academic knowledge can be applied in practice. Unfortunately it is not easy to obtain enough places for these sandwich students with the agricultural chemical firms, and if it were not for the generous help given by the N.A.A.S., their practical training in 'industry' would prove very difficult. I hope the Industrial Training Act will encourage the firms to be more willing to accept students for training in the future.

Post-graduate education

a) Taught courses

Several universities offer postgraduate courses of one year's duration, as follows:

Bangor:	M.Sc. in Crop Protection.
Cambridge:	Diploma in Agricultural Science (specialization in Agricultural Botany or Agricultural Entomology includes aspects of crop protection).
Edinburgh:	Diploma in Crop Protection.
Exeter:	M.Sc. in Plant Pathology
Glasgow:	Diploma in Entomology
London: (Imperial College)	M.Sc. or D.I.C. in Applied Entomology, or Nematology or Mycology and Plant Pathology.
Reading:	M.Sc. in the Technology of Crop Protection.

Probably a majority of the crop protectionists in Britain were trained at Imperial College, London, and the D.I.C. courses are still very popular. The Mycology and Plant Pathology course covers fungi, bacteria, viruses, nematodes and plant pathology: that in Nematology covers systematics and physiology of eelworms, nematological techniques and host pathology; similarly, that in Applied Entomology covers systematics and biology of insects and mites, ecology and pest damage to crops. All three courses treat chemical control of pests or pathogens thoroughly, including the use of application machinery, and also include experimentation and statistics. They are avowedly vocational and are excellent courses for those who will specialize in the different aspects of crop protection. However, they are inadequate because they do not treat the subject as a whole. Neither do the courses at Cambridge, Exeter or Glasgow.

Three new courses have been planned recently which do or will attempt to give a comprehensive coverage of the subject. That at Bangor is well established, that at Edinburgh was due to start this autumn, and the Reading course will start next year. They will cover weeds, animal pests, fungi, bacteria and viruses, crop ecology and pathology, resistance in crop plants, chemical control and application machinery, field experimentation and statistics.

b) Research degrees

Most of the universities that offer undergraduate or postgraduate courses in any aspect of crop protection also accept students for training in research for M.Sc., M.Phil. or Ph.D. degrees. Many universities encourage their postgraduate students to attend some courses during their period of training. Pursuit of new knowledge is an excellent intellectual training, but inevitably it will be in a narrow area of the subject, and most of the studies will be pursued in the laboratory. Nevertheless many workers have been stimulated to an interest in crop protection as a result of the work they did for a higher degree.

The adequacy of present-day courses

To what extent are present-day graduates really fitted to take posts in crop protection ? The subject is very complex and teaching, research and practice have all suffered in the past because of the development of departmentalism. The division of plant pathology rigidly into its mycological, viral, entomological, nematological and other aspects cannot be justified. Plants are seldom attacked by one pest or pathogen in isolation, although one often predominates, and disease may be due to a complex interaction involving several of each. Thus in addition to being direct pests, some insects, mites and nematodes are vectors of viruses, fungi or bacteria. The intensity of disease not only depends upon the reaction of the host to the harmful organisms attacking it, influenced by its genetic make-up, nutrition, environment, etc., but also upon the battles fought between the several organisms inhabiting the rhizosphere and phyllosphere of the plant. It is now well recognized that control must be approached from the ecological and genetical as well as the chemical viewpoint. A study of weeds and herbicides should be included, for herbicide use is an important part of crop protection and the damage they cause to crop plants, and mineral deficiencies, are often confused with damage from pests or pathogens.

Plant protectionists should be trained in the ecological approach to disease, putting the crop plant in the centre of the picture and studying its reaction to the many other organisms that make up its biological environment. The stress has usually been laid upon the pest or the pathogen, not upon the host, and the approach in the universities has too often been very academic rather than applied. Today, as in the past, students are often trained as mycologists or entomologists, knowing little of each other's discipline or of, say, virology or nematology.

The universities are not solely to blame for these attitudes. There has been, and still is, considerable reluctance by most employing institutions to create integrated teams of, say, agronomists, plant pathologists, physiologists and biochemists, to investigate crop protection problems. Industry often employs such teams, but not the N.A.A.S. or the A.R.C. research institutes, where entomologists, mycologists, virologists, and crop protection chemists are usually in separate departments.

The development of Schools of Biology in the newer universities and some of the older ones, and a growing interest in applied biology provides an opportunity to re-plan the education of crop protectionists, and a few universities seem to be taking it.

The undergraduate course at Bath, and the graduate courses at Bangor, Edinburgh and Reading should all provide comprehensively trained crop protectionists. Students will spend four years in training, those at Bath because of their industrial practical periods, and those at the other three universities because crop protection is a vocational course after initial training in agriculture, horticulture or one of the sciences. Many educationists would maintain that this is the right place for such specialized training, superimposing it on a wide basic biological and chemical education at undergraduate level. Not unnaturally, I prefer the sandwich system that we operate at Bath, in which the basic academic and vocational training is given during nine twelve-week terms, and is integrated with about seventeen months of practical training in industry.

Because it has been difficult to find graduates adequately trained in crop protection some people have advocated the establishment of a National College of Crop Protection, possibly on the lines of the National College of Agricultural Engineering. My reaction to the suggestion has not been very favourable for two reasons: (1) teaching at undergraduate level should be combined with research, most of which is now done in ARC institutes, universities and commercial laboratories. The establishment of a central research establishment would be very expensive, apart from the fact that the present institutions would be unlikely to forego their interests in the field; (2) research in crop protection should, in my view, be closely integrated with other research, agronomic, physiological, biochemical, etc. on the same crop, and is better dispersed as at present.

It is also argued that it would be economically advantageous to establish a National College to take over M.Sc., Diploma and short courses from the universities and agricultural colleges, few of which have enough staff to teach the subject in its entirety or facilities for an adequate period of practical field work. It could also provide short courses for agriculturists and horticulturists, and short revision courses for specialists, both of which should be available every year so that growers, advisers, teachers, salesmen and operators can keep up to date.

I consider this second proposal to be worth further discussion, for such a College could be set up without undue expense, and would need only a small administrative staff, if arrangements could be made to utilize the facilities of one of the universities or other established national centres, and specialist staff were seconded for short periods from universities, research institutes and industry. Post-graduate students could attend the College for course-work and pursue their research at their own university.

Table 1 Number of hours training in Crop Protection at British Universites (Undergraduate courses)

UNIVERSITY	General (or Pass) or Honours Degree	Weeds & weed control	Plant diseases & control	Plant pests & control	Chemical ⊛ aspects of protection	Agricultural ⊛ aspects of protection
ABERDEEN	Gen. } Agric.	50	30	40	3	-
	Hon. }	120	120	106	3	-
ABERYSTWYTH	Gen. } Agric. *	14	80	10	-	-
	Hon. }	21 +	80	10 +	-	-
	Gen. } Agric.Bot.	10	83	-	-	-
	Hon. } *	-	80	-	-	-
BANGOR	Hon. Agric *	13	11	188	17	34
	Gen. } Agric. Bot.	17	85	-	-	-
	Hon. } *	26 +	135 +	-	-	-
	Gen. } Agric. Zoo.	-	-	188	17	25
	Hon. } *	-	-	188 +	17 +	25 +
BATH	Hon. Applied Biol. *	30	180	210	60	120
	Hon. Horticulture *	50	99	99	48	included
BELFAST	Gen. Agric.	20	150	90	15	-
	Hon.Agric.Chem.(Plant & soil sci. specialisation)	-	-	-	60	-
	Hon Agric.Sci.(Mycol. & Pl.Path).	31	150 (+ c.400)	-	included	included
	Hon.Agric.Sci.(Agric.Zoo.)	-	-	90(+ c.400)	included	included
BRISTOL	Hon.Bot.	+	+	+	+	+
BRUNEL	Hon. Applied Biol.(Entom. & Botany specialisation)	16	32	6	61	-
CAMBRIDGE	Hon. Agric.	10	48	52	-	included
EDINBURGH	Gen. } Agric.	22	31	40	-	6
	Hon. }	22	31	40	-	6
EXETER	Gen. } Bot.	-	12	-	-	-
	Hon. } *	-	12	-	-	-
GLASGOW	Gen. } Agric.Bot.	6	50	-	2 +	+
	Hon. }	16	105	-	14 +	+
	Gen. } Agric. Zoo.	-	-	78	4	4
	Hon. }	-	12	64	24	18
	Gen. Agric.Chem.	-	-	-	16	-
HULL	Gen. } Bot.	-	124	-	-	-
	Hon. }	-	124	-	-	-

Table 1 (contd)

UNIVERSITY	General (or Pass) or Honours Degree	Weeds & weed control	Plant diseases & control	Plant pests & control	Chemical ⊛ aspects of protection	Agricultural ⊛ aspects of protection
LEEDS	Gen. } Agric.Sci.	5	45	83	3	included
	Hon. } *	9	129	200	3	included
LONDON	Hon.Bot.	-	313	-	30	30
(Imperial Coll.)	Hon. Zoo.(Entom.spec^{n})	-	-	50	35	30
LONDON	Gen.or Hon. Agric. *	10	60	30	28	10
(Wye)	Gen. Hortic.	15	105	65	39	15
	Hon. Agric.Sci.	15	105	74	54	-
MANCHESTER	Gen. } Bot.	-	80	-	-	-
	Hon. }	3	150	-	included	included
NOTTINGHAM	Gen. } Agric. (+ Pl.Path.	50	80	82	20	40
	Hon. } or Econ.Entom. spec^{n}.)	50	80 (+ 150)	82 (+190)	20	40
OXFORD	Hon. Agric.	16 +	24 +	8 +	-	-
READING	Gen. Horticulture	10	60	41	70	-
	Hon. Horticulture *	10	60	41	70	-
	Hon.Agric. (+ Crop Prod. spec^{n}.)	10	40 (+ 75)	41	8 (+10)	5
	Hon. Agric. Bot. *	10	182	41	18	5
STRATHCLYDE (Glasgow)	Hon. Applied Biol.	90	90	90	included	-

* in addition, project and dissertation can be in Crop Protection

⊛ often included in previous columns

\+ additional time devoted to subject in tutorials, seminars etc.

in addition						
EDINBURGH	Hon. Agric. Sci. (Crop path. spec^{n}.)	+	+	+	+	+

THE EMPLOYMENT OF GRADUATES IN THE CROP PROTECTION INDUSTRY

M.E.Putnam

Institute of Corn & Agricultural Merchants

In its overall sense, crop protection involves the sale and use of herbicides, fungicides, insecticides and a certain amount of nematicides. It is an industry which is continuing to increase in size and in the total value of the products sold for farm, market garden and household garden use. Table 1 shows the total value of these chemicals produced by British Manufacturers during 1965 for both export and home consumption.

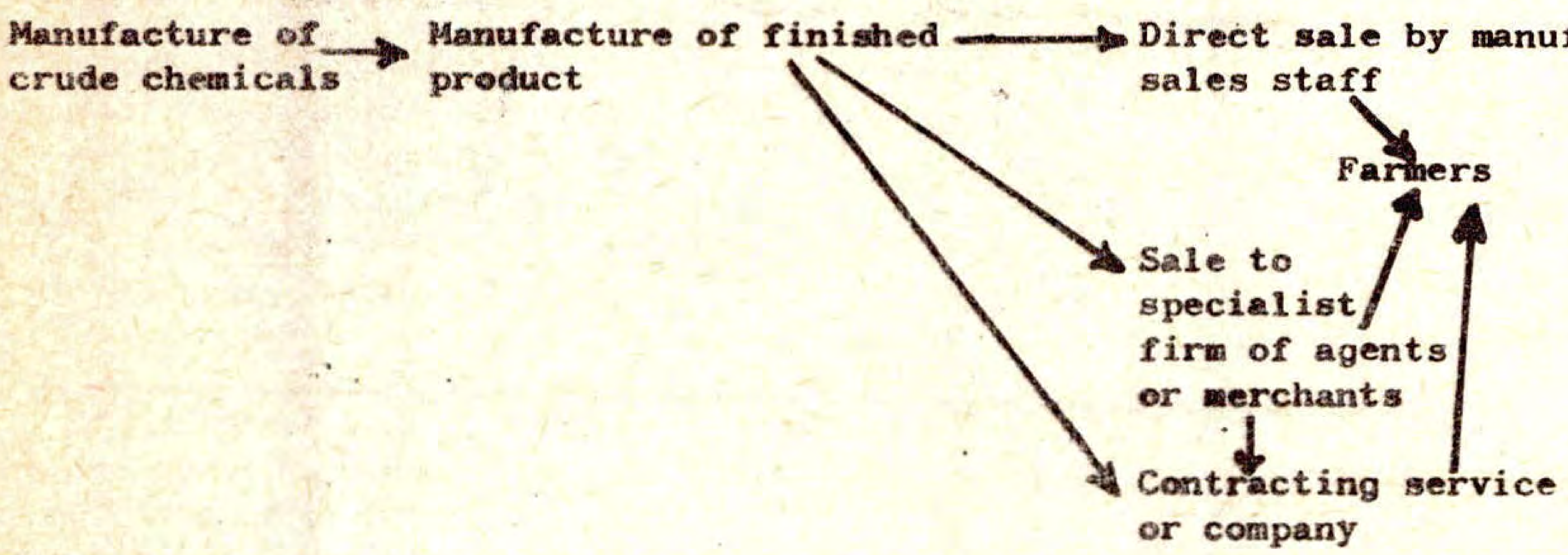
Table 1

Manufacturers' Sales of Agricultural Chemicals 1965

	£,000,000		
	Totals	Exports	Home
Herbicides	12.0	4.8	7.2
Insecticides	6.0	4.2	1.9
Fungicides	3.6	1.3	2.3
Others (including nematicides)	0.4	0.3	0.1
	22.1	10.6	11.5

It will be recognised that not all the sales of insecticides, fungicides and 'others' on the home market relate to direct crop protection; herbicides therefore have a very large share of the market.

The general pattern of the production and sale of a chemical for crop protection after its evaluation through research is:



It is an impossible task to make an accurate assessment of the quantity or value of the sales to farmers by these three routes; the nearest estimate that has been made of the present division of the market suggests that about 15% is sold direct from manufacturers to farmers and other users and 85% is sold either through a merchant or contracting services.

The present tendency is for the proportion sold through merchants to increase at the expense of the proportion sold direct by the manufacturers. The manufacturer's salesman/adviser can only sell his particular range of products whereas the merchant's salesman/adviser is not obliged to handle only one series of products but can suggest the best material or mixture of materials for the particular circumstances. This appeals to a number of users, particularly since the merchant's adviser is unbiased and will be more likely to know the peculiar local conditions over the small area he covers than the manufacturer's adviser who has to cover a larger territory.

Local knowledge, fully understood and properly applied, is the ideal attribute for a technically qualified salesman of crop protection products. Naturally not all merchants' salesmen are as technically qualified as manufacturers' salesmen. In many of the smaller companies men are taken on as general salesmen of seeds, fertilisers, chemicals and possibly feeding stuffs as well. They are principally engaged because they are able to sell.

This gives rise to a situation where a crop protection product is sold as a stock item but with limited knowledge about its suitability for particular needs of the crop in question. Some merchants are ceasing to trade in chemical products because they are unable to offer the service farmers require despite the fact that the manufacturers can back them with a first class advisory service.

The more efficient merchant is either setting up a specialist company to handle crop protection chemicals or has specially trained salesmen/advisers seconded from their normal sales areas to advise farmers and to sell the most effective protection products for the particular circumstances. Such representatives are also being trained in the economics of farm management as it affects crop protection and in effective speaking so that they can address meetings as well as speak to farmers.

There have been many discussions on the most effective means of training these technical representatives. Most of the companies in this specialist field agree that a graduate is not the most suitably trained person. They prefer a more practical background and are recruiting staff with National Diploma in Agriculture (N.D.A) or the cream of those with the National Certificate of Agriculture (N.C.A.) The new recruit is first used as a general salesman/adviser and is allowed to develop a specialist inclination -seeds, animal feeding stuffs or crop protection. If he shows a particular aptitude for advisory work on crop growing, he may be chosen for special training.

Much of the special training is on an in -company basis with senior staff giving instruction on weed recognition, relationships of particular weeds to soil conditions and the growth of the particular crops, the main groups of agricultural chemical materials and the company's policy regarding field-walking and on documentation. Further information is then supplied on specific chemical materials through the co-operation of the manufacturers who organise courses, seminars and one-day training sessions from time to time.

The final stage of training is for the trained recruit to have a season or part of a season with an experienced man, visiting farms to advise on crop protection problems. He is then allowed to undertake these tasks on his own under the broad direction of his sales manager, and an experienced man may walk and advise on several thousand acres in the course of a season. He will spend time during the winter organising and addressing farmers discussion groups, bringing new chemicals and techniques to their notice. He will keep up-to-date by close study of manufacturers' literature and may attend refresher courses organised by his company, by manufacturers or by the Trade -for example the Institute of Corn & Agricultural Merchants' courses.

The fieldsman is the farmers' contact man and he must be technically able to deal with the farmers' crop protection problems. He will be supported in his work by his line management. The manager and senior adviser tend to be technologically qualified; many are agricultural or science graduates and some have senior degrees. Whilst their positions can be filled from within the company, practical fieldsmen do not necessarily make good managers and the posts are usually open to all comers.

Many of the larger companies maintain a field extension trial ground where they test the various manufacturers' products under local conditions. Here, again, a graduate technologist is often in control.

Similarly the management and senior advisory staff of the spraying contractors will be technologists whilst the spraying staff will be craftsmen with N.C.A. as their highest qualifications.

To summarise, certain trends are becoming apparent in the staffing and success of crop protection retail services:

1. Fewer companies are handling chemical products.

2. More specialisation; companies continuing to sell crop protection products are setting up separate units or specially training their advisers.

3. Advisory salesmen are engaged with N.D.A. or N.C.A. rather than with degrees. Future advisers may require C.N.D. or H.N.D. in agriculture as emphasized by the recent Pilkington report.

4. Though advisory salesmen are receiving training in the more advanced companies, there is scope for intensification and extension of this training.

5. Graduate technologists are required for senior advisory, management, field extension and library positions.

6. Companies with technically qualified staff familiar with local conditions are preferred by many farmers to manufacturers selling direct.

7. There will be a greater need for co-operation between manufacturers' salesmen/advisers and the merchants' salesmen/advisers.

8. The technology of crop protection will be applied more effectively to graphic advertising and there will be an increasing need for qualified personnel with a flair for this work.

EDUCATION IN CROP PROTECTION

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INTRODUCTION

A member of the scientific staff of a commercial company who travels abroad a great deal as I do finds in many Universities and official Research Stations overseas, a suspicion of commercial research and development work as of dubious integrity and even more doubtful quality. 20 to 30 years ago the same attitude was prevalent in this country. It may still exist today but I hope at least it is no longer prevalent. I doubt whether it was ever justified because the invention or devising of new methods and techniques requires a high degree of skill and integrity regardless of whether the object is to publish the findings or to sell the result. That such an attitude exists at all indicates some ignorance of commercial work, and I therefore propose spending some of my time in describing the work that is done as a basis for some thoughts about education and training.

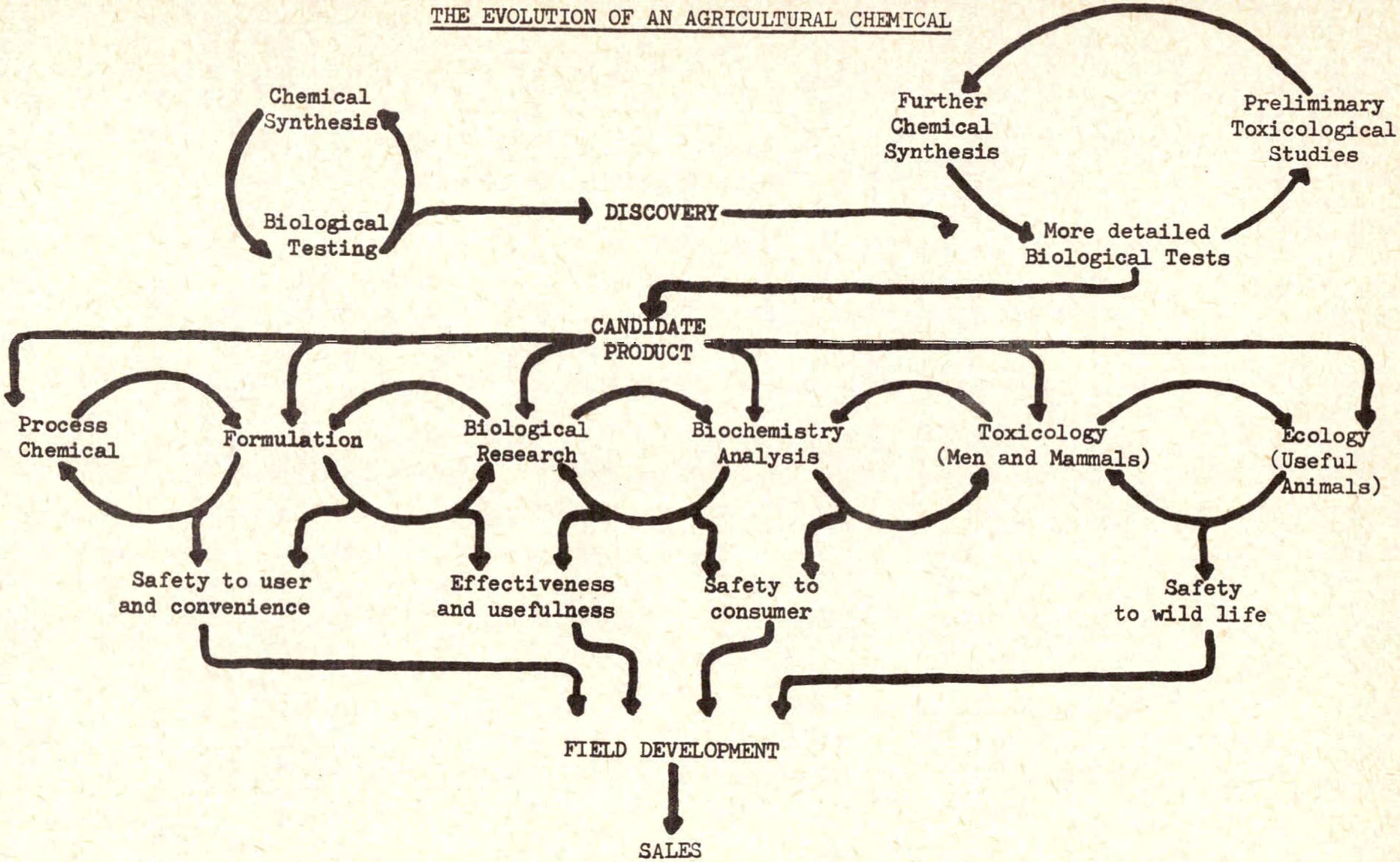
TECHNICAL WORK IN AGRICULTURAL CHEMICAL FIRMS

One may loosely divide the companies employed in agricultural chemical development into those which do "basic" research to discover new chemicals of their own for agricultural use, those which take chemicals produced from "basic" manufacturers and devise uses for them in countries in which they are operating, and finally those which rely on their suppliers to advise such uses and confine themselves to demonstration, sale and (usually) technical service. There is, of course, no such absolute division because many companies manufacture some products and purchase and re-sell others and a varying amount of development effort is put in according to the situation and arrangements for the particular chemical. However, it is a useful division purely for the purpose of this talk in that it separates three stages of work.

Dealing with my list backwards, the skill required in demonstrating, selling and providing technical service for products is very largely that of knowing the properties and problems associated with the product concerned, and having a good degree of farming knowledge. A good knowledge of farming and farm management is just as important as knowledge of the product and the problems with which it deals if the treatment is to fit soundly into agricultural practice so that the farmer is sold a worthwhile technique.

In the field development of new techniques we begin to deal with something which can be described as agronomic or, in a limited sense, ecological research. The person doing this type of work needs to be able to see in his mind methods of farming which may be radically different from those currently in use. He also needs a good knowledge of the tools of field research - statistical and logical methods of designing trials etc - as well as some general knowledge of farming, at least the aspects of farming with which he is dealing, so that he does not try to develop entirely

THE EVOLUTION OF AN AGRICULTURAL CHEMICAL



idiotic changes of practice.

When you come back to the search for and preliminary development of new products, a far wider range of skills is involved and a large team of research scientists is needed to cover aspects that it would be impossible to encompass in one general type of training. One thing they all have in common, from the synthetic chemist who first makes the new chemical to the ecologist and toxicologist who examine the safety of the embryo product, is a research attitude needing a "pure" or truly research training. Every step in the early part of the process is into the unknown, and the way of thinking that leads to success in exploring new ideas is of far more importance than the precise discipline of the training.

It is impossible in a brief talk to deal with the range of skills involved, and I propose merely to indicate it diagrammatically in a sketch which Dr. S. H. Crowdy used to show the inter-relation of the operations at Jealott's Hill a couple of years ago. I would merely emphasise how close must be the co-operation in all the various jobs if discovery and development are to be accomplished at all efficiently. Incidentally, even the initial discovery should not be pictured as a process of mechanical screening of huge numbers of chemicals obtained from a manufacturing "hat". There is a great deal of inventiveness and thought to decide what chemicals to make and, on the biological side, what tests one wants to make and in devising and setting up a series of tests to keep up with changing targets. This is research work in the fullest sense of the word, just as much as the biochemical, toxicological and other work designed to find out how the chemical works, not merely the practical result of using it. There is no real distinction to lead one to say that some of the work is "basic" and some of it that lesser degree of research sometimes contemptuously described as "applied".

Relatively few companies do basic research on a large scale but they need very large staffs to do it effectively. The result of this is that the manpower requirements at the earlier and later stages of the operation are much less unequal than one would expect merely from the number of firms searching for new chemicals.

REQUIREMENTS FOR EDUCATION AND TRAINING

Finally, having worked through my list and then returned through it backwards, let me start again at the beginning on the matter of training.

While it is not essential for all the senior men in a research organisation looking for new chemicals to have the letters Ph.D. after their names, it is most desirable for them to have experience and training in doing research. We need a wide range of skills, from synthetic chemists, biochemists and physicists to entomologists, plant pathologists and botanists of various types. They should have some form of specialist training rather than an Agriculture degree, and research experience as well. It is much less important, perhaps not important at all, that they should have direct training or experience in crop protection chemicals. If they are properly trained as scientists they can easily acquire this. It is highly desirable on the biological side that graduates going into industrial research should not be too wedded to one narrow field of work. No company, perhaps no human organisation, can ensure that there is an equal amount of worthwhile work to be done at any particular time in say, insecticides and weedkillers, and properly trained scientists should be versatile enough to be able to change from one aspect to the other of the same general style of biological endeavour.

When we consider the invention and development of the field uses of the product, experience has shown that with all but the simplest uses (the straight substitution of one chemical for another, for instance) something approaching the same level of research skill is needed as is needed at the earlier stages of discovery and preliminary development. All the same the venture into the unknown is rather less at this stage. An additional requirement is the need to "get on" with people under very diverse conditions, often in out of the way corners of the world. Men who are successful at this work are often those whose experience after graduation has been in agricultural research in this country or overseas.

Lastly, one should not underestimate the need for adaptability and originality of outlook in those doing sales development, i.e. demonstration, sales and technical service. A thorough knowledge of crops, conditions and farming in general becomes much more important at this stage and it is here that the agriculture graduate often scores heavily.

Throughout I would suggest to my University colleagues that the vital training is training in thinking, the basic grounding in scientific method and the background of the subjects rather than any specialist attempt to train in crop protection as a subject. Like most other applied subjects the work required derives from a wide variety of scientific fields. There is little special about crop protection that a well trained biochemist or botanist, for example, cannot acquire in a very short period of direct work in agricultural chemicals.

EDUCATION IN CROP PROTECTION WITH SPECIAL REFERENCE TO WEED CONTROL
REQUIREMENTS OF THE NATIONAL AGRICULTURAL ADVISORY SERVICE

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1. The first point to be clarified as it relates to the N.A.A.S. is the type and level of advice which the various sections of the Service give to farmers and growers as this is all important in any understanding of our requirements. In order to simplify the description, reference is made only to weed control aspects of crop protection and the examples given are largely agricultural.

(a)	General Agricultural and Horticultural Advisers	Day-to-day advice on specific problems and general programmes.
(b)	Crops: Grass: Fruit and Vegetable Specialists including Agricultural and Horticultural Liaison Advisers at Weed Research Organisation	Conduct and interpretation of experiments: collection of data from all possible sources and collation for general advisers. Production of leaflets; bulletins and giving advice to individual producers: to groups by mass media; training operators. Assistance to (a) in special circumstances. Contact with research; manufacturers and trade including contractors.
(c)	Other Specialists - principally Pathologists and Soil Scientists but also Farm Management and Mechanisation Advisers	Investigation of and giving advice on problems and developments where their special knowledge can contribute, mainly to N.A.A.S. but also direct to producers. Contact with research etc.

2. Thus it will be seen that the most suitable training of staff will vary quite widely both in its scope and depth and it is realised that it may not always be possible to tailor university courses to meet the different needs exactly. Consequently it is essential that students receive an adequate training in the basic sciences to enable them to grasp the scientific principles underlying the use of herbicides and to interpret them in terms of the particular situations both technical and economic they happen to be facing. This applies in all three of the groups mentioned above.

3. In the case of advisers working daily among the farmers and growers it must be realised that advice on weed control is only one of a very wide range of duties and one which tends to be very seasonal in nature. Therefore the District Adviser requires a widely based scientific training at under-graduate level which will enable him to understand the basic principles of crop production and the mode of operation of the various methods of weed control together with their effect on the crop itself. This basic training, combined with the experience he will gain after he enters the Service, gives him the knowledge to advise on the technical and economic aspects of weed control in relation both to specific situations and in the wider context of farm programmes.

4. The specialist husbandry adviser is required to act as a 'consultant' to the general adviser for his particular subject which in this case is a group of plants. His training can be similar or even identical to that of the general adviser, which can then be developed by in-service training and experience towards a degree of specialisation in one aspect of agriculture when the person concerned shows special aptitudes. Alternatively, university training may be directed towards aspects of botany and crop production but also covering general agricultural topics as well. Post-graduate training in some aspect of crop production or protection is an added qualification which will be sought in future.

Subsequent experience and training in the N.A.A.S. will be varied for individuals depending on their background and aptitudes, and the time and degree of specialisation in these husbandry fields varies so hard and fast requirements cannot be laid down. It will frequently include some years on a Husbandry Farm or Horticulture Station where experience is gained in crop production and the conduct of experiments and the interpretation of results. Therefore the basic training should be designed to produce a person with a critical and analytical mind, capable of close observation of situations in the field and an ability to summarise information and communicate the technical and economic information to a wide range of people within the Service, among producers and in the trade. Crop Husbandry Advisers require to consider systems of crop production and to treat weed control and different methods such as rotations, cultivations or chemical as a part of the whole.

5. The role of the science specialist in weed control work is a fairly small one, but one which is growing in some respects. With the development of soil acting herbicides and with the finer balance between the weed and the crop the soil scientists and the plant pathologists are becoming more involved in the advising of the use of herbicides and in the elucidation of special problems. Therefore the training of the pathologist and soil scientists should take this into account and ensure that the aspects relevant to their particular discipline are discussed at under-graduate level. Further training and experience will, of course, be given during early years in the service.

DISCUSSION

Dr. J. Dore described the structure of the Applied Biology course at Brunel University in which 3 sandwich periods were graded to the level of academic attainment in the biological sciences. Limited training in management and economics was included. The students produced had specialised in 2 out of 5 applied biology subjects in their final year and were readily employed by industry and found themselves already familiar with the way it worked. Mr. A.L. Abel commented that it was his experience that graduates trained in the more specialised fields of applied entomology and plant pathology more readily acquired a knowledge of weed control than vice versa, and wondered if the training in chemistry was different in these fields. He also reminded everyone that industry was always seeking managerial staff from their graduates and for this a good personality, clarity and ease of communication and a sharp intellect were as important as their technical knowledge. Professor L. Broadbent answered that all biology courses included training in chemistry and bio-chemistry and didn't think this varied much between the different disciplines. Mr. P.S. Hamer remarked that more graduates might find employment in future as crop protection advisers to co-operative groups of farmers and horticulturalists, and went on to ask if Universities paid enough attention to training in investigation methods and the administration and organisation of research in a multi-disciplinary field like crop protection. Professor Broadbent replied that many degree courses in biology included one or more research projects in which instruction in research methods and techniques played an important part. There were few courses specifically on administration techniques but many included management techniques in agriculture and horticulture some of which might be useful in research administration. Dr. D.L. Gunn (Chairman) wondered whether it was possible to train anyone in investigation techniques. Professor Broadbent replied that it finally came down to common sense. Not all students were endowed with this and he doubted if any training could make up for its absence. Mr. P.J. Macfarlane suggested that Universities had enough to do giving the scientific training and that N.A.A.S. regarded investigational techniques as part of their 'in service' training scheme. Mr. M.E. Putnam agreed with this and commented that I.C.A.M. organised courses for fieldsmen on the investigation and recognition of the common diseases and pests of cereals. Mrs. S.D. Feakin asked if there was any communication between Universities and the commercial firms and research institutes employing graduates so that the courses given fitted graduates to take up jobs when they left University. She also pointed out that many undergraduates on non-sandwich courses spent their vacations working with industrial firms and research institutes and many of them found this a suitable introduction to work in their field of interest. Dr. M. Cohen pleaded for industry and the research institutes to give more support to the sandwich scheme idea, and wondered whether other universities might not adopt this idea so that all graduates had some experience of working in some particular research field before completing their studies. It was his opinion that students on sandwich courses were more alive to the outside world and its requirements than the 'raw' graduate from the more academic courses. In answer to these points Professor Broadbent replied that at the moment the amount of interest in applied biology and its relevance to course composition at Universities depended entirely on the personal interests and contacts of the staff concerned. It was certainly true that many university departments already take a lot of trouble to take their students on visits to firms and research institutes and arranged suitable vacation employment for them. Professor W.W. Fletcher pointed out that over a recent 6 month period there were 600 situations vacant for biologists (excluding bio-chemists and microbiologists) in 'Nature' out of a total of 3,000 posts, suggesting an annual requirement of about 1,200 biologists. Only 80 of these 600 posts were in industry, and this figure was surely far too low. He suggested that applied biologists could well carry out some of the jobs in crop protection that are being done by chemists and other pure scientists or by non-graduates and that it was important for Universities to keep industry aware of the type of training given to biologists to ensure a continuous intake into industry. Mr. J.R. Corbett asked if there were any reliable assessments of the national and sectional requirements for biologists and if the Universities were arranging to meet these figures. Professor Broadbent replied that the output of biologists was known reliably - about 2,200 from all British Universities next year but that the Institute of Biology survey due out next year would be needed before there could be any tie up between supply and demand for biologists in different disciplines. There are something like 12,000 biologists working in Britain at the moment and this will undoubtedly increase in the future. Biology was becoming more important in the manufacturing industries as well as in agriculture and horticulture. He reminded the audience of the remarks of the chairman (a non-biologist) at the recent symposium in London on Biology and the Manufacturing Industries that last century was the age of chemistry and metallurgy, the first half of this was the age of physics and the next 50 years promises to be the age of biology. Mr. Putnam commented that industry was unlikely to employ graduates as sales staff for crop protection materials. The wage structure was not attractive enough and he doubted if people of this calibre were required. Mr. J.W. MacKenzie pointed out that this was not the case in America. In his company all the sales staff were graduates about half each with agriculture or business degrees and received comprehensive training on appointment. For Field Technical Service an M.S. was required and for Field Research a Ph.D. was the minimum, both in some agricultural subject. Mr. W.R. Caseby remarked that his company paid a lot of attention to the results of an examination set after a period of training. Dr. K. Holly raised the point that a basic knowledge of agriculture or horticulture was surely essential for graduates employed in a service industry to agriculture or institutes carrying out research in agriculture. He felt that while many of the courses outlined by Professor Broadbent and Dr. Dore gave a valuable grounding in many desirable subjects they were somewhat deficient in the agricultural background. Do employers regard this as a disadvantage. Professor Broadbent replied that he could only speak for Bath on this point and that his students all followed courses in agricultural sciences, and the principles and economics of agricultural and horticultural practices.

A REVIEW OF THE PRESENT POSITION IN CEREAL WEED CONTROL AND AN INTRODUCTION TO RESEARCH REPORTS

S. A. Evans

National Agricultural Advisory Service

The costs and returns per acre in growing barley at present are of the following order:

	£
Variable costs (seed, fertiliser, spray, sundries)	9.0
Gross output (30 cwt of grain at 25 shillings)	37.5
Gross margin	28.5
Basic costs (rent, labour, machinery, sundries)	19.8
Net farm income	8.7

Part of the variable costs are herbicides. The cost of herbicide treatment depends upon the product used and may, for broad-leaved weed control, be from about five shillings an acre for a low dose of MCPA to forty shillings an acre for the top dose of the most expensive herbicides. This difference can mean a difference of about 20 per cent in net farm income. Put another way it is equal to a yield difference of about 5 per cent. The relatively small sums involved in the use of herbicides in cereals can have a marked effect on the profitability of the crop.

Surveys of herbicide usage conducted over the past seven or eight years (Church and Woodford(1960); Church, Dadd, Miller and Page (1962); Church, Kinsey and Powell (1963)) have shown that a large proportion of cereal crops are sprayed for the control of annual broad-leaved weeds. Woodford (1964) has shown how the proportion of the cereal acreage treated with the more expensive herbicides has been increasing. Farmers, therefore, must be expecting appreciable benefits from spraying.

The increase in use of dearer herbicides is a reflection of the farmer's desire to control better those weeds not readily susceptible to MCPA such as *Stellaria media*, *Polygonum* sp. etc. or to obtain a control of the relatively few major weeds of cereals which are virtually resistant to MCPA such as *Galium aparine* and *Chrysanthemum segetum*.

Herbicide manufacturers have developed a wide range of products to satisfy this desire, and these products are invariably dearer than MCPA.

The search for these so-called "broad-spectrum" weedkillers has had two results. First is has led to the introduction of new herbicides such as ioxynil, morfamquat and picloram. Banks of the N.A.A.S. has presented a paper (pages 167-176) describing trials with these herbicides and with chlorflurazole. There are research reports to be presented by Folland, Terry and Wilson of May and Baker Ltd. (pages 177-187) and Joice and Norris of A. H. Marks and Co. Ltd. on ioxynil and bromoxynil (pages 188-196). These papers show that bromoxynil octanoate is more active than ioxynil on certain Polygonaceae and Compositeae species and in some situations there may be an advantage in using bromoxynil rather than ioxynil.

Second, it has led to the mixing of herbicides. All cereal herbicides are available in some mixture or other; some such as 2,3,6-TBA, dicamba, picloram and ioxynil are available only in mixture. There seems however to be surprisingly little systematic study of the principles of mixing herbicides; products are developed mainly on a trial-and-error basis.

INFLUENCE OF HERBICIDES ON CEREAL YIELDS

25 trials
(1958 - 1964)

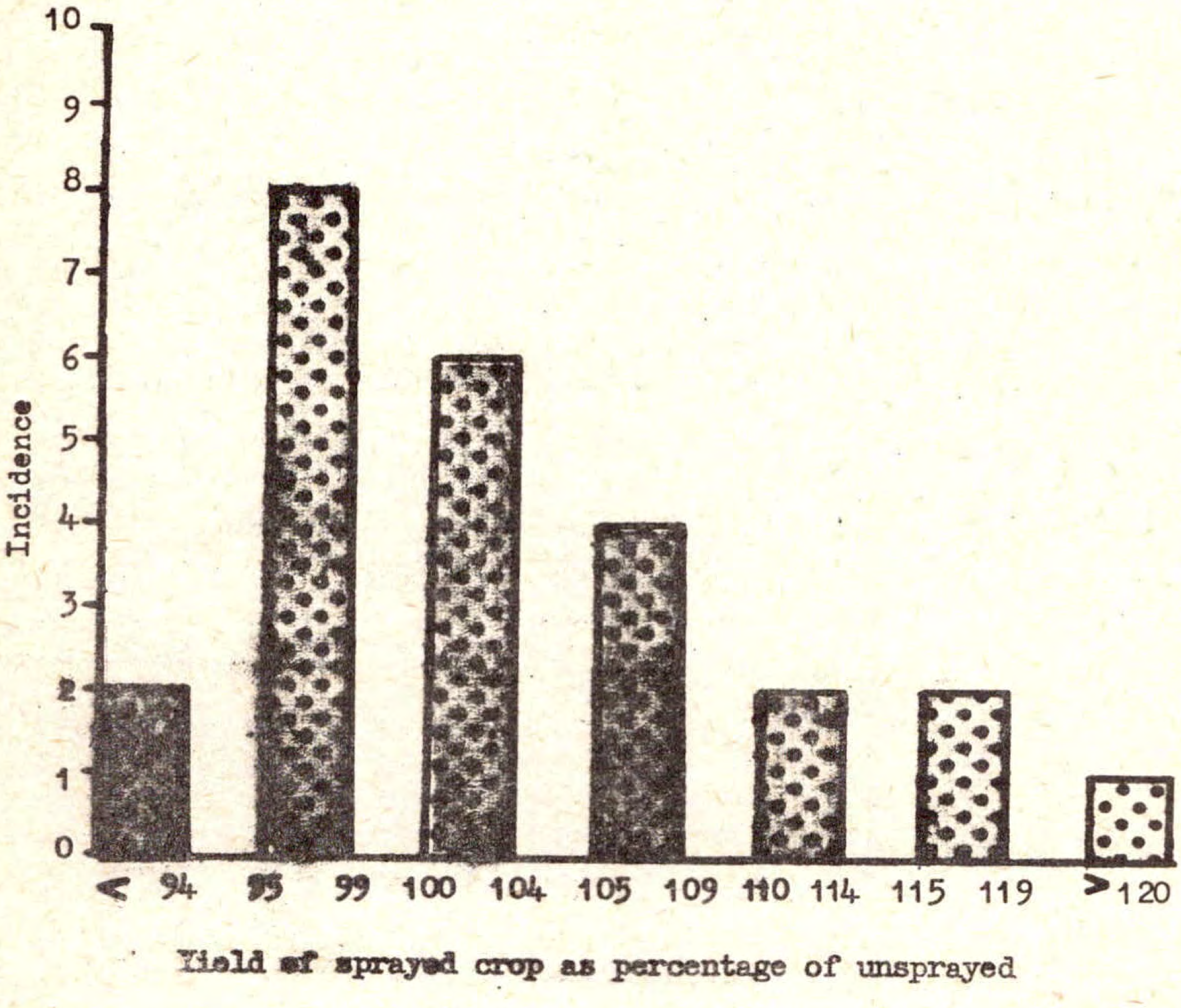

Figure 1.

With the large number of products available there is no longer any combination of broad-leaved weeds in cereals which is not, at least in theory, capable of being adequately controlled by herbicides. In practice however, weed control can still be poor. Banks' paper shows quite clearly the variable results that can be achieved with the same herbicide. The time has now come when the emphasis on the development of new herbicides for cereals must give way to a much greater attention being given to application problems.

There is however a much fewer number of herbicides suitable for use on cereals undersown with clover. Stellaria media is a common weed in this situation and a research summary from Lush, Mayes and Rea of Boots Pure Drug Co. Ltd. (pages 197-199) demonstrates the effectiveness of benazolin on Stellaria media and Galium aperine and its safety on seedling clovers and grasses and on cereals.

Farmers then have been convinced that spraying of cereals is generally desirable and many are prepared to pay a premium for the expectation of getting the best weed control possible. It is worthwhile looking at the main benefits that might be gained from using herbicides.

Yield

The sooner weed competition is removed the greater is likely to be any yield improvement (e.g. Hanf 1957). Logically the aim should be to prevent weeds right from the time of drilling; and as long ago as 1962 Holroyd listed the advantages and disadvantages of using a soil-applied herbicide for this purpose (Holroyd 1962). There are three or four new herbicides being discussed at this conference which seem to be potentially suitable for pre-emergence use in cereals. We have at present, in practice, to consider only post-emergence sprays in so far as broad-leaved weeds are concerned and the present indication is that appreciable yield increases following spraying are not general and that there may even be yield decreases. Figure 1 shows the yield responses of cereals to commercial treatments in a number of experiments published over the last seven or eight years. Rothamsted (1966) report yield losses from spraying. To get some idea of what is happening in practice the N.A.A.S. have been running an investigation and the research report by Hughes gives results from the first year (1965) (pages 200-203). The histograms accompanying this paper (pages 204-205) bear a close resemblance to the data taken from experiments. It should be noted that many of the figures quoted by Hughes refer to the potential yield, for the yields were estimated from samples taken before harvest. They do not take into account any loss in harvesting. It can be argued that losses in a weedy crop could be greater than in a weed-free one. But it must be remembered that the modern combine harvester is a remarkably efficient machine; and moreover the balance is not always necessarily in favour of the herbicide. In several of the N.A.A.S. survey sites in 1966 the sprayed crop has lodged and presented a worse harvesting condition than the unsprayed crop. This is a phenomenon which has also been noticed in Finland by Mukula and Köylijarvi (1965).

There are records of people such as Blackman and Holmes crediting the spraying of cereals with substantial yield increases. It is tacitly assumed by many commentators that the increasing yield of cereals over recent years are due in part at least to the introduction of herbicides. And yet present indications are that many farmers may not be seeing their money back in terms of extra yield from spraying. If there is a lesser yield response to spraying than there was a decade or more ago there could be several contributory factors.

(i) Improved cereal varieties and increasing fertiliser use have led to increasing yields. A heavier crop is likely to be a better competitor against weeds. Mukula and Köylijarvi showed a correlation between yield level and yield increase: at the highest yield levels there were "only minimal increases or quite often decreases in yield" from spraying.

(ii) The weed populations may have changed. There is hardly any recorded evidence on this. Work by Chancellor on the farm of the Weed Research Organisation has shown a rapid decline in the numbers of weeds in the arable fields which have been regularly sprayed. Mukula and Köylijarvi's trials show a high positive correlation between the number of weeds and yield increases. Those trials reported by Hughes did not. Sheer numbers may not always be the overriding factor. It is equally as pertinent to ask if weeds differ in competitiveness and if so which weeds do the most damage. Are farmers, in seeking a control of so-called "MCPA-resistant" weeds, dealing with weeds which tend to have no great effect on the crop?

It is interesting that at the sites reported by Hughes where yield increases were obtained from spraying, Sinapis arvensis was frequently a major part of the weed population.

I approached a number of commercial organisations for evidence of weed changes. This I was unable to get but there was general agreement on the present importance of weeds of cereals in England:

Most important	Polygonum convolvulus Polygonum aviculare	on most soil types and in most cereal crops
Also important	Stellaria media Polygonum persicaria	(on most soil types and in most cereal crops)
	Galium aparine	particularly heavier soils and winter crops
	Sinapis arvensis	spring crops
	Mayweed spp.	mainly drier, lighter soils
Of some importance	Papaver rhoeas Veronica spp.	mainly winter crops
	Chenopodium album	
	Raphanus raphanistrum	

Apart from Cirsium arvense, perennial weeds other than grasses do not seem to have become a general problem. This list is not greatly different from that given by Dadd four years ago (Dadd (1962)). It seems to me that a study of weed changes is required for it is not satisfactory to consider spraying as a single operation without reference to the long-term effect. There is need also to study the competetive ability of different weeds if we are to know more about their relative importance.

(iii) In seeking broad-spectrum weedkillers, has the margin of selectivity tended to be reduced? We know for example from published work that the commercial dose of MCPA + 2,3,6-TBA has a greater toxicity than MCPA (Evans and Holroyd (1962)). Are we quite happy that some of the two, three or even four way mixtures of herbicides now available have a satisfactory safety margin on the crop?

(iv) The question of the safety of a treatment can never be divorced, of course, from techniques of applying the treatments. We may have to accept a reduced margin of selectivity if we wish to gain a good control of a wide range of weeds. This means that the farmer will have to improve his spraying and here there is plenty of room for improvement as is shown by Hughes in his research report. Poor results from spraying may not be the fault of the chemical but arise from inadequate spray operation. Some explanation of current apparent lack of yield improvement from spraying may be that farmers have not appreciated the need to tighten up their spraying methods. Here is a field for some useful advisory work.

(v) Even with correct herbicide use one can observe effects on the crop. Mukula et al. noted shortening of the straw-length in wheat by MCPA/2,3,6-TBA (leading incidentally to less lodging) and a weakening of straw caused by mecoprop. They also noticed a tendancy to delay ripening and this I saw for example in a crop of spring wheat this year sprayed with dichlorprop.

The most interesting aspect of these effects in cereals is in relation to disease. With the intensification of cereal growing diseases such as take-all and eyespot, in particular, become endemic. Many crops are grown at high levels of infection and it needs very little to push the balance in favour of the disease. That herbicides can influence the severity of disease effects is clear. It was noticed by Brenchley (N.A.A.S., Cambridge) from aerial photographs where an overdose due to boom overlap could be clearly seen. Inspection on the ground showed these overlap strips to be more severely affected by take-all than the rest of the field. Several examples of the same effect have lately been noted.

These examples have been from fields in which spraying has not been correct - application was later than recommended. But one cannot rule out the possibility of sub-clinical effects even from correct application. It is known that normal herbicide usage can restrict cereal roots under some conditions (Muzic and Johnson (1961)), and this may be important in relation to drought, nitrogen availability etc. as well as disease. Other interactions between herbicide treatment and pest or disease are recorded. For example 2,4-D has increased stem eelworm populations in oats (Webster (1966)).

(vi) With a few exceptions there has been no differentiation in recommendations for spraying different varieties. Differences in varietal susceptibility have appeared slight to judge from previous reports at this Conference by the N.I.A.B. (Fiddian (1962)). Varietal susceptibility is influenced by growth conditions and under the more critical conditions of today such varietal differences may assume more importance. Research on this problem has unfortunately stopped.

Harvesting and storing

Freedom from weeds can make combining and storing of grain easier. The important question is what level of weed control is adequate for this purpose?

In experiments comparing herbicides, the difference in weed control, even with assessments a few weeks after spraying, is nearly always a matter of degree, and not infrequently the differences are not great. By harvest time these differences can be quite small. Mukula and Köylijarvi state: "The effectivity of all herbicides "(they were comparing MCPA, MCPA/2,3,6-TBA and mecoprop)" proved much better (i.e. at harvest time) than could have been expected on the basis of weed counts made 6 to 8 weeks earlier" and in their conclusion state "In view of the fact that MCPA/2,3,6-TBA and mecoprop on the average provided only a slightly better weed control than MCPA and do not eradicate all species of broad-leaved weeds, the replacement of MCPA by these new products should be considered with reservations."

Delay in harvesting may lead to crop losses but here the plant breeder is beginning to help by producing "weather-resistant" varieties. Impala barley for example can resist a lot of weathering before being harvested. The farmer who has ample combine capacity should question how much he need spend on ensuring that harvesting is easy. The farmers whose combine is working to its limit on the other hand may be wise to pay for the most efficient herbicide. Even crops sprayed with the most efficient weedkiller can sometimes of course present a problem at harvest and we must not too lightly assume that using the most effective weedkiller necessarily obviates all harvesting difficulties. An efficient desiccant could, anyway, solve this problem and an efficient crop desiccant would be a boon in some

THE GROWTH OF CEREALS AND WEEDS IN THE SPRING

CROP[1] Emerges after 7 days and develops 1 leaf per week
CROP[2] Emerges after 21 days and develops 1 leaf per 9 days

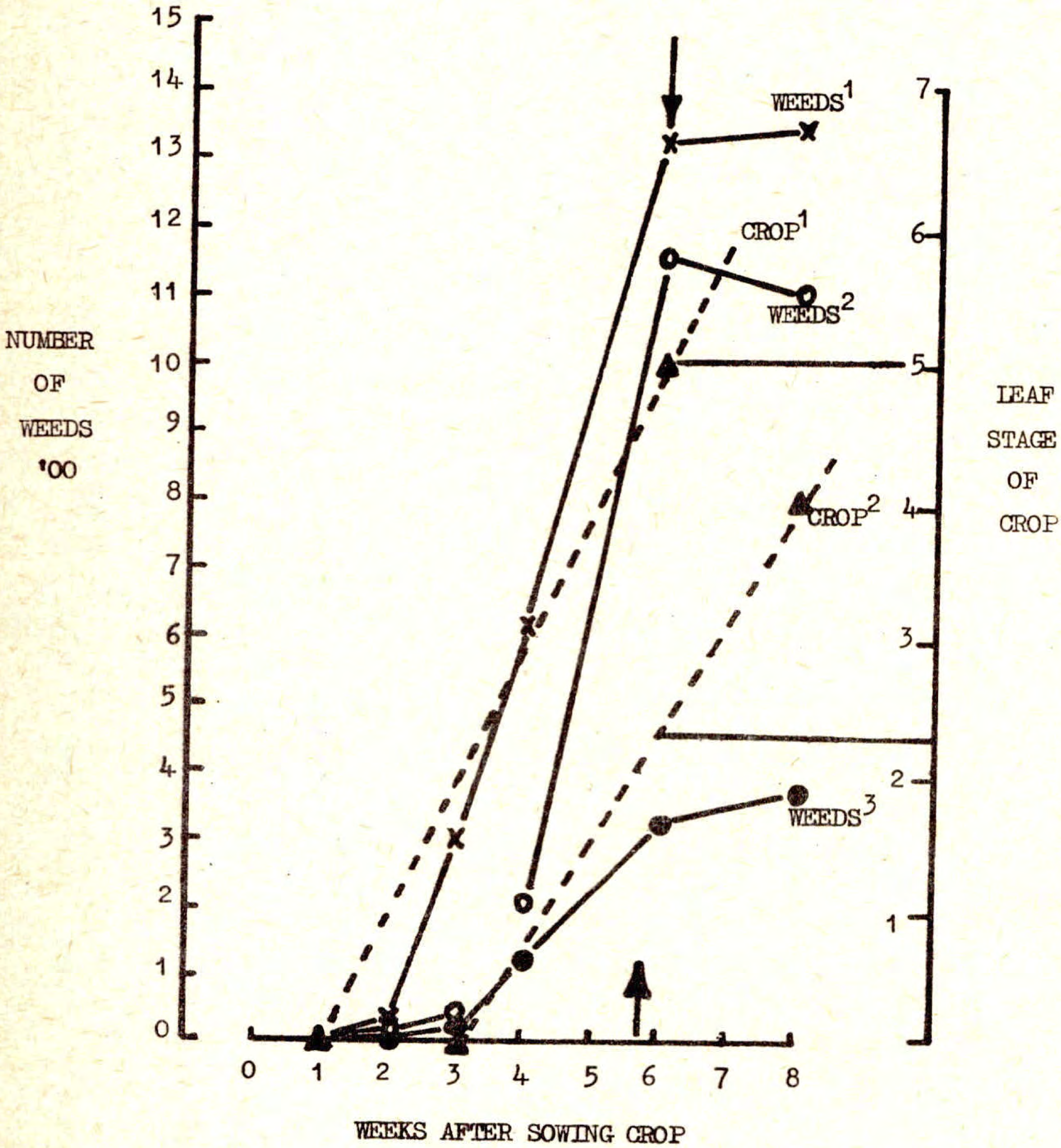

Figure 2.

years. It is a long time since we heard any reports at these Conferences on crop desiccants. But farmers have been using some quaternary ammonium compounds in a way not agreed to by the Pesticides Safety Precautions Scheme. An acceptable desiccant would remove the temptation to use 'uncleared' chemicals.

Cheapening the cost

Attempts have been made to economise with herbicides by using MCPA where a more expensive product would normally have been considered desirable. To achieve a good weed suppression with a sub-lethal treatment it becomes so much more important to have every factor absolutely right. The Weed Control Handbook indicates how seedlings of many weeds are at least partially susceptible to MCPA even if more or less resistant as young plants. This indicates the need for early spraying. Early spraying too will allow the greatest amount of spray to reach the weed. Hebblethwaite and Richardson (1966) have shown that in barley only 6 inches high the amount of spray which sometime reached a 2 in. diameter plate on the soil was only 13 per cent of the dose applied. Figure 2 shows the pattern of weed and crop emergence that might generally be expected. Weed germination is normally likely to be about fully complete in cereal crops sometime between the 3 and 5 leaf stage. Early spraying seems to be called for but if spraying is carried out before the five-leaf stage with MCPA the dose must be reduced for the safety of the crop.

Early spraying may, like later spraying, encounter weather conditions inconducive to good results, and if this is so then obviously spraying should not be attempted. Hanf (1957) in Germany has shown that cool weather is generally no detriment to the effectiveness of growth regulator herbicides providing frost does not occur at night.

When spraying is carried out it calls for a high standard of operation.

Perhaps most important of all is crop competition. A good crop can turn a moderate effect of a herbicide on weeds into complete control. Barban needs the competition of a crop to produce maximum results and it has been shown (Evans (1962)) that the factor probably important in this respect is the speed of growth of the crop after spraying. This may be true also in broad-leaved weed control and may be a particularly important factor when using a sub-lethal treatment.

The effective use of MCPA on partially resistant weeds may be dependant to some extent too on the "strain" of weed. Research workers, in studying the susceptibility of weeds to herbicides, have observed that weeds in some locations are consistently better controlled with a herbicide than the same species in another location. A useful field of study would be to determine the range of susceptibility within a species of weed for, as far as I know, no-one knows how far this is a factor in variable results obtained with herbicides.

Broad-spectrum weedkillers

A sub-lethal treatment demands stringent application conditions. When a farmer has many acres to spray he cannot always spray every field under the optimum conditions. A partial control of weeds may lead to a serious build-up of the more resistant weeds (hence the comment earlier that we need to know about the behaviour of weed populations under different spraying regimes). The failure to prevent seeding of some weeds may be particularly important when a crop for which there is no adequate selective herbicide is grown in the rotation. The farmer who grows non-competetive crops or crops prone to lodging and whose combine capacity is strictly limited needs good weed control. Seed crops may demand a highly efficient kill of weeds. The most efficient herbicide may be required for all these reasons; but the farmer must be more critical when deciding which fields to spray and what to use.

Crop growth regulants, crop protection chemicals and other sprays

Several research reports on chlormequat are to be presented. This chemical is probably the first of a range that may be developed to regulate crop growth in some way or other. The action of herbicides when mixed can be modified. There is evidence too that some systemic insecticide may increase the susceptibility of a crop to a subsequent application of a weedkiller. It is important then that the mutual influence of crop growth regulators and herbicides should be investigated.

The users of liquid fertilisers wish to add herbicides to their sprays despite the need to put liquid fertiliser top dressings in a coarse spray intended to reach the soil: herbicides have been developed to be effective under very different patterns of spray distribution.

It is a matter of concern as to how new developments in the control of crop growth and in crop protection are going to influence the selectivity of herbicides. Weed science cannot be separated from pathology, entomology and crop growth regulation and there is need for people trained in an integrated science.

Minimum cultivations

An attempt to simplify cereal production and reduce costs lies in the research to eliminate ploughing and other expensive cultivations. Under certain prescribed conditions the technique of minimal or nil cultivation can be successful but general adoption seems unlikely until crop establishment can be made more reliable. The influences this technique may have on weed populations, disease and crop growth, and what interactions there will be with herbicide usage, remains to be seen. A research report by Jones (pages 227-228) gives results of a study on the effect of seed-bed preparation on the weed flora of spring barley. Quite marked differences appeared due to cultivations. For example cultivation increased the number of broad-leaved weeds, whilst lack of cultivation or minimal cultivation led to a greater grass weed infestation. Such work as this by Jones is important to help us understand problems arising in a new system of cultivations and will, I hope, be continued, for I feel sure that the trend will be towards eliminating as many cultivation operations as possible.

The paper by Jones points the possible danger of increasing grass problems with minimal cultivations. Agropyron repens and Agrostis gigantea (couch) are already the major weeds of cereal crops. There is a session at the Conference devoted to these weeds: but this review paper would be incomplete with acknowledgement that these weeds are today the cereal growers worst problem.

Annual grass weeds

Avena fatua and A. ludoviciana (wild oats) constitute the biggest problem in this category and there have been many research reports at previous conferences dealing with barban and tri-allate, two herbicides now widely used. A comparison of the two has recently been made (Evans (1966)). The herbicides are expensive and a fairly heavy wild oat infestation is necessary before herbicide treatment is likely to lead to increased yields that would give adequate recompense. The figure of about 10 wild oat plants per square yard as the lowest population at which it is likely to pay to spray, which seems current amongst weed technologists, is supported reasonably well by N.A.A.S. trials and evidence from Canada.

Alopecurus myosuroides (blackgrass) ranks second in importance and there are research reports from J. Rognon, J. Holroyd and R. K. Pfeiffer and H. M. Holmes. The paper by the latter authors shows a mean increase in yield of winter wheat of 23 per cent from using GS 14260, which at even a price of over 90/- per acre for the chemical is profitable. M. Rognon's yield figures are not as spectacular as this and one is prompted to ask : what density of blackgrass is required before it is likely to become worthwhile to spray at this cost and in terms of extra crop yield produced?

GS 14260 is reported as giving reliable control with safety to the crop in both British papers but M. Rognon shows that in trials in France the herbicide was not very selective. M. Rognon too says that the high clay content of the soil was unfavourable to GS 14260 whilst Pfeiffer and Holmes found soil type to be of little influence in the field.

Other herbicides studied by M. Rognon and which look interesting are neburon, which tends to be rather sensitive to soil conditions and soil type, and FW 925. I was pleased to see M. Rognon use the word "economically" in his last paragraph and look forward to hearing the results of his work to study the competitiveness of blackgrass.

Other annual grasses of increasing importance are Bromus spp. and the perennial species Poa trivialis and Lolium sp. which behave mainly as an annual in cereal crops. Some of the herbicides tried against blackgrass can also be effective against Poa spp.. Lolium spp. and Phleum pratense (timothy) too can sometimes be troublesome weeds when the species are included on the rotation as a seed crop, but no evidence is presented on the control of these.

Tri-allate and barban have been used for a few years for blackgrass control. Now there are more herbicides to choose from.

Given the experience of another season or two it will then be necessary to consider the place of these herbicides in British agriculture and to do as Lord Netherthorpe urged us to do at the previous conference in 1964 - "to strive to acquire greater knowledge of the economics of the use of chemical weedkillers and their influence on profitability and productivity".

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Figure 3. Spring Wheat. Interaction between "take-all" and herbicide applied at joining stage. Left: little disease, crop sprayed. Centre: much disease, crop not sprayed. Right: much disease, crop sprayed.

Discussion

Mr. G.W. Cussans (Weed Research Organisation) felt that the main interest in Mr. S. Evans' review was technical and not economic. Some of the biological factors which can influence the effect of herbicides on the yield of cereals would require immediate investigation by specialists. Mr. Cussans asked for further details on the N.A.A.S. survey technique and for the relative importance of the factors listed by Mr. Evans.

Replying to the question, Mr. S. Evans pointed out that the survey was carried out on farms which were selected at random. The farmers were asked to co-operate and no farmer was forced to undertake the survey if he was not interested. It was therefore quite possible that the majority of the experiments were on farms which were managed more efficiently than the average farm.

The technique consisted of the farmer spraying the field according to the advice given by his trade representative, the N.A.A.S., or alternatively what he himself thought was necessary, but leaving one or two strips unsprayed. Yields were then taken either by combine, or by samples taken before combining. Advice on the statistical layout of these trials was obtained from Rothamsted Experimental Station.

Some information was obtained on the factors contributing to the crop response. For instance, the number of weeds was not found to be very important but the type of weed was. All chemicals produced variation in yield and there did not appear to be any particularly good or bad chemical in this respect. As a result of the first year's experience, better data are now being collected and information should be available at the end of the survey on a number of factors which are influencing these results.

Mr. G.B. Lush (Boots, Nottingham) pointed out that farmers did not primarily spray to increase yield of cereal crops. Yield increases do frequently occur and not merely through removal of charlock as Mr. Evans suggested. Frequent increases in yield, for instance, due to the removal of chickweed, were found by Mr. Lush and his colleagues during the decade after the introduction of mecoprop.

Mr. Lush also referred to Mr. Evans' slide showing a field treated with dichlorprop where a strip missed by the farmer showed a much more vigorous crop than the rest of the field. Mr. Evans had stated that the farmer applied dichlorprop according to recommendations, but Mr. Lush pointed out very strongly that he felt that the field was treated at the jointing stage which is, of course, outside the recommended stage for spraying cereal crops. The appearance of the crop in the slide was typical of jointing stage application of dichlorprop and demonstrates the dangers of this survey of herbicide usage where critical comparisons of herbicides are made and where these are based merely on farmers' assurances that they have carried out the recommendations correctly.

Mr. Evans replied that as far as he could reasonably ascertain, the herbicide was applied according to the manufacturer's instructions.

Mr. J. Holroyd (Weed Research Organisation) asked Mr. H.J. Terry (May & Baker) whether the reduction in ear deformity caused by the addition of MCPA and 2,4-D esters to ioxynil or bromoxynil was related to the scorch of the cereal crop. He felt that this could be a likely explanation since the MCPA could be prevented from moving from the site of entry by the scorch produced on the cereal crop. Mr. Terry replied that there was no scorch at the growth stages to which his histogram applied, although there was very slight scorch at very advanced stages of growth (tillering stage).

Mr. S. Evans asked Dr. R.K. Pfeiffer (Fisons Pest Control Limited) what density of blackgrass would give a marked decrease in yield. Dr. Pfeiffer replied that this question was impossible to answer. The likelihood of yield increase depended on a number of factors and their interaction. By early April it was possible to look at an infested field and to judge from the vigour and density of blackgrass whether there was likely to be a substantial loss of yield or not.

Mr. Evans then enquired for the reasons why Dr. Pfeiffer did not find it necessary to adjust the dosage of GS 14260 to soil types in the United Kingdom, while Monsieur J. Rognon in France found it absolutely necessary to do so. Dr. Pfeiffer replied that one possible reason why in the United Kingdom it was not found necessary to adjust the dosage of GS 14260 to soil type may be as follows: due to prolonged and reliable ainfall during the winter months, leaching in light soils (where adsorption is low) and on the other hand adsorption on heavy soils (where leaching is low) may be compensating each other to some extent, thus levelling out differences which one would expect from a variation in soil type.

Monsieur Rognon expressed the same opinion as Dr. Pfeiffer but emphasised the importance of spring germinating blackgrass in France as a further complicating factor. This was not controlled by GS 14260 which had leached out of the soil by the time the spring germination took place.

Discussion on CCC

Mr. G.W. Cussans (Weed Research Organisation) asked whether CCC would have a similar effect on perennial grass weeds as it has on cereals, and in perhaps reducing the internode length of rhizomes or stolons or the ratio between culm and rhizome development of couch grass (*Agropyron repens*). Such an effect may perhaps be useful in influencing the competition between crop and weed in favour of the crop, and there might also be some interaction between the effect of CCC and of herbicides which were subsequently applied to the weed.

Mr. J.J.B. Caldicott (Cyanamid) referred to some work done by Stodart of Aberystwyth on timothy grass. This work has shown that culm length was reduced by treatment of CCC, but there was no effect on the foliar parts of the plant. There was also no evidence to date on the effects of stolon formation in this type of plant but it is known that on certain varieties of strawberry CCC inhibits runner formation. It is possible that a similar effect could be observed on stoloniferous grasses but no further details could be given at this stage.

Mr. G.A. Toulson (N.A.A.S.) contributed an observation on the effect of CCC on the incidence of fungal diseases. He reported an experiment in a crop of spring wheat, variety Opal, carried out in the centre of South Wales. In this excellent crop straw lengths were reduced by approximately six inches. Unfortunately late in June yellow rust was observed in the crop. As this disease increased it was noticed that in the plots in which CCC had been applied not only was the onset of the disease earlier, but it became more severe than in the untreated plots. Mr. Toulson suggested that with the reduction of height of crop, the leaf density of the wheat was increased to such an extent as to create a more favourable micro-climate for the development and spread of this particular disease. CCC applied to spring barley, variety Impala, at three times the normal dose, did not produce a reduction in the height of the crop, nor did this application give a reduction in the yield of grain.

Discussion

Dr. K. Holly asked if the hydroxylation of dicamba by grasses played any major part in the selectivity which dicamba exhibited as a herbicide. Dr. W. H. Zick replied that unsuccessful attempts had been made to substantiate this.

Dr. B. J. Heywood suggested that a great deal of extra work would be involved if it became generally necessary to show that pesticide metabolism was unchanged by the presence of other pesticides. Dr. W. H. Zick agreed but thought this would not generally be the case.

The Chairman asked Dr. Voss if the degradation experiments had been made in other biological contexts. Dr. G. Voss answered that metabolism of fluometuron by soil bacteria had been examined, but that the efficiency of the bacteria which had been used was rather low in this experiment and no clear results had yet emerged.

Dr. Corbett asked if there was evidence for the loss of fluorine on the - CF_3 group from fluometuron and Dr. B. J. Heywood remarked that total Fluorine estimations could give useful information on the presence or absence of metabolites in this case. Dr. G. Voss said there was no direct evidence regarding the metabolism of the fluorine, but that since the radioactive label was in the - CF_3 group and radioactivity was retained in the metabolites isolated, there was therefore strong evidence that the - CF_3 group was intact.

In reply to a question from Dr. E.C.S. Little, Dr. G. Voss stated that the white areas in the radioautographs should be considered to contain relatively less ^{14}C than the dark areas and not that ^{14}C was absent.

Dr. K. Holly asked Dr. G. Voss if the conjugates of metobromuron were biologically active. Dr. Voss replied that this was not known at present since the amounts were too small to carry out bioassays.

Prof. F.L. Milthorpe pointed out that, in the context of the third paper, it was perhaps not valid to assume that the effect of sucrose was upon translocation. Unless figures for total uptake were considered, it might be that the effect could be explained in another way. Dr. R.C. Kirkwood replied that the data in Table 2 showed that there was greater uptake of MCPA at the lowest concentration. However, enhanced uptake does not at first sight appear to be the key factor since a similar pattern of uptake enhancement was recorded for MCPB, but this had no effect on translocation of MCPB.

Dr. P.A. Gabbott remarked that the attachemnt of "wells" to leaf surfaces using lanolin was unsatisfactory in cases where the material being applied was oil soluble. In recent work he had adopted the classical agar block method of application.

Dr. E.S. Little asked if movement of MCPA and MCPB in the xylem had been investigated and correlated with differential activity. Dr. R.C. Kirkwood said in reply that although they had not investigated this, they had noted strong adsorption of MCPB in midrib vascular tissue.

Mr. D.W.R. Headford wondered if there was some practical application of the sucrose enhanced movement of MCPA. Dr. R.C. Kirkwood commented that although the uptake and subsequent injury of the plant was increased, there was also a danger of mildews on leaves coated with a subtrate such as sucrose.

Dr. B.J. Heywood recalled a paper by Pallas in 1958 in which the uptake of 2,4-D was enhanced by glycerol, but Dr. R.C. Kirkwood replied that the effect in this case was ascribed to the humectant properties of glycerol maintaining the 2,4-D in liquid form for a longer period. It was possible, he continued, that some of the benefit due to sucrose could be due to this effect.

Dr. J. Dore asked if light intensity through its effect on photosynthesis would effect the translocation of MCPA Dr R.C. Kirkwood said that this had not been studied but that he regarded the enhancement of translocation as reflecting a sugar deficiency due to the effect of MCPA on the chloroplasts or on the photosynthetic mechanism.

Dr. W. van der Zweep suggested that the reduced translocation of MCPB in relation to MCPA might be mediated by the waxy surface of bean plants acting as a reservoir for the more lipophilic MCPB. The difference in the partition of MCPB and MCPA between lipoid and hydrous phases might laso explain the enhanced toxicity to unicellular organisms which had been noted elsewhere by Prof. W.W. Fletcher. Dr. R.C. Kirkwood replied that the suggestion could be investigated by examining the cuticles stripped from treated leaves. He added that Prof. Fletcher had demonstrated that increased toxicity was related to increased absorption by unicellular organisms so Dr. van der Zweep's second comment might well be correct.

Dr. J. R. Corbett observed that experiments on the inhibition or oxidative phosphorylation, the concentration of plant mitochondria was of considerable importance. Miss M.M. Robertson replied that no experiments had been done to clarify this point, but remarked that in the experiments described this point did not arise since treatments were made succesively on the same sample of plant mitochondria.

Dr. B.J. Heywood asked whether, in view of the lability of the iodine atoms in ioxynil to oxidation and reduction, bromoxymil had been used in any experiments with plant mitochondria. Miss M.M. Robertson replied that experiments had been restricted to ioxynil.

Dr. M.B.H. Hayes enquired of Dr. S.R. McLane regarding the correlation between soil composition and biological activity. Dr. McLane replied that no clear cut correlation was to be found. In answer to a question from Dr. P.A. Gabbott he added that his data was insufficient to justify any very definite correlation between biological activity and any physical parameter such as partition coefficient.

Discussion

Herbicides for sward destruction

Control of broad-leaved weeds

Mr. G. P. Allen said in answer to Mr. P. J. Boyle that present herbicides required competition from a grass sward to control many broad-leaved weeds effectively. When this competition was removed by the sward-destroying herbicide, broad-leaved perennial weeds would rapidly become dominant if control measures were not taken. A programme of control was necessary before, during and after re-seeding.

Liquid fertilisers

Mr. J. W. MacKenzie said that Prof. Klingman, North Carolina State University had used paraquat in 30% liquid nitrogen solutions and aqueous solutions on fescue swards prior to direct drilling of maize. The former gave better control of fescue.

Selective control of grass weeds

Mr. J. G. Elliott in answer to Mr. R. E. Chorley referred briefly to current work at the A.R.C. Weed Research Organization, Kidlington. Mr. G. P. Allen would shortly publish work on selective control of Agrostis spp. in ryegrass and white clover pastures.

Direct drilling machines on wet soils

Mr. Douglas Evans described three sites where the new machines had worked satisfactorily on very wet sites. Emergence was slower on mineral soils than on peat.

Time of application of paraquat and sheep treading technique

Mr. Lewis Jones suggested that Dr. Davies would have had better results using a low dose of paraquat in November to control Festuca spp. He described an experiment at Hurley using sheep treading in spring to establish seed following November spraying of dalapon and paraquat. The results on an open sward were excellent. If a "mat" is present, as is more usual, cultivations will probably be necessary and the new machines may be valuable.

Mr. D. B. Hargreaves mentioned a heavy type of sheepsfoot roller used by construction contractors which could possibly be used to imitate the treading of sheep in the experiments mentioned. A conventional farm flat roll could alternatively be provided with bolt heads on the surface to do the same job.

Weed Control in Grass and Clover Seed Crops

Mr. R. M. Deakins asked whether the prometryne treatment was suitable for all species and varieties. Mr. J. P. Shildrick said that the recommendation applied to well-established perennial ryegrass, cocksfoot, timothy and meadow fescue but not to Italian ryegrass which was liable to damage.

Development of grasses and weeds with different methods of establishment

Mr. Lewis Jones asked how much of the weed growth was due to seedlings and how much to vegetative re-growth. He did not understand Mr. Allen's statement that the choice of method of establishment would depend on the distribution of weed seeds in the soil profile; it was difficult to think of a different pattern of distribution under an old sward from that described.

Mr. G. P. Allen replied that no quantitative assessment had been made of the proportion of weed population from seed and from regrowth. There was little vegetative regrowth on the ploughing treatment, more on the rotary cultivated plots, while on the plots which were not cultivated most of the population was from vegetative regrowth.

The pattern distribution of seed under an old pasture was a factor in favour of ploughing such land in order to reseed. In land which had once been ploughed and cultivated the distribution of seed would be more uniform through the soil profile. Ploughing would then presumably have no advantage over surface reseeding in this respect.

Docks

Mr. R. T. G. Ford said in answer to Mr. J. Holroyd that the docks re-colonising the areas sprayed with asulam were in fact seedlings and not regrowth from old rootstocks. He told Mr. T. F. Blood that they had compared asulam at 4-6 lb/ac with aminotriazole at 2-4 lb/ac in orchards. Aminotriazole had a quicker effect on docks but asulam gave a more persistent control.

Bracken

Mr. M. O'Connor asked if the rhizomes of bracken treated with picloram were examined to determine whether they were completely dead or liable to regenerate after a period of dormancy. Mr. C. L. Donaldson said that from a limited number of samples it appeared that some rhizomes were still alive after the lower doses but that the higher doses completely killed them. Mr. D. S. C. Erskine said that in one experiment now 7 years old the plots treated with 5 lb/ac aminotriazole still had only 2% of bracken. The best picloram treatment of 3 lb/ac, which 3 years ago showed a 100% reduction, now had 40% of bracken. Legumes established well after aminotriazole but not after picloram.

THE DEVELOPMENT OF NEW HERBICIDES - AN INDUSTRIAL VIEW

R.A.E. Galley

"Shell" Research Limited
Woodstock Agricultural Research Centre
Sittingbourne, Kent.

When invited to give this talk today it was put to me that I might care to approach the development of new herbicides on a broad front rather than describe the techniques employed by Industry for discovering and developing new active compounds. The following points were made:-

1) Is Industry only concerned with developing herbicides for current problems? How far is research and development directed towards problems likely to be important in agriculture and horticulture 5 to 10 years ahead?

2) What is the cost to a commercial firm of developing new herbicides and what restriction does this place on the envisaged markets?

3) What types of market are being aimed at by Industry and how does the increasing cost of development influence Industry's attitude towards the smaller but locally important markets?

4) What do you consider to be the role of Government sponsored and University research on herbicides and weed control and in what light do you view the work that is being done by non-commercial organizations?

5) What is your viewpoint on official control of herbicides and the possibilities of a Government or Industry sponsored testing scheme as a basis for official approval?

I think it is useful for periodic reviews of this kind to be undertaken to see where we all fit in, for the winds of change blow in places other than Africa and within the major political parties. Certainly the information required by Governments before a new pesticide is launched is considerably more than it was a decade ago, although by then the writing was, so to speak, on the wall. Each kind of research organization, Government, University and Industry, has its part to play, each depends upon and stimulates the other and, in turn, fits into the whole agricultural picture depending upon farmers and advisers for feed-back into research. Having worked in both Government and Industry, I cannot say whether I am in a very good or a very bad position to give this talk. First let me say that I cannot speak for the whole of the Industry; I can only present a view as a member of an organization that forms part of that Industry. On the other hand, I think that I can fairly claim to be speaking for the whole Industry when I say that Industry has to pay for its research out of profits and that its research programme must be mainly concerned with the production of compounds that will be profitable. Only in this way can we ensure sufficient funds to maintain an enthusiastic, well-balanced team working in good laboratories.

The fact that the main effort must be directed towards the production of commercially viable products does not mean that fundamental work is excluded; in fact we have a laboratory on our site devoted almost entirely to fundamental biochemical studies. Nor does it mean that Industry does not undertake work for international bodies like FAO, WHO or IUPAC, nor play its part in collaborative, mainly analytical work with Government bodies and learned societies. It does this regularly, but as two members of Industry had to point out at a meeting of a specialized agency of the United Nations Organization, Industry cannot go on indefinitely putting research money into the discovery and development of new biologically active compounds unless there is a market for these compounds within a reasonable time. If there is no return on capital in a particular project and research is a capital investment, a halt has to be called at some time. This leads into the first point put to me which was: is Industry only concerned with developing herbicides for current problems? How far is research directed towards problems likely to be important in agriculture and horticulture five to ten years ahead?

For my part I think Industry is looking for compounds with high and selective biological activity, the more novel the response, the more interesting the compound. This goes for all compounds, whether they be potential insecticides, fungicides, nematicides, molluscicides or herbicides. Once interesting biological activity is established in a compound, it is examined to see if current unsolved problems yield to it. Herbicides are examined to see to what extent it is possible to effect the control of a weed, or weeds, more cheaply, or more effectively than can be done by existing compounds and existing practices. In fact, as it can take as long as seven years for a compound to become a viable commercial entity, it is possible that in the course of its development the potential outlets might well change. By the time the new compound becomes generally available, we are already more than five years ahead of the situation as it was at the time of its discovery.

On the other hand, Industry is continually looking ahead and attempting to assess the shape of things to come. It will therefore examine any new compound from as many different aspects as possible in an attempt to cover future as well as current problems. Industry does not claim any special clairvoyance in this respect and will always be grateful for the views of Government and University workers, who, from ecological studies, can suggest new weed patterns and complexes that could be significant in the future. It is clear that the continued use for many years of the hormone type weedkillers, MCPA, 2,4-D, 2,4,5-T and the phenoxybutyric compounds, has changed the weed patterns of cereal lands. It is probable that in some instances hormone herbicide spray treatments could be omitted for a year or two without any loss and sometimes with some gain in yield of cereal.

In other agricultural crops and on Industrial sites the continued application of some weed control treatments has caused the build-up of the few species tolerant to the existing compounds. I have in mind Convulvulus which has withstood attack by triazine herbicides. Clearly all the weeds which tolerate existing herbicides will become more important problems as time progresses.

Industry, in general, does not make a bee-line for the solution of potential problems of the future to the exclusion of other problems nearer in time, but it does not ignore them when following up a new discovery. I repeat, however, that Industry would welcome views on the changes that are occurring and what the future problems in weed control are likely to be. This raises the question as to where the advice and opinions should come from and how the information on which these views are based should be collected. Trends of this kind affect the whole agricultural industry and in my view should be followed by the Ministry of Agriculture, probably through the N.A.A.S., and the data obtained should be processed by the Weed Research Organization.

As the subject of the role of Government sponsored and University research is covered in another question I propose to refer to it later.

The next two questions can be regarded as two parts of the same one:-

What is the cost to a firm developing new herbicides and what restriction does this place on the envisaged market? ..and.. What types of market are being aimed at by Industry and how does the increased cost of development influence Industry's attitude towards the smaller but locally important markets?

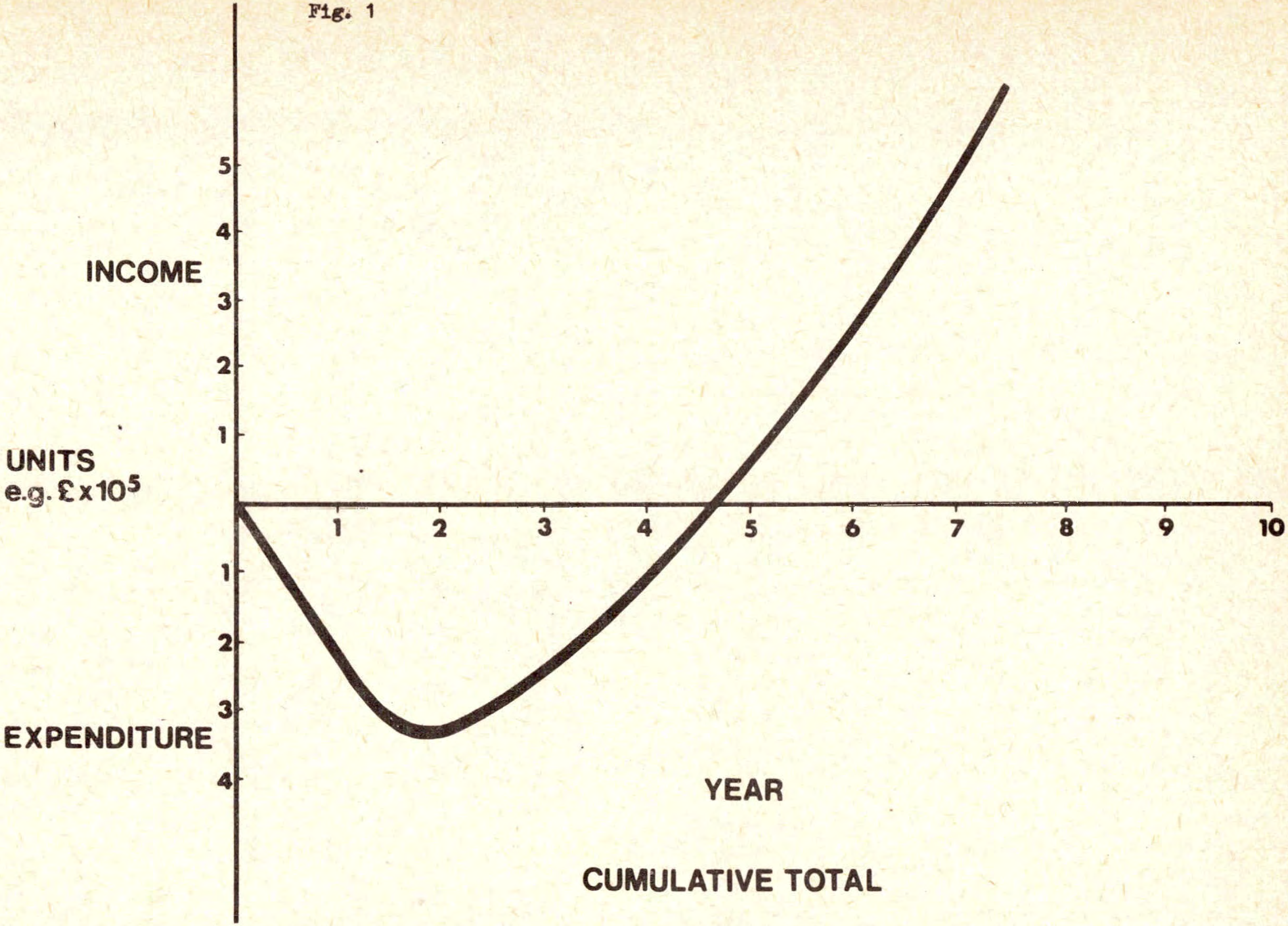
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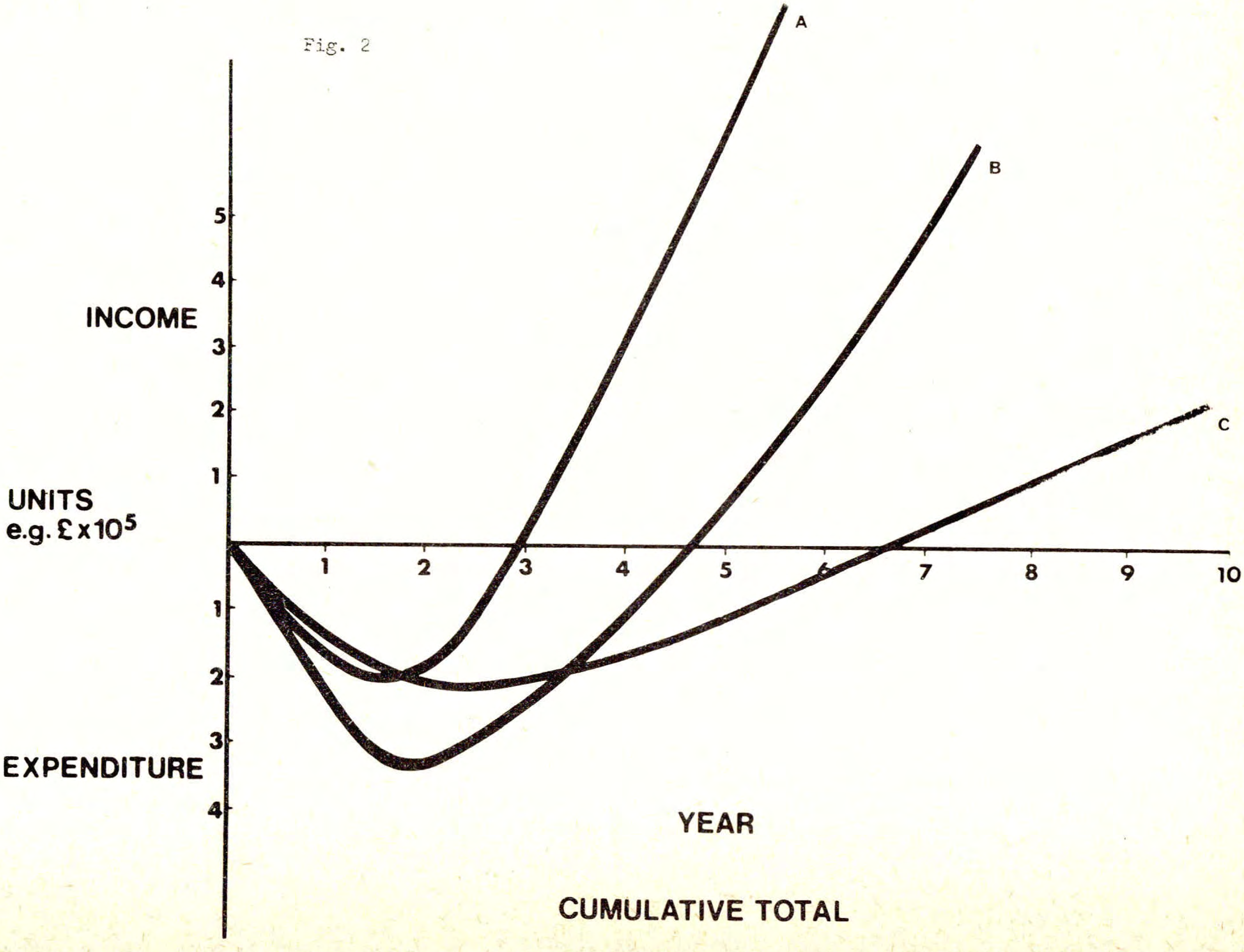
Fig. 1

Fig. 2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The cost of developing any new compound is high. Ten years ago it was estimated as between £250,000 and £500,000. Today it is nearer £1 million, the actual amount depending upon the amount of field testing involved and on the quantity and complexity of toxicological and analytical work, not only on the compound itself but also on its metabolites in plants, animals and the soil.

The first graph gives a picture of the expenditure on a compound which is now on the market. You will see that the firm for the first 4 years was losing money and that it was not until a little over $4\frac{1}{2}$ years after starting the venture that money was recovered and the compound started to pay its way.

Profitability is often considered in terms of discounted cash flow. D.C.F. can be regarded as the maximum rate of compound interest at which the money could be borrowed to finance the project and still break even at the end. A period often used for pesticides in this kind of calculation is ten years, which can be regarded as the average life of a compound.

These are the calculations which have to be made when enough data are available, to decide whether or not a compound should be marketed. The earlier such a decision can be made the better. It would be imprudent to indulge in the luxury of complex and long term toxicological investigations if estimates of cost of manufacture and of the amount which could be sold show that the product can never give a return on the investment.

Therefore at the earliest possible moment the economics of a discovery are examined. The second graph shows three curves showing what would appear to be highly profitable, economically sound and economically unsound products.

Often at the point in time when a tentative decision is made, there is still a considerable amount of research and development to be done. Toxicological and residue indications have to be confirmed and extended to other animal and crop species; analytical methods may have to be simplified and formulations modified to give the requisite high degree of tropical storage stability. Much additional field work will be undertaken to enable the marketing side of the organization to make the most of the new product.

If you add the total research costs to the cost of plant it is quite clear that it is impossible for Industry to consider any market which does not provide an adequate return. This means generally that a small but locally important market, which required the development of a compound specifically for it, would have to be neglected unless there were some feature about it, such as its ability to stand a high cost treatment, which made it profitable. Otherwise in a competitive world it would be preferable to invest the shareholders' money in a building society or lend it to the Government. If an existing or development compound could meet the need, there would be no problem.

It will be obvious from what I have said that in order to be able to afford any research effort at all, a company must have several economically sound compounds on the market.

The fact that Industry would not generally be prepared to spend a lot of time on a small market which required the development of a specific compound, does not mean that it would not be prepared to assist a Government organization in its efforts to solve a small but locally important problem.

This leads us to the fourth question. What do you consider to be the role of Government sponsored and University research on herbicides and weed control, and in what light do you view the work that is being done by non-commercial organizations?

I said earlier that each kind of research organization, Government, University and Industry has its part to play and that each depends upon and stimulates the other. This implies that their parts are complementary, as I think they should be in a country such as ours which can ill afford to waste its scientific manpower in unnecessary duplication of effort. Some might say that there is waste of effort in duplication in the work of research teams of different industrial organizations. There is no doubt that to a limited extent there is, but the advantages of competition more than outweigh any loss of effort arising from duplication.

I am strongly of the view that our Universities should remain independent and that their overall research effort in any field should not be dictated by the University Grants Committee or any Government Department. They should, therefore, receive adequate but obviously limited funds for each Department to be able to carry out a research programme of its choice. These should be supplemented by a limited number of research grants to students for whatever research programme the University Department thinks fit.

Industry can help by providing some "no strings" grants to Departments and Fellowships to selected post-graduate and post-doctorate workers to undertake programmes of choice. This is not inconsistent, however, with University Departments carrying out research on specific programmes sponsored either by Government or Industry. I agree with Professor Flowers, who, at the Conference on "Industry and the Universities - Aspects of Interdependence" at the Senate House of the University of London last year, advocated the orientation of a greater part of financial support by Government of post-graduate work at Universities, towards programmes aimed at solving national problems.

In the way I have outlined, the University Departments would maintain a nucleus of their own basic research and in addition would not only be helping to solve problems of immediate importance to the country, but also getting to understand better the needs of Industry and so enable them to turn out students more suitably oriented towards Industry than many are at the present time.

University Departments will be much more interested in undertaking those problems, the research for which will lead a student to a post-graduate degree of M.Sc or Ph.D. In the herbicide field they are, therefore, likely to be more interested in studies of mode of action and ecological problems than in assessments of crop yield increases at different dosage rates.

Some University Departments have close contact with Ministry of Agriculture specialists, while in some instances the Agricultural Research Council has built up specialist units around leading University Professors. At Bristol University the Director of the Agricultural and Horticultural Research Station, Long Ashton, is a Professor of the University. At many of the State aided research institutes several of the staff are recognized teachers of nearby Universities.

Such close integration also exists between Universities and Industry. Three of my colleagues in "Shell" Research Limited (two on our site at Sittingbourne) are associate Professors at the University of Warwick. Agreement in principle has been reached between the University of Kent at Canterbury and ourselves for collaboration as soon as the biology departments become established.

But what of the existing roles of the main participants in herbicide research? Although Industry must, for its own purposes, establish the field performance of a compound before it markets it and must also establish many other facts about toxicity, persistence, potential effects on wild-life, metabolism and residues for consideration by Governments before marketing can start, it cannot possibly undertake extensive ecological studies nor the detailed studies of the compound's effects on all kinds of crops in all kinds of environments. Here then is the place for the Government Research Institutes who have obligations to different sections of Agricultural Industry. For example, East Malling Research Station serves the fruit growers in the South East. The growers' problems are the Research Station's problems. Although I have mentioned one particular Government grant-aided laboratory, much the same considerations apply to them all, whether grant-aided or 100% Government.

By the time a new product gets to the market, even though this may take six or seven years from the time of its discovery, it cannot possibly have been examined for all possible outlets, nor necessarily, for the optimum timing in a particular environment, nor for the effects of many repeated doses year after year. Here then is where the Government-supported research centres can take up the baton. Detailed studies covering the application of the compound in particular crops and on different soil types and under different climatic conditions can be made to a degree that would be quite impracticable for a company to undertake. This work will confirm and extend the recommendations made by the company and with similar work by the N.A.A.S. provide data for the Recommendation Committee of the British Weed Control Council, for ultimate publication in the Weed Control Handbook. In the course of their work the N.A.A.S. could, and probably does, collect country-wide data on the changes in weed populations. As I said earlier, these data could be passed to the Weed Research Organization for processing to give pictures of what are likely to be the future major weed problems in different areas of the country. In this work ecological studies undertaken by Universities and the N.E.R.C. can provide valuable information. Publication of these trends and forecasts can obviously help Industry in evaluating new herbicidally active compounds.

Examination of the annual reports of the research centres, e.g. those at East Malling, Rothamsted, Long Ashton, Rustington and Wellesbourne, and studies of the papers written by their staffs in the scientific literature, reveal the types of investigations which they are undertaking.

In the herbicide field, we have a situation which is different from that obtaining in insecticides or fungicides. There is among the Agricultural Research Council's Research Stations an organization devoted solely to Weed Research. Originally part of the Unit of Experimental Agronomy in Professor Blackman's Department at Oxford, it began a separate existence in 1960. There is no such single organization for insecticides, fungicides or nematicides, but many of the crop research stations have sections devoted to these topics.

When the Weed Research Organization became a separate entity, it did not take with it any of the basic work relevant to herbicides, which was being undertaken in Professor Blackman's laboratory as a complementary aspect of the more applied and predominantly field work.

As can be seen from the press notice of its establishment and from its first report, the Weed Research Organization has not been encouraged to concern itself with basic or fundamental studies in the weed control area. The original concept behind sanction for its establishment seems to have been that it should be concerned wholely with practical studies leading to effective control measures with an emphasis on field experimentation. In fact, there can be no clear cut boundary between basic and applied research in such areas as the behaviour of herbicides in soils, the penetration and movement of herbicides in plants and the factors influencing microbiological activity in soil. These would all be appropriate to the Weed Research Organization and act as a stimulus to other parts of the research programme there.

The ideal combination of 'basic' and 'applied' research will vary from one laboratory to another. A balance of work between field and laboratory, between applied and so-called basic or fundamental, generally gives rise in the long term, to the most efficient kind of research establishment.

I think that extremes in either direction for laboratories supported by Government to assist an Industry - in this instance agriculture - are wrong. I would no more support the advocate of 100% ad hoc work in a Government supported laboratory, than I would in my own; nor would I support the research worker in a grant-aided laboratory who said in effect "to hell with agriculture, I'm only interested in publishing in the most scientifically sophisticated journals".

Although when first introduced the hormone type weedkillers rapidly became established in the cereal growing areas, research and development in the herbicide field generally was on a smaller scale than in the insecticide field. More recently, in the last ten to fifteen years, remarkable progress has been made in chemical control compounds and methods.

In 1958 there were 10 different active ingredients in approved herbicides, in 1964 there were 34[1] and last year a further 16 were added to the range.

There are, therefore, many problems which need investigation ranging from the microbiological degradation of the herbicides to ecological studies on tolerant weeds growing in a less competitive environment. These problems provide programmes mainly undertaken in laboratories by Universities and Government stations. At this Conference two years ago, Blackman[2], whose Department at Oxford has made noteable contributions both from laboratory and field, reported upon studies which suggested a new hypothesis for the mode of action of 2,4-D and related compounds in plants.

Audus[3], general editor of the book "The Physiology and Biochemistry of Herbicides", records a number of studies of the microbial breakdown of herbicides, in which field he was himself a pioneer with investigations on 2,4-D and MCPA.

Moving finally to the last question of the desirability or otherwise of establishing a Government or Industry-sponsored testing scheme as a basis for the official control of herbicides, my answer is an emphatic NO. Such a scheme may sound wonderful in theory, but I am against it because:-

(i) It would cost either the ratepayer or Industry a lot of money both in capital investment and operating costs to establish such a facility. Its establishment could, therefore, only be achieved by additional taxes or price increases in herbicides. In the country's present economic position such a venture would be unrealistic.

(ii) From technical considerations I think such a testing station is unnecessary.

When Industry has developed a compound to a stage when it has to decide whether or not to go ahead, it doesn't make the decision lightly, because an expensive time is ahead in the development of the candidate compound.

During this development period it is usual for Industry to pass to interested laboratories, such as the Weed Research Organization, samples for experimental work, if they desire them.

At a later stage, all the data relevant to the compound go to the inter-departmental committee for notification and, if there are no further problems, the compound goes on the market, often with official approval under the Ministry of Agriculture's Voluntary Approval Scheme. In my view the Approval Scheme is an essential part of marketing of pesticides with many more advantages than disadvantages.

During this early marketing period, Ministry staff in the N.A.A.S. and research workers in the grant-aided laboratories are able to assess the product in use under field conditions and advise officials as to the efficacy or otherwise of the performance of the compound under practical farm conditions. The Approval Committee can then take the appropriate action.

All the necessary safeguards to the user and the public seem to me to be present, except perhaps for any loopholes which could arise because the Approval Scheme is voluntary.

It is unlikely that any of the companies able to carry out research on the scale that is required to discover and develop new compounds would market them without going through the Voluntary Approval procedure. If it were thought in official circles that there could be dangers arising from the sale of an imported product, which did not go through the Scheme's machinery, it should be relatively easy to convert the present voluntary procedure into a compulsory scheme. Industry, through the Association of British Manufacturers of Agricultural Chemicals would support such an arrangement, not only for herbicides, but for all pesticides.

(iii) My third reason for being against the proposed testing station is that in order to provide for it financially, particularly in the current, critical economic conditions, an organization like the Weed Research Organization might have its terms of reference altered and be relegated to a routine testing establishment and thus be even further removed from the field and laboratory research, which I am sure we all feel are necessary for maintaining the efficiency of both the Weed Research Organization in particular, and agriculture in general.

(iv) My fourth reason is that if an official testing station for herbicides were to be established there is no reason why the next step would not be the establishment of a body to confirm the toxicological aspects of the new compound. This would lead not only to additional extremely high capital and operating costs, but would inevitably lead to unnecessary delays in marketing compounds for which the relevant data are already available. I know this places a great responsibility and great expense on Industry for they must produce toxicological data that satisfy official specialists.

It will be seen, therefore, that, subject to the minor modifications I have implied, I am reasonably satisfied that the existing efforts of research on herbicides in Universities, Government-sponsored centres and industrial organizations, between them, cover most of what is required. It would be unrealistic to imagine that at all times all the problems will be solved by the time the answers are wanted. However, in the existing arrangements there is enough flexibility for considerable manoeuvre to obtain what is wanted, provided the requirements are clearly indicated and those in a position to support the research effort financially do so in clear, definite terms.

I do see possible difficulties which, perhaps, could be ventilated in the discussion:-

(i) in dealing with a relatively small but locally important market, and

(ii) in dealing with the product discovered by a small firm or laboratory without the resources to deal with the extensive, costly toxicological and residue work necessary to establish the product on the market,

but in my view such occurrences are unlikely to be numerous.

Clearly any compound from whatever source has to be supported by data on performance, toxicology and residues, which satisfy the authorities. Whereas it could be considered wrong for public money to be used to support a part of a particular industry, unless the money could be recovered, it would be equally wrong for a good product, which appeared to meet a particular need, to fade out because the necessary data could not be obtained. Mr. Fryer may be dealing with this point in his talk and Dr. Cain, our Chairman, may also have some points to make on the role of the N.R.D.C.

Apart from these and the probable need for chemical producers to get together more closely with the manufacturers of machinery to develop application techniques to match the performance of some of the herbicides now available, I think most of the other problems can be dealt with by the existing organizations.

References

(1) Private communication from Dr. J.G. Davison, Ministry of Agriculture, Fisheries and Food/Weed Research Organization, October 1966.

(2) G.E. Blackman, "Some Aspects of the Mode of Action of Substituted Phenoxyacetic Acids", Proceedings of the Seventh British Weed Control Conference, vol.1, 1964, p.295.

(3) L.J. Audus, general editor of "The Physiology and Biochemistry of Herbicides", 1964, Academic Press.

DEVELOPMENT OF NEW HERBICIDES

A VIEWPOINT OF THE WEED RESEARCH ORGANISATION

J. D. Fryer

A.R.C. Weed Research Organisation, Begbroke Hill, Kidlington, Oxford.

A large part of the resources of the Weed Research Organisation (W.R.O.) is devoted to the subject under discussion this morning and in the short time available I will explain why my colleagues and I feel this is justified in spite of the very considerable efforts by Industry. While what I shall say is with reference to conditions in Britain, I believe it has relevance to other countries and hope it will also be of interest to delegates from overseas.

Although some overlap and duplication of commercial and non-commercial research and development is unavoidable, and indeed is desirable, the two are largely complimentary. It is justifiable, therefore, when considering the role of an official research team such as we have at W.R.O. to consider the limitations of Industry in developing new herbicides. By this I do not wish to imply any criticism but rather to indicate gaps which may need to be filled.

LIMITATIONS OF RESEARCH AND DEVELOPMENT BY INDUSTRY

1. Limitations imposed by facilities and staff

There are at the present time approximately 350 herbicide products approved by the Ministry of Agriculture based on no fewer than 50 different active chemicals. Some of these 350 products together with an additional number which have not been approved are based on chemicals which have been discovered and developed in the United Kingdom. Others have their origin in overseas firms which have undertaken the initial development work in the first place to permit sales in their own country. As far as their use in Britain is concerned all will have passed through the hands of one or other of approximately 16 commercial firms in this country who are either the manufacturers, or alternatively are the main agents for a product which originated overseas. It is no secret that of these firms in the United Kingdom only about half have the staff, facilities and experience needed to undertake reasonably comprehensive field investigations on new herbicides and to be able to carry out ancillary research where this is needed. Some of the smaller firms have very few facilities indeed, although they may nevertheless be able to do a first class development job on the simpler chemicals and problems.

These varied facilities and experience are one reason why the quality and quantity of development work under British conditions undertaken by the supplier and which accompanies the introduction of a new herbicide is extremely variable, ranging from comprehensive evaluation on many aspects to the bare minimum necessary to sell the product for the more easily won uses and to gain official approval - assuming that approval is sought. Evidence that this is the case can be found in the Proceedings of any Weed Control Conference.

Independent evaluation of new herbicides by non-commercial organisations such as the Weed Research Organisation, the other A.R.C. Institutes concerned, the Pea Growing Research Organisation, the Norfolk Agricultural Station and by the N.A.A.S. and others, not forgetting our friends in Scotland and N. Ireland, can assist all concerned with weed control by providing an independent assessment of the usefulness of new candidate chemicals, their probable benefits and problems, and above all by contributing to the overall knowledge available about their activity under conditions in this country.

At this point it is appropriate to comment, particularly for our overseas delegates, that the official approval scheme in the United Kingdom cannot directly contribute to this knowledge since it does not allow for any testing or evaluation by its members. I personally feel it would be a valuable step forward and helpful to all concerned if a small experimental capability was built into the scheme. By this I do not advocate the routine testing of all new herbicidal chemicals but that the scheme should be able to undertake sufficient work of its own to provide a basis for judging the adequacy and relevance of the information supplied by the trade.

It is also relevant to add that since the Advisory Service does not have permanent weed control specialists in this country, the role it can play in providing information on new herbicides, although valuable, is relatively limited.

It is clear that there are still many more new and exciting herbicides to come from Industry to benefit agriculture throughout the world. At W.R.O. we have so far examined around 150 active chemicals which are or have been under development by Industry in various parts of the world. Since the Organisation was set up in 1960, 25 - 30 new herbicidal chemicals under commercial development have been received at Begbroke each year to be included in the evaluation programme. It seems probable that the flow of new chemicals from Industry will expand rather than slow down. I say this because already W.R.O. is in touch with between 40 and 50 manufacturers of agricultural chemicals in Europe and North America who are all searching for new herbicides by synthesis and screening programmes. In Japan the chemical industry is becoming very active in this field, and the day when the first Japanese herbicide reaches this country cannot be far away. How to provide adequate evaluation of so many new chemicals looks like becoming an increasingly difficult task for the Industry which produces them.

2. Limitations of British firms in developing products from overseas

Of the many foreign firms interested in finding new herbicides, less than half are commonly known to be linked, as far as research is concerned, with British firms capable of developing in the United Kingdom any new herbicide which might be found. This position could, of course, easily change, but past experience has shown that firms, for example in the U.S.A., which have discovered and marketed a new herbicide there do not necessarily take much interest in developing it in Europe, having as their target some of the larger and nearer-to-home markets. In such cases independent research and development by W.R.O. and others is needed if growers are to be given the opportunity to enjoy the benefits of all valuable new herbicides discovered overseas.

3. Economic limitations

Dr. Galley has emphasised the high cost of herbicide development by Industry and the limitations that this imposes on the research and development which can be undertaken. A major research programme may be economically justified for an important chemical which can be sold for the large-acreage crops of the world; but what about herbicides for the more local but nationally very important crops or weed problems? Chemical firms are not generally prepared to spend a lot of time on a small market which requires the development of a specific compound. Industry clearly needs assistance here, or else the grower is going to do without - or run the risk of crop damage, or experience other problems, because of insufficient research and development. At the best he will have to make do with chemicals which have really been developed for some other purpose, unless official workers are to step in.

The N.A.A.S. do a lot to help here. Can they do more? An example to illustrate how independent evaluation can help Industry develop herbicides specially for the smaller crop is the discovery by W.R.O. of the selective use of desmetryne in Kale.

An unfavourable relationship between cost of development and probable profits can also place a brake on or practically eliminate effective research and development by Industry particularly on topics which may not appear to be directly the concern of the firm. A list of these could well include: basic investigations on mode of action and persistence; ecological studies on the effect of herbicides, including long-term effects; multi-discipline research on changes in crop husbandry and grassland management made possible by herbicide use; joint studies by biologists and engineers on the effect of application techniques on biological activity. Such research may be of great practical and economic importance to agriculture and in providing information for a public concerned about the desirability of extensive herbicide usage throughout the nation. Where for lack of funds or facilities the contribution of Industry has to be a minor one, then the ball would seem to be clearly in the court of State-aided research organisations and the Universities to organise a research programme to meet the requirements.

I have talked so far mainly with reference to this country but the principle is the same in all countries. As more and more herbicides become available the contribution of the non-commercial research worker and adviser must become increasingly important. More herbicides, more manufacturers, means greater competition bewween chemicals and a tendency towards smaller profits from a single compound. Moreover development costs seem certain to increase with the more stringent standards required by public opinion and official approval authorities. It could be argued that with so many herbicides there will be no problems left to solve but experience so far points the other way - that the research requirement increases as growers learn to rely on chemical methods of weed control and on the new and more efficient methods of crop production made possible by their use. Moreover each new herbicide brings its own problems which may be beyond the scope of the firms involved and which justify attention by non-commercial research workers.

SOME QUESTIONS FOR INDUSTRY

At this point, I should like to digress briefly and to ask my friends in Industry a few questions which appear relevant at the present time:-

1. Are we getting too many new herbicides put forward by Industry as of potential value? Is this leading to the available research effort both by Industry and by non-commercial organisations being spread too thinly over too many compounds?

2. Allied to this is the question, 'What is the right stage of development at which a new herbicide should be passed to non-commercial organisations for inclusion in their research programmes?' There is a considerable variation in current practise at present and also in the information supplied in the data sheets on new products. Some standardization of data sheets and an acceptance by Industry of miminal standards of information contained in them would be of great assistance to the majority of co-operators.

3. Are the right compounds coming out of the screening programmes by commercial firms? Are the screens too unimaginative, constructed only to find chemicals showing the same types of activity as those with which we are familiar and hence missing compounds which produce completely different types of effects on plants which could be utilised in the fight against weeds, for example, the breaking of bud dormancy? Are the screens directed too much at conventional agricultural

uses with too little attention paid to finding new herbicides for aquatic weed control, total weed control, woody plant control and so on?

4. Does Industry do as much as it could to provide certain types of much wanted information? For example Industry has the best facilities for the analysis of residues and these are used primarily for crop residue studies asked for in connection with the Pesticides Safety Precaution Scheme. Are they used enough to provide data on the residues of herbicides in soils? If so then very little information has been released. Do firms provide enough information about consequences of mis-use, for example, on symptoms on susceptible plants, or about resistant crops to sow on fields known to contain significant residues?

Finally is Industry prepared to face up to the problem of mixtures of active chemicals even though the individual components may have to come from competing firms?

THE PROBLEM IN DEVELOPING COUNTRIES

In many countries, there are no official weed specialists, no approval schemes and no chemical industry. Initiative in developing new herbicides is left almost entirely to commercial agencies aided by such official agronomists and others who have an interest in weed control. The results may be very effective or pathetically inadequate. As we heard from Dr. Holm yesterday herbicides are going to have to play a role of revolutionary importance in helping to exploit the agricultural resources of developing countries. Many authorities responsible for agriculture in such countries have yet to learn that the benefits that herbicides can give will come only as a result of adequate research and advice. They cannot continue to rely, as many do at present, on commercial enterprise to accomplish all that is required. Under unsettled political and economic conditions, chemical firms who have the resources to undertake adequate development work in such countries may well be unwilling to commit their funds and their skilled technical staff when the long-term returns are clouded in doubt. In any case the job is far too large for Industry to accomplish on its own. It is essential that the specialists needed come in the long run from within the country's own agricultural service. During the coming years training of such people will be of paramount importance and will impose a considerable burden on the relatively very small number of existing weed control specialists throughout the world who are at present taking care of this enormously important new branch of agricultural science. As far as this country is concerned, Industry, universities and government agencies will need to act in partnership in meeting the requirement. Will we be able to manage it? Here in Britain we are fortunate in having a voluntary collaboration between Industry and official workers which is the envy of many other countries. This great Conference bears testimony to this and to the spirit which has inspired the British Weed Control Council since its inception. I am confident that here in Britain the partnership between the agricultural chemical industry on the one hand and state-sponsored research on the other will continue not only to meet the requirements of British agriculture in developing new herbicides but also to provide the leadership and experience in herbicide research and development which is already the urgent requirement of many countries overseas.

Discussion

Dr. J.C. Cain, National Research Development Council, in his Chairman's Remarks, said that this was a topic which is of very general interest and he was sure there would be many questions and comments to make on these two papers. Dr. Galley had expressed a "down-to-earth" point of view, taking into account the necessarily hard realities of the commercial world. Mr. Fryer, on the other hand, had reminded us that some problems may be difficult to tackle if entirely commercial attitudes are adopted.

Before throwing the two papers open for general discussion, he wished to take just a very few moments to mention the interests and activities of the organisation to which he belonged, the National Research Development Corporation (NRDC) which, he thought, could be relevant to some of the problems touched on by both speakers. He believed that a brief contribution of this type was in the mind of our organiser, Dr. B.J.Heywood, when he had asked Dr. Cain, as representing NRDC, to chair this session.

Dr. Cain said we had been considering that morning the development of new herbicides and NRDC, which is a public Corporation, is also concerned with the development of new things, operating as it does under the "Development of Inventions Acts". Its job is two-fold. Firstly the protection by patenting (wherever possible) and the subsequent exploitation of any significant British invention stemming primarily from public research (Government Laboratories and Universities), and secondly, wherever necessary, financially supporting the development of these and any other inventions, either from private individuals or industry, where the Corporation considers the public interest requires it to do so. In all such cases the intention is to transfer as early as possible the fruits of any successful development. While NRDC had an automatic right to handle the majority of Government inventions and a certain status in relation to those from the Universities, for the most part they had to wait to be asked to take an interest in those owned by private individuals and companies.

It should be made clear that in doing their development work, NRDC do not provide grants or subsidies. They are obliged, by their Acts, to operate commercially insofar as this is compatible with doing their work and therefore they function in many ways like a company, having a Managing Director and an independent Board of Directors. They earn income from the licensing of their inventions and the sale of "know-how", etc. to industry in this country and abroad, but in order, if necessary, to carry on development work at a rate in excess of current earnings they are empowered to borrow public money on which they pay interest. Under the current Act they can have outstanding borrowings at any one time of up to £25 million.

When NRDC was set up in 1949 it was viewed as providing a bridge between academic researchers and industrial users and it was envisaged that it would make its main contribution to innovation by industry through the patenting, development and exploitation of inventions coming mainly from the Government Research Laboratories and Universities and possibly also private individuals.

To date in the field of biologically-active chemicals this has proved to be so and they have, over the years, protected and licensed a number of now commercially successful products of which MCPB and 2-4,DB are representatives in the herbicide field. Where necessary, in such cases they have financially supported the applied research or early stages of development work. This has often been done in the University or Government Laboratory in which the invention was made and, as Dr. Cain's colleague, Dr. M.S. Barber, indicated on the previous day, they would be pleased to hear from University workers attending the Conference about any developments being worked on which might have potential commercial utility.

In recent years an increasing part of the Corporation's work had been concerned with what they called "joint development" with industry of industry's own inventions.

The concept here is the investment of capital by NRDC in the development phase of an innovation by industry, where for any one of a number of reasons the company may not feel able or willing to make unaided the total development investment which is required, to the extent that a piece of work which might contribute in some measure to the economy of the country, or serve the public interest is not undertaken at all or is carried out at a rate which is well below the optimum. This NRDC activity is in essence the unsecured underwriting of a part of the speculative risk in such enterprises. However, as mentioned earlier they operated commercially. If the project is a technical and commercial success their agreements with the company provide for the recovery of the Corporation's capital + interest + a profit, the level of profit being related in part to the speculative nature of the investment. On the other hand if the project fails, the Corporation accepts that its money is lost entirely and it has no call on the company for repayment. Naturally in such cases the company also loses its investment.

To date such "joint development" projects have been mainly concerned with engineering developments of a wide variety including one recently in the field of minimal cultivation with the "Sisis" Equipment Co. Ltd. of Macclesfield. They would be very willing to look at any further proposals for assistance from companies with novel ideas on equipment required in using old or new herbicides.

In principle there could be situations where the Corporation might properly join with a chemical company in sharing some of the financial risks involved in the development of specific new herbicides. Perhaps the most immediately obvious cases would be those mentioned by Dr. Galley where the herbicide could have important but nevertheless special and therefore limited uses, and those mentioned by Mr. Fryer aimed at dealing with problems in the developing countries such as the control of aquatic weeds.

While in the short time available to him it was impossible to present effectively any overall picture of the breadth of NRDC's interests and its varied methods of working, Dr. Cain hoped that he had made it clear that he felt NRDC could probably help in tackling some of the problems remaining to be solved in the herbicide area, and highlighted in the two papers delivered that morning.

Dr. B.J. Heywood, May & Baker Ltd., said that a vital question in the search for a new herbicide is the chance of finding a useful compound. How many compounds must be synthesised and tested before a winner is found? Curiously, a similar chance of of success prevails in a number of other screening programmes for biological activities, e.g.,

Drugs	40 marketed out of 114,600 (one in 3,000)
Acaricides	One in 2000-3000 compounds examined
Pyridazinone herbicides	One in over 2000 " "
Urea herbicides	One in over 3000 " "

The chance of finding a winner is thus about one in 3000. A large item of cost in the development of a new herbicide is the 2999 compounds which are rejected. Over eight years ago Dr. Wellman of the Union Carbide Company summarised the screening of fungicides as follows:-

Initial screening	1 in 45 succeed
Further laboratory and greenhouse work	1 in 20 succeed
Initial field tests	1 in 3 succeed
Company development	1 in 2 succeed
Overall chance	1 in 5400 succeed

The search for fungicides is very similar to that for herbicides. Incidentally, the cost of development, without the analytical and toxicological work, was about £500,000 - a figure in close agreement with the up-to-date figure given by Dr. Galley.

Dr. E.K. Woodford, Grassland Research Institute, commented on Dr. Galley's satisfaction with the position as it existed - he disagreed with him and suggested there is need to think about change. Several suggestions had already been made as to methods of improving the Country's research service. Dr. Shaw suggested yesterday morning that there should be close collaboration between economists and research workers. With this Dr. Woodford wholeheartedly agreed, but he was taken back when Dr. Shaw went on to say that economists should be stationed at Research Institutes to suggest the sort of treatment the experimenters should include in their field trials. Surely the function of a scientist is to determine principles and the biological efficiency of herbicides so that the economic data can be added later when the herbicide is ready for sale. Neither Dr. Galley nor Mr. Fryer had mentioned the economic aspects of herbicide evaluation. Where did they consider economic assessment fitted into the scheme as far as the State Service was concerned? Dr. Galley had suggested that one of the functions of the Research Service was to take over the evaluation programme where Industry left off. Was this not asking rather a lot? Such work is of a routine nature and not the sort of work normally undertaken by Research Organisations. Would it not be a much better arrangement if such work was undertaken in a separate branch of the W.R.O. and sponsored by Industry? Small firms and foreign firms, as well as all the others, would thus be able to pay to have their herbicides tested. If such a scheme was in operation the W.R.O. would not have the invidious task of trying to decide which herbicides to evaluate with their limited facilities. Such sponsored research and evaluation is undertaken by the N.I.A.E. and the N.I.A.B. Would Industry be prepared to co-operate in such a scheme?

Dr. Galley said that the grant aided research institutes are there to assist different parts of the agricultural industry; therefore, the problems of this industry are also the problems of the agricultural research institutes. Specialists in these institutes are far better equipped to deal with some of the detail of this research than is industry, which has to cover a wider field at home and overseas more broadly. Clearly the research institutes have many other problems to deal with, as well as those of weed control. If weed control is an important problem in the field covered by the research institute it falls, in his view, within the terms of reference of the research institute and should, therefore, receive attention by it.

Mr. I.E. Darter, Plant Protection Ltd., commented that Dr. Galley and Dr. Heywood both stressed the cost aspect of industrial research into herbicides - a cost which is continually rising. He was particularly interested in Dr. Galley's reference to the question of looking ahead to what the future weed problems are going to be. A compound which shows herbicidal activity in a primary screening test today will not come on the market until 1973, even if its development proceeds smoothly. If it has a life of ten hears, as suggested by Dr. Galley, it has to remain useful in agriculture or horticulture at least until 1983, and we would hope for a longer life than this. So our present screening and research should be trying to take account of what the problems will be in the 1980's. We would welcome any attempt which could be made to try to predict what the situation will be, or to try to throw up novel ideas concerning herbicides and growth regulators. This is a field where universities, crop research stations and government departments could make a very useful contribution which companies like Dr. Galley's and Mr. Darter's own, could use for guidance, so that our research is aimed in the right direction.

Dr. P.A. Gabbott, Shell Research, suggested that not enough thought was given to the results of screening of compounds. New tests should be developed which were designed to meet future needs and not the old problems.

Dr. Heywood thought that screening should perhaps be directed towards short- and long-term objectives. The short-term being the conventional screen concerned with the direct control of weeds in crops. The long-term screen would be more sophisticated, designed to answer the weed problems ten years ahead.

Mr. Fryer, commenting on Dr. Gabbott's remarks, said that it occurred to him that many compounds were now back on the shelves of chemical firms which had been rejected by the results of the rather crude screening tests which were commonplace ten years ago. It may well be that a re-examination of such compounds using the more refined tests now developed by industry would be worthwhile, and would bring to light very interesting new herbicides as judged by present day standards and requirements.

Dr. J.G. Davison, Weed Research Organisation, felt that it was reassuring to know how much money is spent in the development of new herbicides, but disappointing that, after all this money has been spent, there were still many aspects affecting its commercial use not fully investigated. This is particularly so since final field evaluation represents a relatively small amount of the overall development cost. Whilst there is generally good liaison between manufacturers and the Approval Organisation, it would be wrong to imagine that all firms enter into the spirit of the Scheme as agreed by the Ministry and ABMAC, and it must be remembered that there are firms outside ABMAC. Whilst he agreed that there is no need for a compulsory scheme or an official testing organisation similar to those in other countries, an organisation which is unable to undertake experimental work is at a considerable disadvantage. Since we are dependent on information supplied by Industry, we have no means of knowing if any information has been withheld. If Industry wishes to support a voluntary Approval Scheme, it should ensure that the organisation should have the necessary resources to enable it to provide the standards expected by both manufacturers and users.

Dr. Galley, replying to Dr. Davison, said information would be welcome as to how to make the final detailed field evaluation stage a cheap process. It is, in fact, quite a costly one. He was disappointed to learn that the spirit of the scheme is not always entered into. He did not think that reputable manufacturers would be likely to withhold information, quite apart from the fact that it would not be in their interest to do so. He thought all the safeguards that are necessary to support a voluntary approval scheme are there and that the research institutes, including the W.R.O. and the National Agricultural Advisory Service, should make it possible to maintain the standards expected by all concerned in agriculture.

Mr. A.L. Abel, Fisons Pest Control Ltd., in taking up two of the questions Mr. Fryer posed, asked what were his own thoughts behind his questions. In asking "Are too many new herbicides being introduced", did he feel that individual companies were not selective enough in choosing the materials they introduced, or did he feel that industry in general was introducing too many potential products? Secondly, in asking "What is the right stage for passing compounds to non-commercial organisation" what did he himself consider to be the right stage. Once a company has established its patents position, there are a number of stages at any of which one could consider passing the product to organisations such as the W.R.O. He would make a plea that such organisations do not undertake work of a development nature without first establishing that the company intends to commercialise the product, so as to avoid possible irritation and frustration which could prejudice the necessary close collaboration between commercial companies and non-industrial organisations.

Mr. Fryer, replying to Mr. Abel, said that some herbicides (both active ingredients and formulated mixtures) have been introduced into this country which have no clear technical or economic advantages in comparison with existing materials. These result in more work for everyone without aiding productivity and it is obviously desirable that consideration should be given to this problem by Industry before any decision is taken to market a new product.

In referring to the optimum stage for Industry to pass on new compounds for testing by non-commercial organisations, he was not thinking of the W.R.O. or other advanced research teams which welcome notification of new products at the earliest possible stage in their development. He had in mind the problem of the agronomist or adviser, who is not a herbicide specialist, receiving samples of new products from the Trade often with little relevant information about their action. In such cases a valuable new chemical may show up poorly because the experimental work has not been done properly. Misleading results are obtained and time is wasted.

The discussion was terminated at this point by the Chairman because of lack of time.

Discussion

Dr. K. Holly asked whether the new CIBA herbicides had been compared directly with existing compounds having a similar action, for example linuron for use on carrots and legumes. Mr. H. Green replied that such trials have been carried out but that he did not have the details available.

Dr. E. Nikles commented that it is wellknown that azides of nitrogen-containing heterocycles may in reality be tetrazoles. He wondered whether this is the case with WL 9385; also what are the products of photodecomposition of the compound. Dr. P. A. Gabbott replied that the I.R. spectrum of WL 9385 indicated that the structure is not that of a tetrazole but of a 2-azido-s-triazine, as indicated in their paper. Continuing, Dr. Gabbott said that WL 9385 decomposed under both ultra-violet and daylight irradiation. The products were mainly high molecular weight compounds resulting from the polymerisation of two or more triazine nuclei presumably formed by a free radical mechanism. In addition traces of the 2-amino compound were found, presumably formed by reduction of the free radical.

In reply to a question from Dr. B. J. Heywood as to whether the performance of SD 11831 was known under European conditions, Mr. P. H. Rosher said that SD 11831 had been fairly widely tested in the United Kingdom and a number of countries in Europe. As in America they had found that field performance was dependant on soil type. Further work was planned in those areas where light soils and suitable crops suggested that results were likely to be most promising, particularly with regard to the control of annual grass weeds.

Dr. R. H. Schieferstein replying to a question from Dr. E. C. S. Little said that he hoped SD 11831 would have a useful role in cotton in comparison with trifluralin.

Dr. M. H. B. Hayes commenting on the paper by Dr. Furness, explained that a considerable amount of work had been done by Weiss on the interlattice adsorption of diamines by montmorillonite clays. The extent of the lattice expansion had depended on the concentration of the diamine and the length of the hydrocarbon chain in the diamine. He wondered if there was any experimental evidence to show that herbicides formulated with oleylpropylenediamine are trapped in the expanding lattice structures of some clays. Dr. N. Furness replied that the oleylpropylenediamine salts of both mecoprop and dicamba were adsorbed strongly by organic humus in soil and to a lesser extent by sand. There was no direct evidence to show how the salts were adsorbed on montmorillonite clays, but it was known that the degree of adsorption on china clay, for example, was very small.

Mr. H. J. Terry asked Dr. Pfeiffer whether chlorflurazole and chlorflurazole + MCPA was really more active in the United Kingdom than in Canada, and if so whether the explanation lay in differences in weed populations. Dr. R. K. Pfeiffer said that it was difficult to compare the performance in the Canadian trials with that in the United Kingdom trials in absolute terms. It appeared, however, that the all round activity in Canada was slightly lower because of the dominating importance of weeds of the *Polygonum* group in Canada. These species were slightly less susceptible than the majority of other annual broad-leaved weeds. Bromoxynil which was included as a standard proved particularly effective against *Polygonum* species and was in this respect superior to chlorflurazole. On the other hand chlorflurazole was very much superior to bromoxynil on *Spergula arvensis* and *Stellaria media* in the Canadian Prairies.

Mr. J. Holroyd asked whether Mr. Smith and Dr. Schwer could clarify whether in their paper they referred to the depth of incorporation of the herbicide in the soil, or to the depth to which the implements were working. Dr. J. S. Schwer said it was the latter, as he considered this more easily understood by farmers and because the actual depth of incorporation achieved by a given implement varied a great deal under different soil conditions.

In reply to a question from Mr. H. J. Terry, Mr. J. Holroyd speaking on the paper by Holly et al. said that in field trials CP 31675 had given results on potatoes that were comparable with those obtained with linuron.

SESSION VII A - SUGAR BEET AND FODDER CROPS

Discussion

Mr. N.B. Joy (du Pont) asked M. Detroux whether post-emergent trials had been carried out with lenacil plus surfactant, as they had found that the addition of surfactant increased the leaf uptake of lenacil, resulting in much better weed control in post-emergent treatments.

M. Detroux (Gembloux) replied that in these experiments surfactants had not been used, but in other experiments they had been and had given good results.

Mr. Rose (British Sugar Corporation) asked Ir. de Bruin whether he felt that the use of herbicides obviated the need for manual cultivation, and whether he had experimental evidence that this was not detrimental to beet.

Ir. de Bruin replied that there had been trials in the Netherlands with shallow mechanical treatment, and with no treatment at all. No differences had been observed on various soil types, but soil structure had to be in good condition.

Mr. North (NAAS, Cambridge) asked how mechanical harvesting was affected by irregular plants resulting from thinning of crops due to herbicides. He said that experience suggested that in the field efficiency was reduced.

Mr. Bond (British Sugar Corporation) said that the question came back to the degree of irregularity. They had grown very large acreages of the crop and where treated with herbicides the results with the harvesters were inferior to cultivated methods of weed control. He felt that perhaps they could overcome this by using lower dosage rates and accepting a limited number of weeds in the crop.

Mr. Rose then asked the Belgians about post-emergent sprays. Had these reached a commercial stage in Belgium?

M. Detroux replied that this varied from area to area, but about 20% of the total acreage was treated post-emergence.

Mr. Elliot, (NIAB, Cambridge) asked if there was yet any reliable evidence on interaction of herbicides with different varieties of sugar beet, and also could the variety of sugar beet in the conference papers be named.

Mr. Rose replied to the second part of the question, saying he was sure this could be done in future.

Mr. Lush (Boots) replied to Mr. Elliot's question by saying that over the years they had, with the collaboration of various sugar beet breeders, compared many sugar beet varieties in trials with Pyrazon and had never found any varietal differences.

Mr. Rose went on to say that they had taken this up with the Americans and there was a suggestion of susceptible varieties in the early days, but they had heard nothing recently.

Mr. Allott, (Ministry of Agriculture, Northern Ireland) said that in varietal trials at Loughall over the past two years, overall treatment of Pyrazon and lenacil had not shown any differential varietal susceptibility, but no critical assessment of this aspect had been attempted.

Mr. Rose remarked that at Loughall Mr. Allott had come out in favour of incorporation - and asked whether he considered this was desirable.

Mr. Allott replied that whilst it would seem in trials at Loughall that some advantage was to be gained by incorporation on some soil types, the benefits from this were not as yet well defined, and it would seem that this was only likely to be a possibility where overall applications were given, as distinct from band application. Incorporation also added another operation which could increase the overall cost.

Mr. Bray (Norfolk Agricultural Station) replied to the question of the use of soil incorporation by saying that from trials at the Norfolk Agricultural Station over the past few years, applications made early in the season never seemed to give them a definite answer. By a specialised time of drilling investigation and screening of the soil, incorporation after application of Pyrazon and lenacil had shown that from March drilling there was little to choose between soil incorporation and surface application; as drilling progressed into the season soil incorporation of the herbicide gradually became superior to surface application and by May surface application, in some instances, showed no activity at all. However, the activity of soil incorporation late in the year did not reach the efficiency given by either soil incorporation or surface application early in the season.

Replying to the question of varietal susceptibility, Mr. Bray said he had no evidence of this and specialised trials could be conducted on different varieties in the field. In addition, B.S.C. records could be examined where instances of herbicide damage had occurred and the correlation between this and variety calculated.

M. Gautier, (du Pont, France) said that soil incorporation of Venzar in sugar beet was recommended in France as the main technique in 1966 and excellent results had been obtained as far as selectivity and efficiency were concerned. The incorporation could be carried out by means of a spike harrow incorporated to a depth of 2 - 3", and the same overall application with incorporation avoided band spraying and minimised possible mistakes in the dosage rate.

Mr. Rose asked Mr. Everest Todd about the granular herbicide formulation. Did this go into the soil or remain on top - and what about birds?

Mr. Everest Todd (Mirvale Chemical Co.) said this formulation did not kill birds. They are suffering from the same sort of hazards as with liquid application, but by using a very rapidly decomposing granule, it goes into the soil very quickly.

Mr. Allott asked if any critical experiments had been conducted in relation to methods of incorporation.

Mr. George Cussans, (W.R.O.) said that the answer to this specific question was 'No' although they could refer to work done with other chemicals.

Mr. Lush replied to Mr. Allott's question regarding implements for incorporation advising that they had found that a straight toothed harrow penetrating the soil to the same depth as the distance apart of the tines (allowing for the stagger) gave them the most reliable incorporation.

PHYSICS OF FOLIAR APPLICATION IN RELATION TO FORMULATION

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Herbicide molecules, to be effective, must travel from solution or suspension within the supply tank to the sites of vital biochemical mechanisms within the plant. The latter may be localised within particular organs and often within specialised organelles within the plant cells. The whole sequence of processes starts out as a mechanical one involving fairly small particles and subject to some control by formulator, machine designer and spray operator, but finishes with the transport of separate molecules at great dilution by passive diffusion or active physiological processes.

By and large, the further the molecule has moved along its complex path the less is known about the processes involved, because plant physiology is an inherently more complex subject than external physics. By and large, also, the less are the processes subject to predictable influence by mechanical physics - i.e. by formulation or machine design. The physics of formulation is concerned with the modification of properties - surface tension, viscosity, solvent action - of matter in bulk, albeit very small bulk, while, when the active ingredient molecules get near their site of action, at a concentration of probably less than 1 part per million of wet tissue, any wetting agents or other spray adjuvants will be similarly diluted and exert negligible effect among the far more numerous molecules native to the plant's vital processes. One can only expect specific biochemical, not generalised physical, activity to occur at this level.

Physical formulation devices may therefore influence the efficiency of the earlier, more external, steps of the total process but are unlikely to help in the later, more internal steps. This is not to say that these later steps may not be influenced by adjuvants to the spray, but rather that such influence must be via influence on the physiology of the plant: it reveals itself as a true synergism.

In what might be called "chemical formulation" we apply a chemical progenitor of the active molecule. This will have different partition and solubility properties and be subject to different transport mechanisms. The effect of this may persist into the later stages of the sequence, according to how quickly the progenitor is converted to the active molecule. The use of an ester of an active acid is the most common example.

One very justifiable object of close study of the totality of the transport process is to see which of the successive steps are the limiting ones. There would be no point in attempting to improve systemic properties by adjuvants intended to accelerate cuticle penetration if the active compound is not translocated after penetration. There would be no point in attempting to accelerate phlœm transport by physiologically active adjuvants, if the spray is totally reflected from the leaf surface. These are obvious examples. There is no doubt that more subtle ones could be revealed. There has, however, been little attempt to study the totality of the transport process in typical cases, although many ingenious and scholarly studies have been made of particular sections of it. The decision by the organisers of this Conference to devote a special session to the subject is therefore very much to be welcomed.

I shall confine my remarks as far as practicable to the external physics of the application - penetration - translocation complex, Dr. Sargent having the more difficult task of dealing with the physiological processes. It is not, however, practicable to get very far by adding up, as it were, physical studies which assume the plant to be inanimate and physiological studies which take the external physics for granted. There is too much interaction. On the face of it, the physicist should have an easier job than the physiologist, but the trouble, as I see it, with the development of this subject in the past, is that the physicist as such is not attracted to it and tends, when introduced, to be too non-biological in outlook, while the physiologist, aware of the very complex behaviour of the growing plant, tends to assume the external physics to be simpler than it really is.

SPRAY RETENTION

In application to foliage by spray, the first phenomenon encountered on those species having the characteristic surface appearance known as "bloom" e.g. the fruit of the plum and the leaf of the pea, is that water drops of above about 100μ diameter, unless the surface tension is reduced below about 40 dynes/cm., are totally reflected from this surface. Spray must, of course, be accepted and retained on the leaves if physiological action via the leaf is to follow.

Many leaf surfaces, e.g. nettle, lettuce, bean, will accept any water drop impinging. Spreading, even of pure water, may be nearly complete or may require the addition of a wetting agent to make it so. The amount of spray retained in low volume spraying is mainly determined by efficiency of reflection, if it occurs. The amount retained in high volume spraying is also influenced by fusion of received drops and run-off, which are affected by the nature and posture of the leaf surface, surface tension and viscosity of the spray liquor and the drying power of the atmosphere.

The phenomenon of droplet reflection has been considered from the physical point of view by Hartley and Brunskill (1958) and in its agricultural significance by Pfeiffer et al. (1959) (both with earlier references) and included among other factors in a comprehensive study by Blackman et al (1957) of spray retention in relation to species and spray variables. The pure rheology of drainage from smooth and rough surfaces has been examined by Bikerman (1959) and the influence on it of surfactants and evaporation by Stanley and Radley (1960). The spread of accepted droplets on leaf surfaces, their fusion and run-off have been studied by many workers over a long period, particularly closely by Furmidge in a recent series of papers (1962,1964,1965).

It would be impossible in the time available to summarise all this work effectively. All I will attempt now is comment on some aspects often overlooked.

Spraying at so high a volume (ca. 50 gals/acre and above) that continuous wetting and drainage from leaves as a whole results is hardly ever carried out in weed control practice. The dynamic aspects of drainage are, however, important when even a single drop moves down a steeply inclined leaf surface. Does the sliding drop leave any smear of liquid? If the receding as well as the advancing contact angle is finite, it does not. If the receding angle is zero one is inclined to assume that a permanent smear track must be left, but this, if true, is not due to zero contact angle as such but to other phenomena difficult to separate from it experimentally.

I have drawn attention elsewhere (1966) to the fact that the upper edge of a drainage residue on a vertical plate of a pure liquid making zero contact angle is still finite. A thin film of liquid may still exist above this edge, but only because the thin film has different properties from the bulk or speed of drainage is very slow. The absolute rate of thinning by drainage at any one level is proportional to the third power of the residual thickness at that level. When the thickness of a water film has fallen to about 5μ, its rate of thinning by drainage is about comparable with its rate of thinning by evaporation under normal conditions. For thinner films evaporation will be far more important and will lead to secondary effects - increase of concentration of less volatile components, leading to increased viscosity and deposition of solids.

If a surfactant is present, one result of evaporation could be decrease of surface tension in the film which would lead to the free surface being pulled towards the thicker region and so accelerate drainage. Such acceleration has been reported by Somers (1957) and is opposed to the effect of solid deposition or increase of viscosity. The form and area of the residue left by a draining and drying drop is therefore determined by a balance of opposing factors and it may be possible to exert more useful control over it than has so far been attempted.

Despite wide variation in retention, little use seems to have been made in practice of changes in formulation and spraying technique designed to exploit this variation. A good reason for this is that plant surfaces are considerably modified by environmental history so that successful "finesse" in practice requires more knowledge, skill and luck than can normally be devoted to it. Only "extreme" recommendations have received approval, such as the non-use of wetting agents in dinoseb formulations for use on peas and avoidance of the use of dinoseb on a weather-beaten crop.

It must also be noted that economics dictates the use of the lowest practicable spray volume and that most herbicide operations can be successfully carried out at 20 gal/acre or less. At these volumes, under normal conditions of evaporation, a water spray does not attain the run-off level. We must remember, however, that the lower the volume used the more practicable is it to replace water by other liquids. Run-off of a low volatile, low surface-tension liquid would occur at much lower volume per acre if absorption did not occur first.

On a question of terminology, it is a pity that so many different processes are brought, without differentiation, under the heading of "retention". Droplets are first accepted or reflected, the accepted drops then spread to varying extent and may fuse, large drops formed by fusion may run off or a completely spread film may drain off. Both the proportion of spray retained somewhere and the relative densities of residue on different parts of the plant can be influenced by these largely distinct processes.

PENETRATION

In order to gain access to the living tissues of the plant, the applied compound must penetrate the cuticle or the protoplasmic channels which pass through it. Despite its accessibility, less seems to be known about the cuticle than about some of the internal cells. One may note that a similar apparent paradox is evident in the study of animals. The dermatologist is often more completely baffled than other hospital specialists who are concerned with less accessible organs. In both plants and animals the skin has to have the potentiality of rather complex behaviour because it has to protect the internal tissues from the effect of variations in the environment; this protective function is all the more important for a plant which, unlike the mobile animal, cannot retreat from adverse climatic situations.

Even the chemical nature of the cuticle is not completely agreed. The view of Lee and Priestley (1924) that it is formed by oxygen-induced polymerisation of unsaturated oils, excreted by the epidermal cells, is still supported (see for example Schieferstein and Loomis, 1959) although the earlier view of Fremy (1859) that the structure is held together by hydrolysable ester links, elaborated by Matic (1956) and Martin et al. (1958/59) is now more widely held. Probably both mechanisms contribute and have different relative importance in different species.

The cuticle is predominantly paraffinic in chemical composition, i.e. H atoms are about twice as numerous as C atoms. O is the only other element inextracticably present. Hydrolysis yields mainly poly-hydroxylated fatty acids of about 18 atom chain length. Hydroxy fatty acids alone could make only linear polymers by condensation and these would be soluble in suitable solvents. There is no doubt, however, that the cuticle fabric is highly cross-linked as it is completely insoluble in all liquids if there is no chemical attack. The cross-linkage could be brought about by unsaturation in the component monomers or by the incorporation of di-carboxylic acids, of which suberic is known to be present, particularly in "suberised" old tissue. The cutin layer is cemented onto the more or less continuous outer cellulose walls of the epidermal cells by a layer of pectin, and isolation of the cuticle is achieved by solution of the pectin in oxalate solution, ethanolamine or enzyme preparations.

The insoluble cutin is associated in its native state with various soluble oils and waxes. Although botanists have generally been very keen to coin new words of Latin or Greek origin for a host of special organs and attributes, they have left the Teutonic "wax" alone in all its vagueness to enable authors to confuse themselves and one another. In the use of beeswax in a honey-comb, of sealing-wax on a letter, of hard vegetable waxes to take the fine detail of master gramaphone records and of softer waxes to polish furniture, one is selecting preferred extreme combinations of the same set of properties. When the pesticide chemist talks about waxy leaves reflecting spray, waxy leaves absorbing pesticides and oil solvents penetrating wax barriers he is not talking about waxes which are even remotely the same in physical properties. A richer and more respectable - or at least, more respected - vocabulary would help.

The first barrier, where it exists, is the reflective one created by upstanding acicular crystals. These are formed of compounds chemically similar to those spread over or embedded in the cuticle, but the reflective property is mainly due to their geometry. This barrier can be overcome by addition of adequate wetting agent to the spray. It is no barrier to molecular diffusion of gases or, when wetted, of liquids.

These crystalline wax extrusions are composed of straight-chain saturated paraffins of about 29 - 35 C atoms (nearly all with odd number only of C atoms), ketones or secondary alcohols (also odd) and primary alcohols (even). More highly substituted paraffins and esters of long saturated alcohols and acids may occasionally be present.

Wax of the same kind chemically, if spread to a smooth layer, has no reflective properties at all, but may limit the spread of an accepted droplet. There is no evidence that such a layer, which could not be a perfectly continuous one at the molecular level, is a significant barrier to penetration. Similar waxes are known to occur embedded wholly within the cuticle (Frey-Wyssling, 1953). In this situation, they may significantly increase the resistance of the cuticle to the diffusion of applied substances, (van Overbeek, 1956). In many structures and coatings, both artificial and natural, the use of two complementary phases, one filling the imperfections of the other, often greatly reduces permeability. Darlington and Barry (1965) found that prolonged soaking of isolated apricot leaf cuticle in chloroform considerably increased its permeability to isopropylchloro-acetamide and they attributed this effect to removal of the embedded crystalline wax.

Such an effect of a wax solvent in a spray is quite out of the question. The solubility of the most soluble crystallene wax components in the best solvents is only around 5%. A layer of solvent more than 2μ thick (20 lb/acre) would be necessary to dissolve wax only 0·1μ thick and any such wax enclosed within the cuticle must find its way out. A solvent oil could perhaps in theory "bore a hole" through the soluble parts of the composite cuticle if it could be held in sufficient depth without spreading, if it were sufficiently involatile to remain long enough and sufficiently rapidly diffusing to penetrate fast enough - a collection of incompatibles, making the suggestion very theoretical.

There is no question of the applied substance dissolving, at low concentration, in the crystalline wax obstructions. The crystalline wax must be dissolved, to dilute solution, or remain. Other materials of an oily liquid nature are, however found in and on the cuticles of many leaves. Chemically they may be not far away from the waxes, but with double bonds present or more substituent groups. Physically they could play a very different part because they are liquid. They could dissolve the applied substance and help retain it in the non-vital part of the leaf, or they could provide a pathway for its penetration - two partly conflicting properties. These substances may well be incomplete cutin, the molecules being available for cross-linkage to form the final insoluble film.

One could expect, by analogy with man-made polymer films - which cutin perhaps resembles more than it does organised skeletal tissue, because it is made by external inanimate chemical reaction - that the cutin may be greatly influenced in penetrability by the presence of auxilliary solvents. Many compatible dyestuffs, for example, will not stain unplasticised cellulose acetate even on prolonged contact in water but can be taken up into plasticised film. They are taken up much more rapidly if presented in solution in methanol, a liquid of low molecular weight which can also swell the film appreciably.

I know of no clear evidence that permeability of plant cuticle as such is capable of modification by the use of auxilliary solvents or plasticines. The observations of Darlington and Barry (1965) could perhaps be explained this way, but soaking detached cuticle for 4 hours in chloroform is a long way from spraying practice. It is possible that some of the favourable effects of wetting agents in high concentration (see below) may be due to a swelling effect.

Such evidence as is available on the permeability of isolated cuticle indicates that it is a very good film indeed. Schieferstein and Loomis (1959) measured the diffusion of water vapour through the isolated 2μ thick cuticle from the stomata-free upper surface of Hedera helix leaves. The resistance, despite the presence of -OH groups in cuticle, is about the same as that of good quality polythene wrapping film, when allowance is made for thickness. The resistance is about 4×10^5 times greater than that of a similar thickness of stagnant air. The resistance to diffusion of 2,4-D (Na Salt) in aqueous solution through isolated Hedera cuticle from a leaf in early maturity was only about 7×10^4 times as great as that of a similar thickness of stagnant water. Had both the water and 2,4-D been diffusing through similar micro-cracks, greater resistance would have been offered to 2,4-D. In the water-permeation experiment the cuticle was not in contact with liquid water, while in the 2,4-D permeation it was immersed. If the cuticle is appreciably swollen by water, this would facilitate diffusion of a water-soluble substance.

The 2,4-D penetration was considerably lower in 2 and 3 year old leaves. Data was also obtained for the lag-time elapsed before penetration was first detectable. This gives us another measure of the complex diffusion coefficient and leaves no doubt that 2,4-D is accumulated in the cuticle to a higher concentration than in the ambient water. Its mobility must therefore be much restricted as compared with that in water. One is dealing with diffusion among the macromolecular segments - not diffusion through micro-cracks. It is not certain from these experiments whether the 2,4-D is dissolved in the cuticle as the free acid or as the salt. Sargent and Blackman (1962) observed that penetration rate increased with decrease of pH of the external solution and concluded that penetration occurs mainly, but not exclusively, by diffusion of the free acid.

The low permeability for 2,4-D salt is consistent with the maximum values which can be derived from the work of Fernandes (1965). This author could detect no permeation of mercury or copper salts through isolated cuticle from the stomata-free adaxial surface of another evergreen, Euonymus japonicus. The permeability of isolated cuticle to 2,4-D may, however, be far from negligible. If a water layer of 100μ thickness could be maintained on the _Hedera_ leaves examined by Schieferstein and Loomis, it would lose about 7% of its 2,4-D content per hour by diffusion into the leaf if the resistance of the resident cuticle were the same as that of the isolated cuticle and no other resistance was important.

It is, of course, possible that the attached cuticle is more resistant than isolated cuticle. The observations of Sargent and Blackman (1962) on discs of living _Phaseolus_ leaves, which have a thinner cuticle than _Hedera_, indicate a resistance, in the dark, at least as high. Sargent and Blackman found a greatly increased penetration when the leaves were exposed to light. From detailed observation and inference from other work they consider that penetration does not occur through the stomata themselves but rather through the ectodesmata, which occur in higher concentration in the stomatal guard cells than elsewhere and which are assumed to become more accessible when the guard cells expand to open the stomata. Fernandes (1965) demonstrated the permeability to salts of isolated cuticle from stomata-bearing leaf surfaces. In this case diffusion would occur through water-filled holes formed by the more delicate cuticle lining the stomatal cavities being torn off during stripping of the cuticle. Such permeation probably does not occur through the intact leaf because the stomatal port is not normally entered by the spray liquid and the internal cuticle is also still present.

No discussion of permeability of leaf surfaces to dissolved salts could be considered complete without reference to the undoubted, though limited, success of foliar nutrition and to the known removal of tissue salts, particularly potassium as carbonate, by rain washing. I have neither the time nor competence to undertake this comparison, but it should prevent us assuming that significant penetration of herbicides can only occur in non-ionised form.

SURFACE TENSION

Surface tension is a quantity of great importance in regard to reflection of incident drops or the spreading of accepted drops, but it is only a simple and definite property of a pure liquid. As soon as we make use of surface-active compounds to reduce the surface tension of a highly cohesive liquid, like water, the surface tension operating in any instantaneous and local situation is not necessarily that measured with rather misplaced carefulness in the laboratory. The operative value depends on history and geometry. The surface-active compound is highly concentrated in the surface where highly mutually attractive water molecules are effectively replaced by the non-polar portions of the surfactant molecules. Molecules from the bulk of the solution cannot migrate into a newly-formed surface immediately. The new surface has therefore a high tension initially which falls substantially in a time of the order of micro- or milli- seconds. During this time, however, a lot can happen to deformed drops. Conversely a drop slowly deformed will accumulate surfactant molecules in its extended surface which will now behave as though it had an abnormally low tension if given the opportunity to contract rapidly.

Dynamic aspects of surface tension of surfactant solutions are of considerable importance in break up of liquids at nozzles and reflection from surfaces. Of more importance in spreading and penetration is a direct effect of the concentration of the surfactant in the surface. An average efficient surfactant is used at low concentration and is very strongly adsorbed at the surface where it occupies an area of some 25 - 100 A^2 per molecule depending on the concentration and on size of the hydrophilic group. If we assume the molecular weight of the surfactant to be 300 (about average for widely used compounds) and its concentration to be 0·01% by weight, we can calculate that the area of surface which could be populated by _all_ the surfactant molecules from 1 cm^3 volume, at an average area of 50 A^2 each, would be 1000 cm^2. Now a droplet of 100μ diam. has an area/volume ratio of 600 cm^{-1}. In such a drop of such a solution therefore, most of the surfactant would be in the surface which it could not populate as densely as when a large volume at the full concentration can be drawn upon.

If a large volume is shattered into small drops, the tension in the greatly expanded surface must therefore increase. The same problem arises when a droplet spreads over the surface of a solid. If the surfactant is necessary to promote this spread, its action requires that it is adsorbed on the surface covered and total content of surfactant, if supplied in less than 1% concentration, is seriously depleted when the thickness of the film has fallen to a few microns. This limitation of the wetting action by surfactants is a purely quantative matter. It cannot be cured by using "very efficient" surfactants (e.g. the very expensive perfluoroalkyl compounds). It can only be cured by using more surfactant, which must now be cheap.

A difference between an aqueous solution of a surfactant and a pure liquid of the same surface tension comes into play when the liquid is called upon to spread over a surface having a geometrical component in its resistance to wetting - e.g. the rigidly-spaced hair structure of Salvinia or the sharp micro-corrugation of a "bloomed" leaf like the garden pea. Although drops of some other pure liquids, e.g. nitrobenzene and, of course, mercury, will lie, like water, on top of the fibre mat of Salvinia, most liquids of lower polarity will penetrate rapidly although their surface tension may be higher than that of a surfactant solution which will not penetrate. A very high concentration of surfactant will penetrate and it is not established whether the difference just noted, and a similar difference in advancing contact angle on pea leaves, is due to adsorption, to actual solution of surface substances or to yet another factor.

I suspect there is another factor. Only the thermal movement of small molecules is involved in the creep of a simple liquid over a sharp edge. With an aqueous solution of a surfactant, the water molecules themselves will have no tendency to creep and the surfactant molecules cannot do so without water to mobilise them. A sort of excessive politeness may stop either party from going through the door!

The analogy is worth making because there has been much discussion as to whether stomatal cavities do provide the main route of access of sprayed substances to the interior of the leaf. While many oils will rapidly flood the internal air spaces, aqueous solutions containing surfactants do not appear to do so. We shall learn from Dr. Sargent that the more rapid penetration through stomata-rich surfaces as compared with surfaces having no stomata is probably due to permeability of the associated guard cells.

It should not therefore be surprising that the effects of surfactants, except the intitial ones of eliminating reflection and promoting gross spreading, are in some degree specific. The differences may arise from differences in adsorption, in "micro-channel" wetting or in auxilliary solvent behaviour.

SOLUBILITY

The mutual solubility of two liquids, and the partitioning of a third component between two liquids, are determined by a balance of inter-molecular forces which is fairly well understood. In the solubility of a crystalline solid, another factor becomes of great importance - the efficiency with which these forces can be satisfied by the particular pattern of packing adopted in the crystal. The more satisfying is the crystal packing, the less is the tendency for molecules to pass from the crystal into solution in any solvent and, for the same reason, the higher the melting point.

When efficient crystal packing (high melting point) is responsible for very low solubility, there is little the formulator can do about it. Thus simazine has to be accepted as a substance of very low solubility. If the low solubility is a hindrance to penetration, one must make the molecule less symmetrical (e.g. atrazine) and hope that the more soluble analogue will not have lost in intrinsic toxicity.

The practice of "chemical formulation" - e.g. the use of an oil-soluble ester in place of a water soluble salt of an active acid - makes use of a solubility changed by chemical alteration of the active molecule, but the applied compound is one which can give rise to the active one in the plant tissue.

It will usually be possible, though perhaps not economic, to replace part of the carrier diluent by a better solvent for the active ingredient, but it is by no means necessary that this will increase activity. The active ingredient has got to be dissolved eventually in the plant tissues, not in our formulating solvent. If this solvent could not itself penetrate the plant cuticle, its continued presence would tend to hold back the active ingredient. If the solvent evaporated, the active ingredient might be left in crystalline or super-cooled form. If crystallisation occurs, the crystals will usually be larger than any provided in an alternative wettable powder form, and one has little, if any, control over the crystallisation process.

Even if the auxilliary solvent, like most non-ionic wetting agents, were almost involatile, and even if it were itself non-penetrating so that its presence is wholly undesirable in terms of thermo-dynamic potential, it might so greatly improve the contact between cuticle and active ingredient that the net effect could be advantageous. It is the auxilliary solvent action of wetting agents which is probably important in the increased activity found by Jansen (1964).

One meets this opposition of factors very frequently in the course of formulation studies. It would be dangerous to over-simplify the picture. An advantage is always likely to be attained at some optimum stage in the course of any changes which can be made.

The increase of solubility when an active acid is used as a soluble salt provides another example. A much more concentrated aqueous spray may be used and the concentration in the residue after evaporation may be increased still further, but not the concentration of undissociated acid molecules as such. Their concentration in the water is lowered by the presence of the salt-forming alkali and, if penetration could <u>only</u> occur by diffusion of undissociated molecules <u>as such</u>, the rate of penetration would be reduced by salt formation. On the other hand the total amount available in molecular contact with unit area of leaf would be greatly increased.

COMPETITION BETWEEN PENETRATION AND LOSS

Although penetration in ionised form certainly can occur, and although permeation of phenoxyacetic acids in non-ionised form is probably more significant, the most puzzling thing to me that emerges from penetration studies to date is the slowness of total penetration combined with a reasonably consistent response to applied dosage in the field. It seems that only a small fraction at best will have penetrated in the first half-day after spraying, and yet rain washing does not save the plant unless it occurs very soon after spraying. I can only appeal to Dr. Sargent to explain in plant physiological terms why apparently only the fraction of applied compound penetrating early is of significance.

The penetration of systemic insecticides is likely to show simpler behaviour than that of herbicides because, if the systemic insecticide is to be useful, it must not be phytotoxic. It is more likely therefore to be accepted and transported in a passive manner whereas the herbicide is likely to initiate physiological reactions which may interfere with its own transport. Again there is no possibility in the time available to make a properly documented comparison, but it seems generally accepted that the insecticides with really good systemic properties have some degree of oil solubility assisting their diffusion through the cuticle and are sufficiently water soluble for rapid translocation. In the case of demeton and its close relatives a highly oil-favourable substance is applied which is rapidly oxidised in the leaf to a water-favourable one. Despite their generally better penetration and translocation, the insecticides appear more vulnerable to rain washing than many herbicides.

Not only can rain washing provide a serious mechanism of loss, competing with transport of herbicide to the active site, but so, for many herbicides, can evaporation. There is probably no physical property of active pesticides so inadequately examined and appreciated as that of volatility. The laboratory chemist has to revise his standards of volatility very drastically when he comes into our field - and "field" is the operative word. 1 lb uniformly distributed over a smooth acre would provide a layer about 1/10th of a micron thick. If this film were deposited on an entirely clean, non-adsorbing surface and evaporation into the moving air followed the same pattern as for water, it would evaporate completely within 24 hrs. if the vapour pressure were about $1{\cdot}3 \times 10^{-4}$ mm. which is less than that of many non-ionised herbicides.

Evaporation will, of course, be retarded by solution in the oily components of the leaf surface but these represent only of the order of 0·1% of the leaf weight, i.e. an effective thickness of the order of 0·2μ. The cross-linked cutin itself, having a thickness of the order of 1 - 3μ might retain more pesticide than the oils, but this point has not been investigated. Once penetration has occurred, water, owing to its greater abundance, may be a more significant solvent, so that volatility from water solution may be more important than volatility of the pure substance.

Nothing is, of course, completely involatile. The differences between compounds are in <u>rates</u> of evaporation. Penetration, chemical reaction and fixation at physiologically active sites are competing rates. Whether evaporation loss is significant depends on the balance of these competing rates. I have attempted elsewhere (1963) to describe theoretically the sort of relationship which could be expected between toxicity and the balance of these competing rates.

The different effectiveness of various esters of bromoxynil and ioxynil, reported by Heywood (1966), were found to be related to the rates at which they are hydrolysed, enzymically, in the leaf tissues to the much less volatile, ionised, active acid. The rate of hydrolysis, relative to rate of evaporation, would probably be found even more significant. While simple esters of 2,4-D are effective herbicides, generally more effective in terms of lb/acre than the salts, equivalent esters of TBA are almost useless, despite the extreme stability and persistence of effect of TBA salts. TBA esters are hydrolysed much more slowly than esters of 2,4-D and therefore, because of competing evaporation loss, a much smaller fraction is usefully converted.

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