PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Project Approach to Crop Protection [and Discussion]

E. E. Bernet and B. Steele

Phil. Trans. R. Soc. Lond. B 1981 **295**, 199-212
doi: 10.1098/rstb.1981.0133

Phil. Trans. R. Soc. Lond. B **295**, 199–212 (1981) [199]
Printed in Great Britain

The project approach to crop protection

By E. E. Bernet
Ciba–Geigy Limited, 4002 *Basle, Switzerland*

While industry continues to discover more effective, biologically active chemicals, which are increasingly expensive and difficult to develop and market, their present use is often inefficient.

Better utilization would reduce unwanted side effects and public concern, but many problems have to be solved by ecologists, chemists, physicists, engineers and managers. Many pests are highly mobile, and their control calls for operations on a scale commensurate with their habits, not constrained by field boundaries. Such extensive pest management demands the most efficient methods of using pesticides, and therefore the integration of skills and expertise from a wide variety of disciplines. This is expensive to achieve, and brings little immediate financial reward.

The project approach to crop protection adopted by Ciba–Geigy attempts to provide such integration of skills, and examples are given to illustrate the problems faced, the experience gained and the results obtained.

1. Introduction

It is often asked why Ciba–Geigy, as a chemical company, adopted the project approach to crop protection and thereby entered the field of commercial application on a large scale. The motive has been both scientific and commercial.

Traditionally, the role of the chemical industry has been to invent, synthesize, test, develop, manufacture and market better pesticides. A chemical is marketable if it is safe to use, effective in killing pest species at commercial application rates, and sufficiently cheap to manufacture. Its performance, compared with other compounds, is tested in the field, usually by commercial companies and government extension services in small plots laid out to satisfy the accepted statistical requirements of agronomic experimentation. The resulting data, together with toxicological information, permit the authorities to consider registration of the compound for certain purposes. By registration, the authorities confirm that the chemical is effective and safe if used in a prescribed way.

In crop protection, however, pest infestation must be kept below the level that causes unacceptable damage. In the past, persistent pesticides and repeated spraying have been considered an adequate strategy. The consequences of this empirical approach have been the emergence of resistant strains of pests, exacerbation of pest problems, and public concern about environmental pollution. To avoid these problems much more information is needed on insect population dynamics, migration and ecosystems. The basic biological research is conducted largely by universities and government bodies and has been inadequately employed in commercial crop protection. It is long-term and expensive.

Various authorities, for example, Graham-Bryce (1976) and Southwood (1979), have for many years drawn attention to this unsatisfactory situation, and called for improved pest-control practice. This needs a coordinated effort from specialists in pest ecology and the pesticide industry.

The project approach represents an important contribution that industry can make to more effective crop protection and to the concept of integrated pest management (i.p.m.). The agrochemical industry cannot impose its views on farmers concerning their crop rotations, crop varieties, economic thresholds or the standard of their work, but in its projects it can develop ecological selectivity in the use of pesticides. Ecological selectivity is achieved by applying compounds, often with rather broad spectra of activity, in such a manner as to ensure contact of the toxic dose with the target species, while at the same time minimizing or avoiding completely the contact of a toxic dose with non-target surfaces.

Studies of the bionomics of the pest and the establishment of survey methods, to obtain an understanding of the population changes, are essential for attaining ecological selectivity. The most important aims are:

(*a*) the selection of a target stage, the destruction of which will prevent the occurrence of damaging infestation levels in the crop;

(*b*) understanding the interactions between insecticide and pest, between pest and plant, and between insecticide and plant;

(*c*) forecasting the occurrence of damaging infestation levels in the crop;

(*d*) the development of target-specific methods of pesticide application;

(*e*) monitoring and evaluating results of the operation in respect of short-term (yield) and long-term effects.

Crop protection is extremely complex since it is conducted in open fields, where the pesticides are subject to the vagaries of the atmosphere and confronted by the biological adaptability of pests and diseases. Improved efficiency in the use of pesticides calls for contributions not only from ecologists and chemists, but also from physicists, engineers and managers.

Such complex work is beyond the capabilities of farmers. It is expensive and carries little immediate financial reward to them or to the pesticide suppliers.

R. J. V. Joyce has for many years called for the reassessment of traditional spraying procedures (see, for example, Joyce 1972, 1980). In work on the control of insect pests in the Sudan and eastern Africa he became interested in the control of pest numbers by direct attack on the insects. This strategy was very successful for the control of locusts, armyworm, mosquitoes and tsetse fly. He advocated the development of spraying methods tailored for each key crop pest, taking into account its behaviour and population dynamics. The management of the Agro Department of Ciba Limited, Basle, subsequently Ciba–Geigy Limited, considered that the methods proposed by Joyce could offer a solution to the pest control problem in rice in Indonesia. Since 1967 he has been associated with Ciba–Geigy Limited, first in Basle and later as Director of the Agricultural Aviation Research Unit (A.A.R.U.) in Cranfield. His work and that of the scientific staff directed by him has shaped the Company's project approach to crop protection. He saw pest control with the eyes of an entomologist and not with those of a scientist in the services of a chemical company. Some of the opinions expressed in this paper are unmistakably his. He persevered and was rewarded by many positive results, which encouraged the Company to continue its engagement in projects.

2. Crop protection practice

Chemicals should be used in crop protection in such a way that the agro-ecosystem is disturbed as little as possible. Two basic approaches to crop protection by chemicals can be distinguished: the agronomic, which directs the chemical to the crop, and the ecological, which directs the chemical to the target organism. Both approaches are valid, but in the long run the ecological approach must be adopted.

(*a*) *The agronomic technique*

It is customary to regard application of pesticides to a crop as another agricultural input, comparable with fertilizer, and for its value to be assessed by classical field plot experiments. The general demands are: maximum recovery of the chemical on the crop, good penetration of the crop, an even cover on the foliage, and the elimination of spray drift.

In commercial practice the farmer tries to achieve all this with placement or swath spraying. The decision to spray is based on his judgement of the cost and possible benefits. The efficiency of the treatment is measured by the reduction in pest numbers in comparison with those present in untreated fields, and by crop yield. This method of application can have its merits where high-value crops are grown on small areas, but it is very inefficient in terms of the amount of applied chemical that is collected by the ultimate target.

Graham-Bryce (1976) reported that only 0.03 % of a foliar spray was required to kill infestations of aphids on field beans, whereas in air to air spraying of locusts utilization was 200 times more efficient. Graham-Bryce warned that such poor utilization not only wastes material, but also introduces biologically active substances unnecessarily into the environment.

Losses may be even greater when the target for the spray is selected without proper regard to the bionomics and behaviour of the pest. For example, damaging levels of the bollworm, *Heliothis armigera*, occur in the Sudan when only 10 % of plants are infested. To provide protection by conventional crop spraying, Joyce (personal communication) calculated that 10^7 more toxic doses were applied than would be necessary if it were possible to apply the insecticide directly to the few larvae.

(*b*) *The ecological approach*

For large areas with monocultures, which are liable to be afflicted by devastating outbreaks of insects, a more sophisticated approach to pest control is called for, commensurate with the complexity and scale of the problem. This is particularly true where pests are highly mobile and where sudden outbreaks of pests or diseases are liable to spread rapidly, if left unchecked. In such cases crop protection must be organized and executed on a scale dictated by the biology and distribution of the pest, and not on a scale imposed by artificial boundaries, such as fields and farms. Experience in locust control led to the recognition of the need for synoptic survey and the synchronized application of a control agent. Efficiency in pesticide application is to be measured in terms of collection of a calculated required amount of chemical on defined biological targets. The successful application of such pest management techniques minimizes many of the problems associated with programmed spraying, but it requires more knowledge and skill on the part of the farmer or applicator.

3. The project approach of Ciba–Geigy

The requirements of the ecological approach to pest control can best be fulfilled in large-scale operations, such as those in developing countries with large monocultures. However, such countries usually lack finance, technology, management and inputs such as chemicals and appropriate machinery, to change their agricultural systems. On the other hand, these are also the countries where the greatest opportunities exist for achieving dramatic improvements in crop yields by better crop protection techniques. In the past, the chemical industry was concerned with the supply of effective chemicals and technical advice for their proper use in crop spraying. No application on a commercial scale on behalf of the customer was envisaged. The former Ciba Limited saw, in accepting responsibility for controlling pests, an opportunity for a more effective use of its chemicals in the solution of some major problems in different parts of the world, where no local organizations were available to realize improved pest control strategies. This added a further dimension to the wide range of services that the industry traditionally provides and led to the creation of 'application projects' or 'package deals'.

These operations offer an opportunity to utilize and try out thoroughly all those factors that can improve pest control. They not only offer a customer a specific solution to his problems but also give an opportunity for developing and testing the validity of novel approaches to particular situations. This activity has, in addition to its scientific content, a commercial motive, without which no industry can survive. A project may not only open a new market, it is also a major motivating factor to obtain better results with the compounds employed, even if improved methods may call for less chemicals. Project work requires great flexibility because effective control methods developed in one geographical area for a particular insect pest may not be effective in another setting.

A project is always considered to be of limited duration, to solve an immediate problem, to gain an entry into a market or to determine market requirements. The Company always foresaw its transfer to the country of operation within a reasonable period. If its impact is to be lasting, the training of local technical personnel becomes important and represents an effective transfer of technology to third world countries, to mutual advantage.

In the execution of an application project the responsibility is assumed for controlling the pests in a certain area for a fixed price per area unit. This covers the supply of chemicals and the execution of the application programme. The customer has the advantage that he has to deal for pest control problems only with one partner, who assumes full responsibility for the result. This work requires a well qualified staff of specialists, such as biologists, administrators, accountants, logistics experts, cartographers, mechanical engineers, pilots and radio engineers. The project group in Ciba–Geigy consists at present of 102 staff members. The satisfactory solution of personnel and infrastructure problems is a very important factor in any project.

The main research-orientated projects executed by Ciba–Geigy concerned the important crops of rice and cotton. Projects were executed almost exclusively in countries where crop protection was controlled by a single administration, which took an interest in new application methods, and where conditions permitted the synchronized application of chemicals on an appropriate scale.

Table 1 lists the major project activities of the Company.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Table 1. Major projects carried out by Ciba–Geigy

country	period	crop or pest	area/kha	staff per peak season
Sudan	1971–81	cotton	524	45 expatriates
		wheat	128	510 local
Egypt	1971–7	cotton	39	6 expatriates
				44 local
Zaire	1973–8	coffee	48	4 expatriates
				12 local
Nigeria	1974–7	rice	32	4 expatriates
		maize		14 local
Indonesia	1968–72	rice	934	50 expatriates
		palm trees	28	400 local
Saudi Arabia	1974–8	houseflies	132	35 expatriates
				515 local
Bangladesh	1971–2	rice	237	14 expatriates
				60 local
Pakistan	1973–5	rice	394	13 expatriates
				20 local
Iran	1973–5	rice	92	12 expatriates
				60 local
Thailand	1969	cotton	69	5 expatriates
				40 local

4. Research elements in project work

(a) *Analytical approach to aerial application*

The application of scientific methods to pest control involves an analytical approach to the biological, biochemical, chemical, physical and meteorological problems involved. When Ciba–Geigy embarked on its project activities, most of the factors were not fully understood and it was necessary to start a comprehensive programme of basic and applied research in laboratories and in the field. At the same time, and often as a result of new findings, the development of new or improved equipment was undertaken. Considerable progress has been made. The 250 scientific papers that have been written by scientists of Ciba–Geigy and of institutions that were participating in the research programme are an outward proof of the efforts made.

Basic studies covered the following areas: definition of the biological target and dosage requirements; determination of optimum droplet sizes; droplet production and transmission.

(i) *Definition of the biological target and dosage requirement*

The key to the development of improved methods of pesticide application is the definition of the target (Joyce 1980). In relation to *Heliothis armigera* on cotton in Sudan detailed studies were undertaken, of the stages available for attack, the scale on which they occur, and their distribution in space and time.

A stage particularly attractive as a target is the airborne adult. The influence of this stage on outbreaks of spruce budworm in Canada and of *Heliothis armigera* in Sudan was investigated, over about 4 years in each case. Joyce (1972) suggested that the destruction of airborne insect concentrations could considerably improve pest control with less risk of environmental contamination. He proved the validity of his theory in the case of spruce budworm in Canada, but airborne adults of *Heliothis armigera* in Sudan were found to be an unsuitable target. As few as 20 moths per hectare gave rise to damaging larval infestations, and not all adults were airborne above the crop at one time. The moths in the vicinity of the crop, and the terminals of the

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

plant on which they laid their eggs were, however, a better target than the larval stages that had been attacked in the past.

These studies of insect flight activity employed ground-based radar, a Pilatus-Porter aircraft fitted with Decca type 71 Doppler radar navigation equipment and a specially designed insect-collecting net that permitted insects to be collected undamaged. With this equipment Dr R. C. Rainey, F.R.S., of the Centre for Overseas Pest Research determined the structure of many types of wind fields in Africa and Canada and measured the concentration of airborne insects.

In Sudan, cartographical analysis of pest survey data demonstrated that heavy oviposition by *Heliothis armigera* on cotton, and heavy concentrations of grasshoppers, jassids and whiteflies could be found on the day after the passage of convectional storms. These concentrations of insects were on the edges of the paths taken by the storms. Radar observations showed that these storms collected, concentrated and later deposited insects that had been airborne at dusk.

In Canada, aerial spraying experiments showed that the entire spruce budworm population from a forest area could be destroyed if the moths were attacked as airborne targets concentrated in the zone of nightly temperature inversion. This method of control used less than 1% of the chemical and was one hundred times quicker than when the larvae were selected as the spray target.

(ii) *Determination of optimum droplet sizes*

Research had shown that one of the most important factors in determining the amount of spray collected by a target is the droplet size. It is likely that for each combination of biological target, chemical formulation, and type of action there is an optimum size of droplet (Spillmann 1980). Extensive investigations were therefore conducted to determine the optimum particle size for efficient collection by different target surfaces.

Since the attainment of the required droplet size depends to no small extent on the physical properties of the pesticide formulation, this research acted as a stimulus to the development of formulations that were non-volatile, non-phytotoxic and of high biological activity. The necessary elimination of water as a carrier, moreover, provided an opportunity for formulating to secure rapid entry of the toxicant into the target organism.

(iii) *Droplet production and transmission*

Maximum accuracy in the distribution of chemical materials requires a narrow range of desired droplet sizes and accurate transmission of the droplets from an airborne source to a target near the ground. This called for a search for methods to control the droplet spectrum and for investigations into the dispersal process by air, to permit a deliberate exploitation of atmospheric processes by appropriate spray techniques. Various investigations were conducted into the microclimate above and within crop canopies. It was established that turbulence, resulting from both crop roughness and thermals, made an important contribution to the transmission of small droplets to the target. This led to a reversal of some generally accepted concepts of the requirements of accurate aerial spraying, and to an empirical formula that predicted the position of the peak deposit in terms of spraying height and turbulence.

(*b*) *Operational techniques*

The traditional techniques of placement spraying are rarely adequate, both in terms of cost and speed, when extensive areas have to be protected against massive insect invasions. These

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

situations call for insect population management and demand an understanding of pest population dynamics.

The project approach requires accurate timing and target-specific application. Accurate timing is achieved by synoptic survey, to determine the scale and time of appropriate action. The synchronous application of pesticides, over areas commensurate with the distribution of the pest and at a speed dictated by the pest's mobility, is achieved by aerial spraying at ultra low volume rates (u.l.v.).

The Ciba project in Indonesia offered an opportunity to demonstrate the advantages of the system on a scale that had not been attempted before in agriculture. It proved that synchronous spraying of large areas was more successful than the treatment of individual plots by farmers.

(c) *Equipment development*

Experience of project work and improved application methods provide a constant challenge to design new equipment and to improve that already in existence.

When working in large, featureless areas, visual tracking is not feasible and aircraft instrument aid is essential. Ciba–Geigy was confronted with such situations in Indonesia, Bangladesh, Iran, and certain parts of Sudan. The Decca Navigation System offered a solution, and the company worked together with the manufacturers on the required modifications. There was also cooperative development of special track guidance equipment for agricultural aircraft. Despite modern improvements in design and production techniques, such equipment remains, however, expensive and can only be justified for really large-scale operations.

Extensive evaluation and modification programmes for spraying machinery were also undertaken, since most commonly available atomizers emit an unwanted wide range of droplet sizes. This led even to the development of novel types of spray devices, like the Bi-foil and Rotanet atomizers. The equipment programme expanded and encompassed the whole aircraft spraying system and such components as flowmeters and electric shut-off valves.

5. Projects carried out

(a) *Indonesia*

Indonesia was once one of the great rice-exporting countries, but during the 1960s the entire crop was needed for home consumption. The country was obliged to import over 1 Mt of rice per year, absorbing about 15% of the country's available foreign exchange.

To overcome this drain on the country's resources the Government embarked on a programme of guidance for farmers – the Bimas Project – which planned to increase yields by encouraging the adoption of improved varieties, better methods of agriculture, increased use of fertilizers, and better crop protection. The progress of the programme was, however, extremely slow, because of financial and organizational difficulties. A total of 1 Mha of rice land required protection in one year, mainly against stemborer (*Tryporyza incertulas* and *T. innotata*), which caused crop losses of 25–75%.

To assist in the solution of the problem, Ciba offered a crop protection programme, based on a successful pilot project on the Island of Sulawesi during the previous year, where the most effective spray schedule and target doses had been determined. It provided fertilizers, which were to be obtained from various sources, and Ciba pesticides. 160 kt of fertilizers and high-yielding seed had to be distributed to 4000 villages, the insecticides applied from the air, extension services had to be provided and short-term suppliers' credits granted.

From the beginning, the Government viewed the programme of foreign participation as a temporary measure. The operation lasted for four seasons during which 934 kha of rice fields in Java were sprayed, 3–4 times each season.

A system was developed in which the aircraft, the flying technique, the specially designed atomizer, the navigation and the insecticide were integrated for achieving the objective, namely, transmission, as near synchronously as possible, of accurate doses of pesticide to all areas of rice where moth infestations were reaching peak numbers. Synoptic survey was achieved by means of a pattern of kerosene light-traps – one per thousand hectares – by which the pest situation in regions consisting of hundreds of thousands of hectares could be surveyed at one time. Synchronous control was made possible by incremental spraying at u.l.v. rates under a Decca Hi-Fix Track Guidance system.

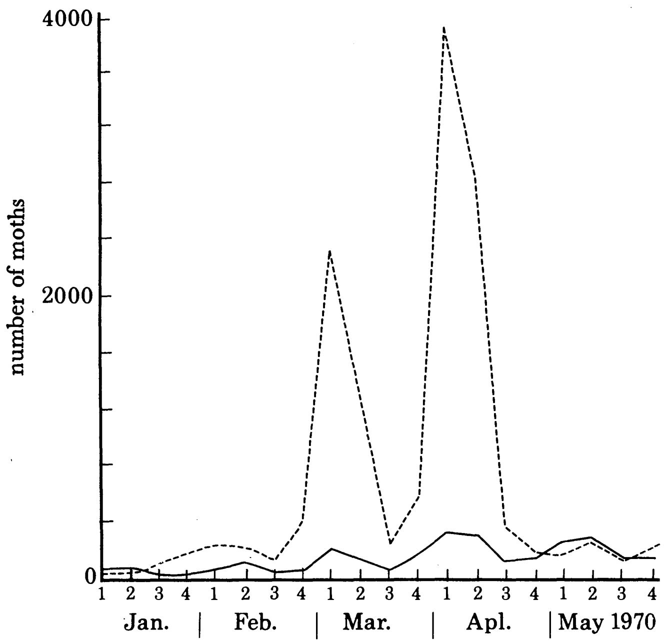

FIGURE 1. The result of a country-wide investigation in West Java into the project to control stemborer carried out during the wet season 1969/70 (Singh & Sutyoso 1973). Solid line, inside treated area; broken line, outside treated area. The differences in this part of Indonesia were more pronounced than in others, owing to the large areas and the high density of stemborer populations.

For these manifold services, a set price per treated hectare was agreed upon with the Indonesian Government. The rice farmers originally participated in the cost of the projects by ceding one-sixth of their rice harvest to the Government. It was basically agreed that payment to Ciba would take place after the harvest.

Despite certain shortcomings, the project approach was a step forward in the improvement of rice production in Java. Much statistical information documented the substantial yield increase, the pest population reduction, and the contribution that the scale of the operation made to this result.

Figure 1 and table 2 are two representative examples of surveys carried out in cooperation with Professor Gunawan Satari by students from the Padjadjaran University, College of Agriculture, Bandung and by Ciba Limited, who collected and evaluated field data with the Agricultural Extension Service of the Ministry of Agriculture.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Figure 1 shows the positive effect of the project approach, which resulted in a marked diminution of the number of moths caught in light traps inside the project area compared with the catches outside the area. This shows that application on a scale commensurate with the pest distribution maintained the stemborer moth at a low level throughout the season. When pest control was carried out by the individual farmers' uncoordinated efforts, the pattern of stemborer population followed that which can normally be expected, namely increasing as the rice season progressed.

Table 2

size of block/ha	mean percentage reduction in stemborer moth population	mean percentage increase in yield
5000	70.9	94.8
1000	37.0	40.1
500	40.0	41.0

The correlation between the plot size and the effectiveness of aerial application at u.l.v. rates was demonstrated by the results obtained in a formal experiment (S. R. Singh, unpublished) in which phosphamidon was sprayed by aircraft at u.l.v. rates against stemborer (see table 2). This showed clearly, possibly for the first time, that over larger compact areas significantly better reduction of pest numbers and higher yield increases can be obtained than over smaller areas with the same insecticide and the same dosage rate.

Judged from the point of view of the national economy the projects were successful. The average rice yields during four seasons of the project were 33 % greater than the average during the 5 preceding years. For the 1968/69 wet season alone, Mr James E. Hawes, Agronomy Advisor USAID/Indonesia, estimated very conservatively that an additional quantity of 150 kt of rice was produced (Hawes 1970). If this had been imported, it would have cost the country $19.5M, whereas for the Ciba service $12.3M was paid. Hawes therefore confirmed that from the viewpoint of the balance of payments the project was a good investment for Indonesia.

To realize the full benefit from the production increase, it would have been essential that the rice was suitably harvested, processed and stored and that no excessive losses occurred during transport. This proved, however, to be a weak link in the chain of Indonesia's agricultural production and resulted, unfortunately, in a large, unexpected budgetary deficit for the Government. The authorities not only failed to obtain from farmers the expected volume of credit repayment in kind, but the Government infrastructure was also unable to handle and process the paddy that was brought in. The result of the increased yields was in certain cases a collapse of prices, insufficient storage space and a wastage of grain.

Based on a system of repayment in kind, which puts a premium on low productivity and dishonesty, the programme was doomed to failure if judged narrowly only from the point of view of internal revenue.

Despite this deficit, the overall benefit to the country has been positive. Besides saving Indonesia large amounts of foreign exchange, the project also brought the country the advantages of a modern pest control strategy, based on extensive research, and resulted in a substantial and lasting reduction of the level of stemborer infestation. The project constituted a great leap forward in rice production techniques. The programme considerably increased the awareness of the farmers of improved methods, and demonstrated that better harvest results can be obtained through fertilizers and crop protection.

The transition from subsistence farmer to producer of surplus for the market is, however, no easy matter for a peasant, and this aspect may not have received the necessary attention. Intensifying the nation's rice growing is primarily a matter of education of the farmers. They were coerced into participating in a programme, the scope and methods of which were not sufficiently explained to them by the Government Extension Service or by the project staff. They were inadequately informed, especially about technical aspects and the methods of aerial application.

Ciba may in many respects have attempted too much too quickly. It was necessary not only to change the attitude of the farming community but also to solve many technical problems. However, much experience was gained in the management of such pest control operations. The results in Indonesia strengthened the conviction that large-scale treatments could also be successful against *Heliothis armigera* in Sudan.

(*b*) *Sudan*

Cotton is the most important crop of Sudan. It is grown on over 535 kha of irrigated land around the Blue and the White Niles. The areas are administered by different authorities as cooperative ventures. The largest and oldest is the Gezira Scheme. Scheme managements are responsible for the supply of seeds and other inputs, including fertilizers and crop protection. The latter is carried out by aerial application, for which the chemicals are purchased on the basis of tenders and the services of predominantly foreign applicators hired on the basis of competitive bids. For the results, neither the suppliers of the chemical nor the applicator can be held responsible. In this system much more effort is put into routine screening of pesticides than into biological investigations (Bashir 1978*a*).

Late in the 1960s Sudan experienced severe crop losses caused by *Heliothis armigera*, the cotton bollworm. This highly mobile pest was at that time relatively new and no effective control programme had been fully developed. Besides, little was known about its behaviour, flight activity, dispersal and breeding (Bashir 1978*b*).

In early 1970 Ciba–Geigy worked out suggestions for a control programme based on a study of the ecology and behaviour of the bollworm. The research contracts that followed became designated as 'package deals', and the areas treated during a season advanced from the first pilot operation of 420 ha to 100 kha. Ciba–Geigy took over the task of determining the spray programme, supplying the chemical and carrying out its application, coupled with a guarantee for effectiveness. From 1970 to 1981, 520 kha of cotton fields were treated, four to seven times per season.

The research programme was constructed to seek an approach to pest management based on ecological, rather than exclusively agronomic, principles. In this programme Ciba–Geigy has often been supported by eminent scientists from independent research establishments, for example the Centre for Overseas Pest Research, Rothamsted Experimental Station, Cranfield Institute of Technology and the Universities of Loughborough, Nottingham, Wales and Zurich. Among these have been world authorities on insect migration, radar entomology, crop climatology and even on biological control of insects, and experts in light-trapping, micrometeorology and experimental entomology. The involvement of these experts was completely or partly financed by Ciba–Geigy. The full research team in Sudan was never less than five scientists, and often as many as ten. The research programmes not only yielded results of scientific value, but also generated effective techniques of pest control.

Careful studies were made of the ecology and behaviour of the two major pests, bollworm and whitefly (*Bemisia tabaci*), to determine a statistically valid sampling scheme of specified reliability. Infestations of damaging levels of *Heliothis* occur overnight over thousands of square kilometres. This called for synchronous control if the crop was to be effectively protected from damage.

Ciba–Geigy chose to use an insecticide of short persistence lethal to bollworms, whiteflies and jassids, applied at low (partly selective) dose rates to get away from the use of excessively persistent, high dose rates of chlorinated hydrocarbons formerly used. This, however, made more demand on exact spray timing and a high work rate.

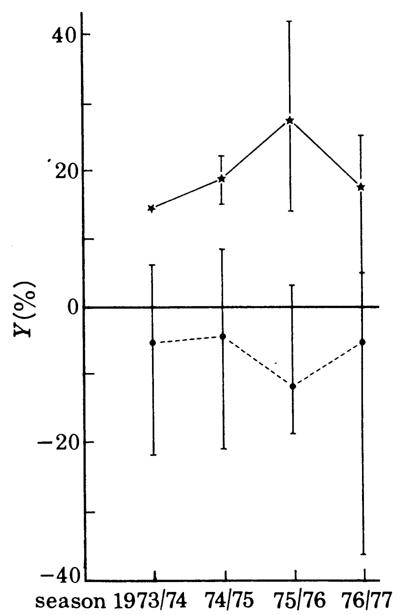

FIGURE 2. Yields of seed cotton in Kantars per Feddan in the Sudan Gezira: Y is the mean percentage deviation from long-term mean yields of Gezira groups, expressed as 100 $(T/\overline{T} - A/\overline{A})$, where T is the current season's yield and $\overline{T}$ the long-term mean yield of the group, and A is the current season's yield and $\overline{A}$ the long-term mean yield of Gezira. Solid lines, groups in the project area; broken line, all other Gezira groups. Ranges about the means are shown. (From Joyce (1978).)

The results of the projects have been positive. The yields in the Ciba–Geigy area were for many seasons higher than in other comparable Gezira groups, and during the first four seasons of large-scale operations it was possible to establish yield increases that varied between 15 and 42 % above the long-term average for the area (see figure 2).

Since 1977, however, owing to the introduction of a species of cotton not previously grown, there is no basis for comparison, either with yields to be expected from the project area or with yields of neighbouring areas where the former species is still grown. It is evident, however, that yields generally in the Gezira have declined alarmingly during the three seasons since 1977. The decline has been accompanied by increasing severe whitefly infestations. The tendency is apparent throughout the irrigated cotton areas of Sudan, and is not connected with the pest control strategy developed by Ciba–Geigy. It is an ecological problem, which a company can understand better if it is deeply involved in pest control practice than if it had remained with its experience limited to the performance of its pesticides in the controlled conditions of experiments and trials.

The success is due not only to the careful scientific work, but also to the efficient management of the projects. An important factor is also the excellent infrastructure provided.

Package deals are, however, not without their detractors, who concentrate mainly on two aspects:

the continuous use of the same proprietary product over many seasons may lead to a build-up of resistance and this may have aggravated the problem of whitefly;

the initiative of local entomologists, who were responsible for the area previously, was curtailed when the Company took over the determination of spray schedules, and some may even have become redundant (Bashir 1978*a*).

In fact the choice of products is constantly being critically evaluated, and no clear signs of resistance have so far appeared. The increased importance of whitefly is alarming but it has coincided with changes in the cotton species grown and with changes in and the deterioration of many agricultural practices. The complaint about redundancy of entomologists in the scheme is hardly sustainable, especially if one considers the large number of local entomologists employed in the project who received an excellent training in modern pest control methods.

6. Conclusions

The constantly increasing world population will pose a tremendous challenge to agriculture and to crop protection, and insecticides, which will probably remain the key to insect pest control, will have to be intelligently applied. Improved methods can greatly enhance their effectiveness. Changing and new agricultural techniques require not only new biologically active chemicals but also new application techniques. There should be increased technical commitment from chemical manufacturers, as well as from official bodies, especially in programmes that because of their scale may be beyond the capacity of the normal consumer of pesticides.

Such involvement is, however, not without its problems. Reference has already been made to some of these when discussing individual projects, but some major constraints still bear mention.

As soon as a project assumes a certain size, unexpected problems of an economic, social, political and psychological nature can arise. A project may introduce on a massive scale modern technology into a rural environment, for which the farmers may not perceive the need or the resulting advantage. They also do not like to pay for something that they never handle or see, like pest control operations from the air at u.l.v. rates. It is also debatable whether high technology is suitable for every situation and whether, for instance, aerial application is an effective means for educating farmers in modern pest control.

The local extension service is often unable to carry out the necessary educational programme to convince the farmers before the start of an operation of the effectiveness and profitability of the changes. The acceptance of programmes by the farmers might also be more enthusiastic if the style of execution is more adapted to the local mentality rather than a completely alien style of efficient organization on a European pattern, even though this may mean a certain loss of efficiency. After all, one of the objectives of a project is to introduce a new crop protection method that will continue beyond the duration of the contract. Too much dependence on foreign assistance, which suppresses the initiative of the local population, should be avoided.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The presence of a large number of foreigners and their life style may cause resentment. Projects may also tend to widen the gap between different sectors of the population, since it is often the more progressive and affluent owners of larger farms who benefit most.

The advantages of a project to a community are often quickly forgotten, especially once a pest population in an area has been brought down to a certain level, which makes it difficult to produce similar spectacular results in subsequent years.

All these constraints emphasize the great importance of communication. The customer and his staff, the authorities and the community have to be kept informed about the objective of the project, the methods employed and the results achieved. Under pressure of work and the need to reach a certain goal, these aspects are often neglected and result in misunderstanding, resentment and opposition.

The project staff have here a very important task. Therefore, the proper selection is of utmost importance. They have to be willing to work hard, often under difficult conditions, they have to have an outstanding degree of competence, and they ought to be good ambassadors for the company. This calls for a considerable degree of motivation.

At the beginning of this paper, it was stated that the company's motives for entering the application field were both commercial and scientific. In assessing the gains, it would probably be concluded that the greater weight is on the side of science. Project work gives technical staff a unique opportunity to gain in the field an intimate knowledge of the effectiveness of the chemicals, their interaction with the environment and possible hazards. It offers new insight for the improvement of application methods, through which customers can obtain superior pest control results.

For all these advances the company has expended large sums but enjoys no proprietary protection; the benefits are for all who wish to take advantage of them. This may be a reason why the chemical industry in general has been somewhat hesitant to engage in basic application research. Many problems still need investigation if we wish to achieve the better utilization of chemical compounds that we expect and, which new concepts of crop protection like integrated pest management demand. This may call for a certain degree of cooperation among the leading chemical companies in a joint research effort.

I gratefully acknowledge the assistance provided by many of my colleagues in Ciba-Geigy's Agricultural Division. I wish to express special thanks to Professor R. J. V. Joyce who has helped in reviewing the text and has offered many suggestions.

References (Bernet)

Bashir, S. El 1978*a* The package deal strategy. Presented at Symposium on Crop Pest Management, Khartoum.

Bashir, S. El 1978*b* Future Cotton Pest Control Strategy. Presented at Symposium on Crop Pest Management, Khartoum.

Graham-Bryce, I. J. 1976 Crop protection: present achievement and future challenge. *Chemy Ind.* 3 July, 545–553.

Hawes, J. E. 1970 *Rice in Indonesia*. Report prepared for USAID/Indonesia.

Joyce, R. J. V. 1972 The application of locust control techniques to other pests. In *Proc. Int. Study Conf. Current and Future Problems in Acridology*, London U.K., July 1970.

Joyce, R. J. V. 1978 Yield response of *Gossypium barbadense* in the Sudan Gezira to aerial spraying at ULV rates with Nuvacron 40. Presented at Third Seminar on the strategy for cotton pest control in the Sudan, Basle.

Joyce, R. J. V. 1980 Biological objectives. In *Cranfield Short Course on Aerial Application of Pesticides*.

Singh, S. R. & Sutyoso, Y. 1973 Effect of phosphamidon ultra-low-volume aerial application on rice over a large area in Java. *J. econ. Ent.* **66**, 1107–1109.

Southwood, T. R. E. 1979 Pesticide usage: prodigal or precise. In *Proc. 1979 British Crop Protection Conference – Pests and Diseases*, vol. 3, pp. 603–619.

Spillman, J. J. 1980 The efficiency of aerial spraying. *Aeronaut. Jl R. aeronaut. Soc.* February, pp. 60–69.

Discussion

B. Steele (*Centre for Overseas Pest Research, London, U.K.*). I wish to pose a general question. Dr Lewis mentioned, in passing, in his paper, that not all farmers in this country are able or willing to take the official advice on pest control which they are offered. The same is certainly true of most farmers in the Third World. Most of the world's farmers cannot hope to undertake more with regard to pest control than a fairly simple operation aimed at saving their crop if threatened with attack or, at best, carrying out a simple prophylactic treatment.

I wonder, therefore, if we are right in continuing to develop more and more sophisticated systems of pest control. Indeed it may be, if we again consider the problem on a global scale, that the expenditure of more and more of the world's resources on the development of these sophisticated systems is not likely to yield an economic return in increased food production. Surely there is much that the agrochemical industry could do in making efficient use of the existing range of pesticides, and academic and government research should be directed towards the same end.

If I may try to phrase my question in a deliberately provocative way, are we not in danger of pursuing a pest control mystique which has the largely unreasonable aim of solving every pest problem without reference to practical realities of the farmer's ability?

E. E. Bernet. The question raised by Dr Steele is very pertinent. The danger certainly exists that in our endeavour to solve pest problems in the most effective manner known to us, and to utilize the available chemicals as efficiently as possible, we may offer to Third World countries systems that at the moment are too sophisticated for wide application by their farmers. I have referred to this fact in my paper. We are very conscious of our obligation to adapt certain techniques to the capabilities of the communities in these countries. Besides carrying out large-scale operations, which I have described, we and other chemical companies also conduct in many countries small operations in which farmers are taught better crop protection methods with equipment that is available to them and which is simple to operate and maintain. Some of these methods may be based on basic experience previously gained in larger field operations and adapted to the conditions faced by the small farmer.

One of the prime objectives in all these operations is to achieve a positive economic return for the farmer. Systems that are uneconomic will die a natural death within a short time and it would not be in the interest of the industry to advocate them. We must, however, realize that in most developments the right answer is often only found after some trial and error. One can hardly expect to always find a solution in the first round. On the other hand, we must not overlook the fact that some pest control problems can be solved economically and efficiently only if the operations take into account the scale of the pest infestation and the mobility of the pests. From this point of view the traditional approach and the treatment of individual fields at the discretion of the farmer is inefficient, and large-scale operations become necessary. These are certainly beyond the capabilities of individual farmers and they should be carried out for him by a central authority, be it a cooperative or a government department, engaging the services of an experienced specialist, in the larger economic interest of the community. To reach this stage requires a considerable educational effort.

All these actions are undertaken to a large extent for utilizing the existing range of pesticides more efficiently, as Dr Steele is demanding.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES