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Crop Protection: The Role of the Chemical Industry in an Uncertain Future [and Discussion]

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Crop protection: the role of the chemical industry in an uncertain future

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Chemical means for the control of weeds, pests and diseases have become legion during the last 40 years, to the point at which it might superficially appear that all the major problems are solved. An international industry earning more than £4000M has grown up, and spends around £250M annually on research and development: in a period of increasing economic pressures on the heavy organic chemical industries, the speciality field appears increasingly attractive to prospective entrants.

The future contains opportunities and constraints, and above all uncertainty. While minor innovation may be slowing down, major advances continue in the direction of more active or more specific chemicals, new formulation methods and revolutionary application systems. At the same time, regulatory, legal and social pressures call into question the validity of the judgement of experts and reinforce underlying trends in cost inflation.

Under heavy techno-commercial pressures, and from a science base that is as yet inadequate, the chemical industry is striving to assess its long-term role in relation to changing market needs and the potential contribution of other technologies.

Introduction

The original title for this paper was the simple but unpromising phrase 'techno-economic considerations'; however, the notion of uncertainty expressed in the present title is appropriate because the problem facing the chemical industry is described by several propositions whose consequences cannot yet be clearly seen: maintenance of safe, efficient and economic crop protection practices will depend for the far foreseeable future on the evolution, introduction and servicing of new products and new approaches. The chemical industry has provided this thrust, over the last 50 years, by reinvesting profits in a massive international research-based enterprise in which the aggregate R & D expenditures of the 25 or so 'majors' must be around £250M in 1981. This means on average about 7% of sales income, which is well above the chemical industry's average of about $3\frac{1}{2}$% or a typical figure for the 'heavy end' – fibres, for example – of $1\frac{1}{2}$%. It goes without saying that over a period of years the agro-chemical industry must pay its own way, although this is not usually feasible during times of major growth. Examples of such enterprises are operating divisions of large companies, whose boards – in effect, the companies' shareholders – have an array of investment options. So the key questions are: Can the business of agrochemicals continue to satisfy its shareholders? What changes will be necessary if it is to do so? Will the industry be able, or prepared, to make these changes? If not, how will the manifold requirements for safe and effective innovation in crop protection be met in the future? As far as this last question is concerned, it should be borne in mind that currently the basic parameters for the introduction of a major product

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are approximately: an R & D cost of £10M from test-tube to product launch (*excluding* capital investment), a timescale of between 5 and 8 years, and the necessity to envisage a mature annual sales value to the manufacturing company upwards of £15M (at 1981 prices), for there to be reasonable prospects of rewarding investment.

These are just a few elements of the techno-economic equation. None are unchangeable, and all have been changing to our disadvantage in the past; some of the possibilities for the future will emerge from other papers at this symposium, but whatever the technical options appear to be, it is illusory to suppose that agriculture's requirements could be met in the long term by ceasing to do costly research and concentrating on the bulk manufacture of existing or commodity products extended only by biological agents and minor specialist materials.

If the future needs of crop protection can indeed only be met by the continuing commitment of resources by the chemical industry, then, however uncomfortable it may be, the course of development will to a significant degree depend upon the needs and capabilities of that industry. This paper deals with some of those needs (and constraints), and more briefly with how opportunities appear to be changing in relation to our industrial capabilities.

Financial profile of the agrochemical business

The following summary of what happens to sales income will underline some of the points just made, and will provide a structure for follows.

Worldwide (but excluding Russia and China), farmers and growers paid approximately £4000M ($9700M) for agrochemicals in 1980. But this is not of course the sales income of the manufacturing industry (Bayer, Ciba-Geigy, I.C.I. and so on); arrangements for product distribution vary widely, but often involve two intermediaries between the external face of manufacturing industry and the customer. The industry's income in 1980 was of the order of £3000M ($7200M).

The calls upon income naturally vary from one company to another, depending upon the nature and maturity of their product range. However, a hypothetical but sufficiently typical model will serve as an illustration.

The first, and much the largest, item is the combined variable cost of production (including formulation and packaging) and sales. Together, these can account for as much as half of total sales income, and the raw materials and processing elements feature largely. Fixed capital costs (plant and buildings) are significant, even if modest in comparison with other parts of the chemical industry such as petrochemicals and fibres, and the overhead charges over relatively small tonnages can account for a further 5% of sales income.

At this point, then, there is a rough figure of 40–45% for gross margin on sales, averaged over a typical range of products. This figure is under pressure from cost inflation in manufacture and price competition in the market-place, and it has to provide all the fixed, or overhead, costs of the business including, for example, R & D (averaging 7%) and technical service (an additional 2–4%), and still leave enough money to finance future growth, i.e. capital investment, and persuade the shareholder that over a period of years this business is a better investment than, say, the National Savings Bank.

This is only the sketchiest outline of the financial profile of the agrochemical business; cash management adds several other problems such as the difficulty of maintaining control of stocks due to geographical diversity and seasonal demand, and of debtors, owing to fluctuations of the economic climate at the national as well as the personal level.

This paper will concentrate mainly upon three aspects of this total techno-commercial scene: income, production costs and the promise and problems of R & D. I shall first summarize some of the changes that are taking place in these areas, and subsequently suggest the impact that they may have upon the role of the Chemical Industry.

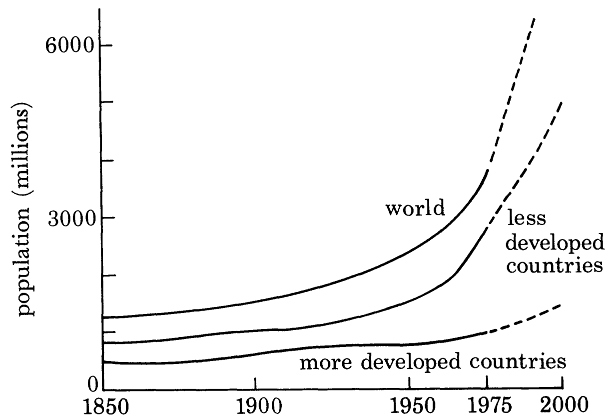

FIGURE 1. World population growth.

Sales income

In considering sales income, it is as well to remember that it is characterized by features such as stability, quantity and quality (or profit content); these will be examined here by reference to the contribution of agrochemicals in the past and what is likely to take place in the future. This will involve some consideration of demography, a reminder of yield and energy effectiveness, and the establishment of present geographical and end-use profiles, together with the trends of observed changes.

The first point to be made is that our customers will not go away; this is a stabilizing influence that some major elements of the chemical industry do not, at present, enjoy. Indeed, it is generally accepted that the growth of world population along the lines indicated in figure 1 will, broadly speaking, give us the task of doubling food production between now and A.D. 2000. There are a variety of estimates of the precise level of population at the turn of the century; whether 4×10^9 in 1975 will grow to 6×10^9 or 6.5×10^9 is perhaps academic, but it is highly significant to be reminded of the differences in growth rate between the more and the less developed countries. Within these trends, for example, Africa, South America and southern Asia have the greatest growth, with 2.5–3 % annually, and west Europe and North America are projected to fall below 1 % annually.

Although production is for the moment theoretically in balance with the total requirement, there are already major problems of food supply already: in the face of existing malnutrition and inadequate distribution systems, some countries of the developing world prefer to spend money on national airlines or sophisticated defence systems.

Before considering further the matter of regional differences as they affect crop protection chemicals, let us turn from demographic trends to look at potential and performance in defending and improving yields.

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F.A.O. has estimated that crop losses of 30% and more occur in many developing country crops as a result of inadequacy of crop protection practices; some of these losses are shown in table 1. Vegetables and fruit are high on the list from all three continents, and this of course includes a component of post-harvest loss.

To quote examples from the more developed world, it has been estimated that the elimination of all pesticide use in the U.S.A. would reduce the production of crops and livestock

Table 1. Estimated average losses (percentages) of potential crop yield for 1973

Latin America		Africa		Asia†	
maize	40	ground nuts	33	rice	30
rice	25	cotton	23	cereals	32
small grains	21	cocoa	51	cotton	24
cotton	33	coffee	32	vegetables	47
sugar cane	26	bananas	36	fruits	39
coffee	40	vegetables	61		
bananas	29	fruits	64		
vegetables	44	palm oil	19		
fruits	42				
beans	46				

† Excluding Japan.

by 30%, and would increase the price of farm produce by 50–70%. Similar action in the U.K. would give rise to yield reductions of approximately 42% in potatoes, 45% in cereals and 67% in sugar beet.

Some further illustrations of the contribution of agricultural chemicals to productivity per hectare are given in figures 2 and 3. Figure 2 illustrates the reduction and stabilization of losses of paddy rice in Japan during the period when chemicals were finding wide use for control of weeds, pests and diseases. These are difficult assessments to make, and must not be taken too literally, but there seems to be an indication that not all the problems are solved! Figure 3 shows the increase in productivity in maize growing in the U.S.A., relating it to what is admittedly only one of the relevant variables, namely herbicide usage.

If the need for crop protection seems assured by the part that it has to play in increasing the productivity of land, or opening up hitherto unfruitful areas, we should also look at the energy equation. Energy input into production processes is rightfully a matter of concern, in agriculture as elsewhere, but the pesticide component is only about 2–2½% of the total used in agriculture in the developed nations (table 2). Bearing in mind that in such a situation agriculture itself accounts overall for only about 4% of national energy requirement, the use of pesticides to improve and safeguard yields can be seen to be a highly energy-efficient approach. The figures shown include chemical intermediates, process energy, formulation and packing.

Just as a matter of interest, table 3 illustrates the very wide disparities that exist in the energy-efficiencies of various agricultural product choices, mostly in the developed world but including a comparison with the low-input production of cassava.

As a final indicator of the potential contribution of crop protection chemicals to energy productivity, I shall cite the use of appropriate herbicides in various reduced tillage régimes. The figures in table 4 show that energy consumption per hectare can be almost halved by

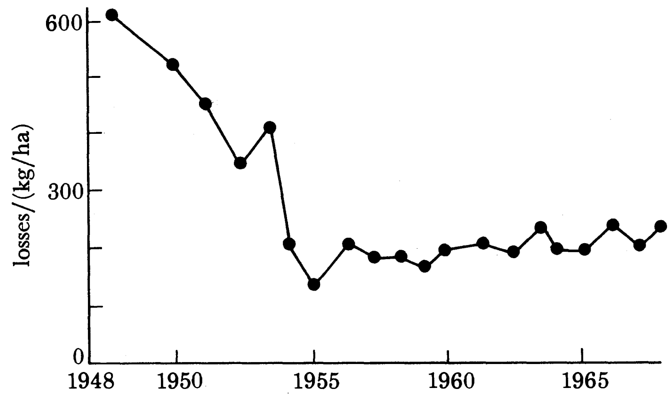

FIGURE 2. Losses in flooded rice in Japan, 1949–68.

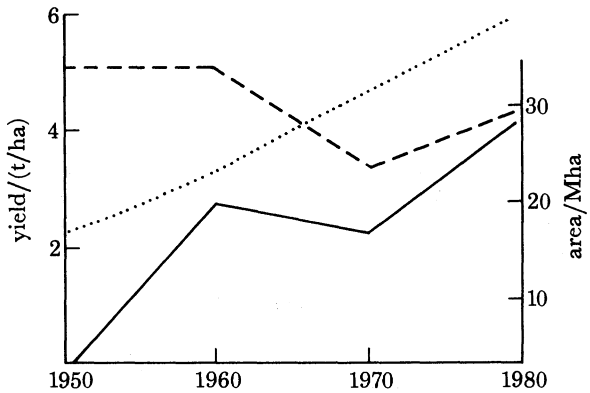

FIGURE 3. Acreage (---), yield (···) and acreage treated with herbicides (——) in maize production in the United States (Doane: *Agricultural Chemical Market Study for Speciality Crops*, 1958–78).

TABLE 2. ENERGY USED IN AGRICULTURE UP TO THE FARM GATE: NEEDS OF DIFFERENT ACTIVITIES

(Percentage of national energy consumption.)

machinery, buildings and imported feedstuffs	1.2
petroleum fuel	0.8
fertilizers	0.8
labour	0.7
agrochemicals	0.1
other	0.4
	4.0

changing over completely to zero tillage; the benefits of minimal, or reduced, cultivation lie in between, except for the special situations – for example, in arid areas – where chemical input is unnecessary. Quite apart from the attractive potential for cost reduction, these techniques are well aligned with the need to conserve both fuel and soil fertility, and can be expected to receive added impetus from the growing interest of international bodies such as F.A.O.

Commercial problems

So far I have been giving the grounds for confidence in the future of the agrochemical industry; some of the uncertainties arise from the possible impact of technical or quasi-technical trends, which will be considered shortly. There are, however, some more obviously commercial problems that arise from the structure of the market for agricultural chemicals.

The first concerns the quantity and quality of income, as distinct from its stability. Projections as to quantity are summarized in figure 4 for the period 1960–90. On current views, the future growth rate is probably somewhat overstated, particularly from 1985 onwards; real growth in 1979 was 4%, and it would be prudent to base business projections on the range 4–5%. This, however, masks considerable regional differences arising from cropping and economic factors and satisfaction of market needs. Western Europe, North America and Japan are typically showing the slowest real growth rates; Latin America, and Africa and the Middle East, are now the highest growth areas, although from an absolute position in which the developing countries account overall for only about one-quarter of world agrochemical usage: 20% of herbicides, 40% of insecticides (this actually includes public health, and is therefore overstated) and 15% of fungicides.

Table 3. Estimates of efficiency of agricultural use of energy

(Ratio of output metabolizable energy to input energy.)

cassava (subsistence level farming)	70
wheat	3.1
white bread	1.5
potatoes	1.3
milk	0.7
eggs	0.26
lamb	0.25
poultry	0.15
glasshouse tomatoes	0.05
fishing fleets, U.K.	0.05
other fisheries down to	0.005

Table 4. Energy used in conventional cultivation and zero tillage

cultivation system	fuel (litres/ha)	energy (GJ/h)
conventional	61.8	2.06
no-tillage	20.2	0.68
paraquat (0.84 kg/ha = 0.75 lb/acre)	—	0.39
total		**1.07**

The same information is presented in a more informative way in figures 5 and 6 and table 5. Figure 5 shows how the market is split between product groups, and how this split has changed over 20 years. The most striking points are the tremendous upsurge in herbicide usage, and the relatively small contribution from 'others', mainly nematicides and plant growth regulators, where major commercial progress is still awaited. Keeping in mind the earlier remarks about the minimum viable size of target market, let us analyse the pie-chart in more detail (table 5). To do so emphasizes (not surprisingly) the overwhelming importance of maize, soyabean, cotton and rice; this in turn illustrates why the R & D field is becoming so congested, with so much competitive work overlapping in the race towards a limited number of targets. Finally, to relate the crop pictures to markets, figure 6 shows the territorial profiles of the three major product groups. Not surprisingly, the U.S.A. dominates the herbicide market and West Europe the fungicide; the importance of insecticides in 'the rest'

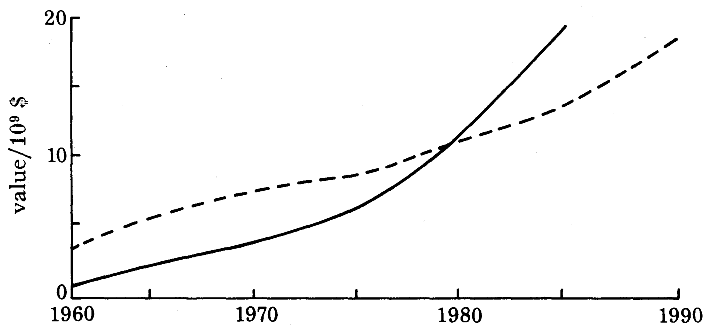

FIGURE 4. Agrochemical market value, 1960–90: ——, dollars of the day; – – –, constant 1980 dollars.

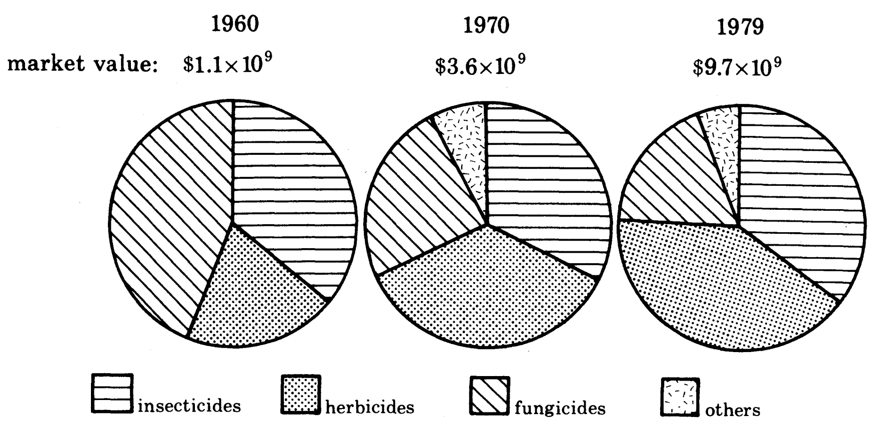

FIGURE 5. The development of the market, 1960–79.

(developing world) and of Japan – particularly for rice fungicides and insecticides – also stand out.

I have so far reviewed some of the problems and opportunities that are inherent in the present structure and trends of the crop protection market, problems and opportunities that are only underlined for us in the Western nations when we consider the huge unsatisfied needs for crop protection of countries such as Russia and China, with whom we still do relatively little trade in agrochemicals. A look at world production of cotton (figure 7), rice (figure 8) and soybean (figure 9), three of the key crops mentioned earlier, will illustrate this point.

MANUFACTURE

Manufacturing considerations represent the second major variable in the techno-commercial equation. In considering the impact of developments in the field of manufacture, three elements will be covered: location and scale (which interact with one another), and production costs.

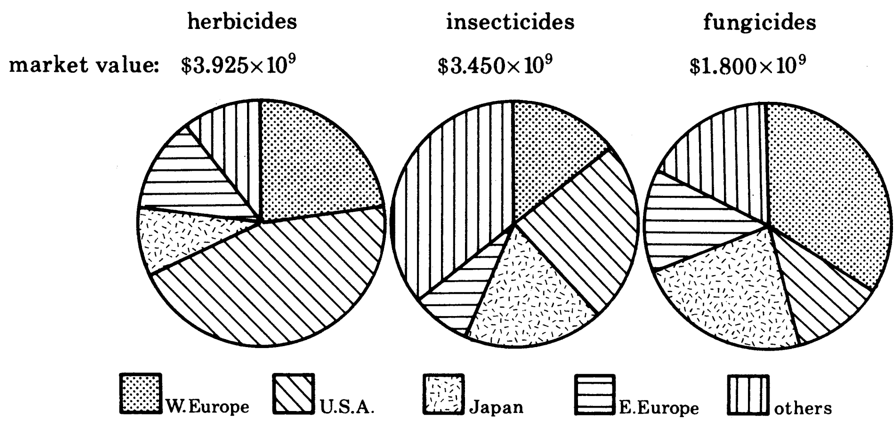

FIGURE 6. Product groups in 1979, divided according to region.

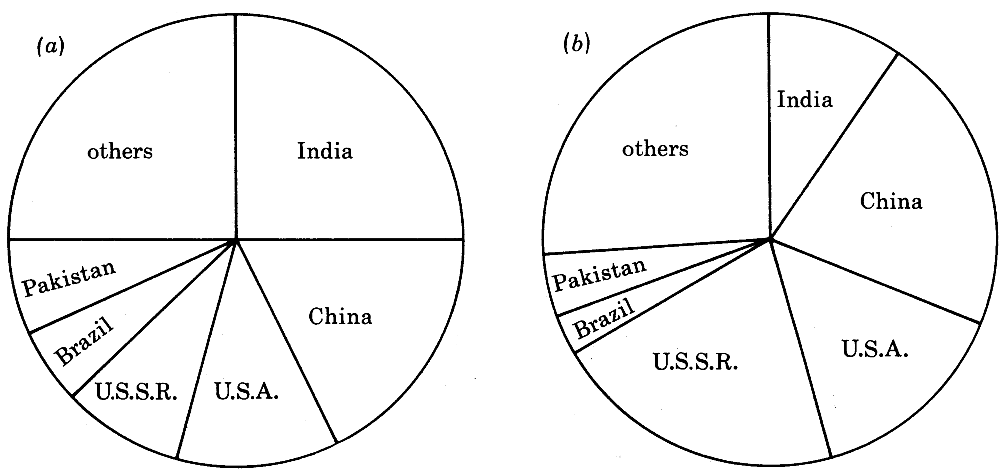

FIGURE 7. Cotton growing in 1979: (*a*) areas; (*b*) production.

TABLE 5. CROP PESTICIDE SECTORS

In terms of their estimated 1979 end-user $ value, the leading crop pesticide sectors are:

maize herbicides, $1050M
cotton insecticides, $975M
fruit and vegetable insecticides, $900M
fruit and vegetable fungicides, $860M
soybean herbicides, $760M
rice insecticides, $420M
maize insecticides, $360M
cotton herbicides, $350M

Historically, the manufacture of the active ingredients (a.i.) for crop protection products has followed the same pattern as the rest of the fine chemicals industry. Single, world-scale, plants have been established to satisfy total demand for a.i. from one of the home-based factory sites of the company concerned at least until patents are close to expiring; during this period, formulation and packing has been developed within the local market, followed by basic manufacture when the direct effect of market economics has demanded it.

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Now, however – and this again is not peculiar to the agrochemical industry – demands for the transfer of technology from the more to the less developed countries have led to growing pressure to go beyond local formulation at an early stage; increasingly, tariff barriers or constraints upon import licences are being used by the countries of Southern Asia and Latin America to apply pressure for basic manufacture. As a result, process development is beginning

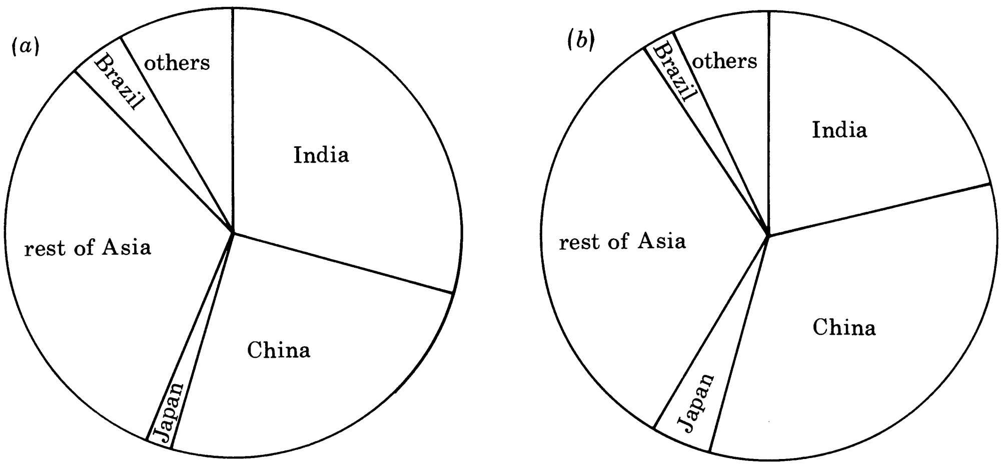

FIGURE 8. Rice growing in 1979: (*a*) areas (total 142842000 ha); (*b*) production (total 366505000 t).

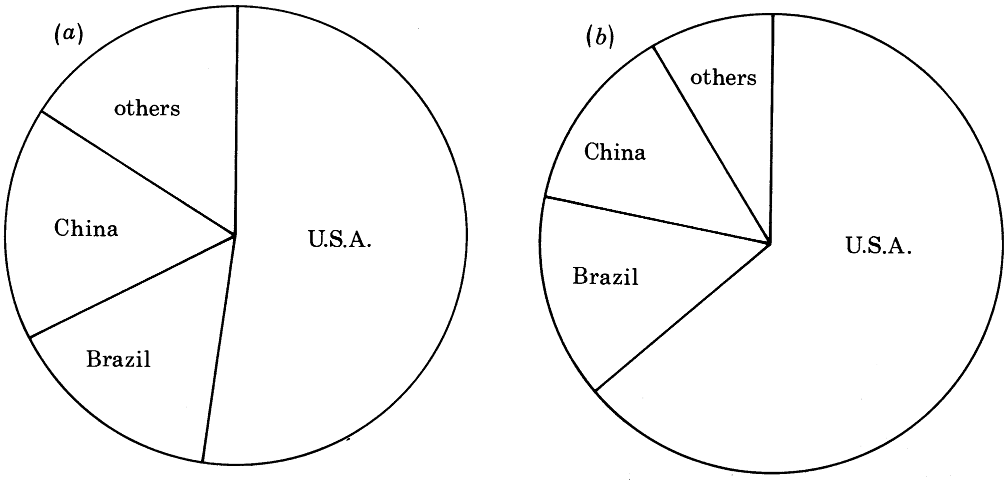

FIGURE 9. Soybean growing in 1979: (*a*) areas (total 48149000 ha); (*b*) production (total 79541000 t).

to be aimed at the add-on modular plant, capable of scaling in multiples of a few hundred tonnes, rather than towards the large monolithic complex that becomes obsolete if large overseas markets cease to be economically sourced from it. Economics of scale are less readily achieved, but there is a greater flexibility to tailor the process to an appropriate mix of labour intensity and capital intensity, or to bring back into production plant previously dedicated to a now defunct product.

Another aspect of the diffusion of manufacturing technology is the establishment of capacity to manufacture bulk commodity chemicals, including old pesticides, as part of the growth of national chemical industries. This may or may not be the best use of local resources at the time, but there is certainly nothing surprising or unreasonable about it. However, it needs to be recognized that it may result in the preservation of some of the older aspects of crop protection technology to the detriment of safer and more effective products and systems.

A new attitude towards future economies of scale, and the likely size of plant units, is being pressed upon us by the outside world. It is also arising from the technical achievements of the crop protection industry, in putting into the market more effective products and in learning

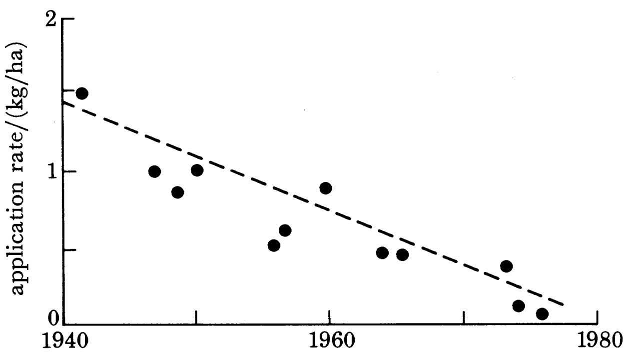

Figure 10. Rates of application of insecticides.

to use them more intelligently. Figure 10 presents a rather generalized picture of this point, and depicts the steady reduction in application rate of a.i. per hectare required to produce acceptable control of cotton pests in the U.S.A. A more specific example derives from the group of synthetic pyrethroids discovered by Dr Elliott at Rothamsted. A world-scale plant for the most active of these need have capacity to manufacture only a few hundred tonnes of a.i. – a dramatic comparison with the thousands or tens of thousands of tonnes of the 1950s or 1960s.

Production costs

Production costs contain a number of elements that are all rising, but that are doing so at different rates in different parts of the world: cost of plant, raw materials, energy and labour. Because of their varying impact on agrochemical businesses, it would be inappropriate to comment at great length. From a U.K. base, a few salient points are: the chemical plant construction index has virtually doubled in the U.K. since 1975, while the world price index of a basket of pesticides has not increased by as much. During the same period increased energy prices have pushed up the index of raw material and energy prices by 125 % with a consequent malefic effect on production costs. The investment bracket for the first serious production plant is now nearer £20M than £10M, and it will typically take $2\frac{1}{2}$ years from sanction to beneficial production. The problem of estimating bearable production cost, and likely profitability, will be obvious with capital cost per tonne per year ranging from £2000 to £6500. It is well known that the costs of some raw materials and intermediates have increased steeply in recent years, following the price of naphtha which effectively trebled in 1973–4, and again in 1978–9; table 6 gives three examples.

Other features of the cost picture, some of which show through in these figures, are the following.

(*a*) The contribution to manufacturing cost of the price of process energy is usually not more than about 10 %, and naturally depends upon the complexity of the product and number of stages involved. Products built up from, say, aromatic hydrocarbons contain an added energy component in the cost of raw materials.

(*b*) Cost increases in raw material and energy costs take 12–18 months to work through into the finished product.

(*c*) With speciality organic products, the impact of naphtha cost increases depends upon the nature and complexity of the finished product: MCPA will be affected more than pyrethroids.

(*d*) Industry's view of the cost of materials has a distinct geographical flavour. At this moment, we in the U.K. are buying cheaply compared with most of the world; in Germany the opposite holds; in the U.S.A. the last 12 months have been something of a switchback.

Table 6

	£/ton	
	1973	1980
phenol	100	300
m-chloraniline	1100	2100
pyridine	400	1800

The way in which these factors finally work through to the farmer also depends, of course, on market factors; the industry's present and future problems in this area may be summarized by noting that a number of widely used commodity products such as organophosphorus insecticides and triazine herbicides are now selling at, or near to, their marginal cost of production. As an example, the dollar price in the U.S.A. of malathion, parathion and toxaphene was virtually unchanged during 1975–9, and of atrazine and 2,4-D it was significantly reduced. In Japan, the retail price index rose during 1970–8, by just over 100 %, while the pesticide price index increased by approximately 60 %.

Research and development

Under this heading will be included the whole area of work to satisfy regulatory bodies.

First, let us consider the company profile of the business: if one talks of some 25 'majors' from whom most of the innovations of the last 50 years have stemmed, then half of them are listed in table 7. Please do not bother with the mass of numbers: the point is that these names emphasise where we have come from and therefore what we should be good at and the nature of investments with which our companies have hitherto been familiar. The skills of the organic chemist have increasingly been wedded to those of the biologist to produce new molecules that could be patented, for which the chemical engineers could design manufacturing plant, and which could be formulated in simple equipment; the chemicals are then sold in cans across the counter and applied with the use of technology that in many respects seems hardly to have advanced over the decades. The following papers in this symposium will show how the position may be changing, and why the chemical industry needs to review its position. I cannot avoid making some comments in advance on the possible techno-economic impact of some of these changes.

First, what is the likelihood of continuing success in the traditional search for new products, depending as it does on chemical and biological perspiration, inspiration and luck?

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The accepted view is that invention is becoming more and more difficult and that we can expect the rate of introduction of new chemical products to diminish markedly in the future. There are certainly statistics to demonstrate this (figure 11), but they may well conceal what is really happening: that, for reasons to be given shortly, it is the introduction of 'average' or 'minor' products that will tend to fall away. The appearance of the real breakthrough products,

TABLE 7. MAJOR AGROCHEMICAL COMPANIES

Bayer	Rhone-Poulenc	Du Pont
Ciba-Geigy	I.C.I.	Stauffer
Shell	B.A.S.F.	Dow
Monsanto	Eli Lilly	American Cyanamid

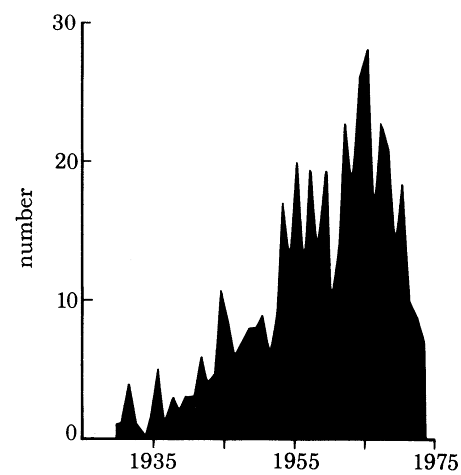

FIGURE 11. Number of pesticides introduced each year from 1930 to 1974.

upon which companies and the industry as a whole grow, has never been a particularly frequent occurrence. Examples are the original discovery of organophosphates, DDT, BHC, phenoxyacetics, triazines, bipyridyls, azolylmethanes and synthetic pyrethroids. It is of course true that the cost of making these discoveries, through the traditional exploratory process, has increased rapidly (table 8), and the screening rate necessary per commercial success has now reached a level that must increase our doubts about dependence on this approach.

Reason requires us to consider alternative approaches, in which a basic understanding of the target systems plays a bigger part. But all present-day financial pressures tend to operate against this essentially long-term view. Industry cannot be expected to invest more heavily in this area of pesticide research, so that the potential scientific contributions of University and Research Institute are of fundamental importance; it is probably still true to say that our science base is alarmingly insecure in relation to the money and resources devoted to empiricism.

Extending the illustration of the screening explosion to the question of total cost of R & D per product commercialized, table 9 shows figures generated by I.C.I. colleagues from industry statistics, as best we can obtain them. Since 1972 the cost from test tube to market place has more than doubled (less than \$10M to more than \$20M).

This trend adds weight to the present-day statistics at the beginning of this paper: if under normal conditions a target market of around $35M is necessary, only by achieving higher than average profitability, or faster than average market penetration, can we reduce this figure to, say, $20M.

Little can be said to encourage those dependent on specific chemical innovation to satisfy the needs of the specialist or small user. I believe that the majors would find the opportunity

Table 8. Number of chemicals screened to obtain one commercial success

year	1956	1965	1970	1973	1978
number of chemicals screened	1800	4000	7500	10000	15000

Table 9. Estimated total cost of R & D per product commercialized (Lever & Strong 1973)

year of estimate	1956	1964	1967	1969	1970	1972
total cost/$10^6$$	1.2	2.9	3.4	4.1	5.5	> 10

cost of targeting in this way too great, even if the development and registration pathway could be eased, so that the route to new products will be through spin-off from other uses, and generally through direct intervention of specialist growers or their associated research organizations.

New approaches to crop protection

Let us now consider the question of impact of new approaches to crop protection. Fruitful research is being done on crop protection systems bearing a variety of labels: 'biological', 'biorational', 'integrated', and so forth. Later papers in this symposium will be dealing with this work. It is common to almost all of these approaches that chemicals have an important or vital place, often on the assumption that through timing or intrinsic biological effect they can be used as selective agents. But we do not yet know how to design species specificity into our molecules: it just happens. We are therefore faced as an industry with a question that has several parts: how widely, and how fast, will new systems of pest control show their technical and economic feasibility and be accepted into grower practice? To what extent will the existing industry find a planned role – as opposed to one based upon serendipity – in providing the chemical components of such systems? And – the really difficult question – what part can we, or do we want to, play in the biological research, system development and subsequent commercialization of non-chemical or non-traditional agents?

Safety and registration requirements

Finally, I shall outline the other major component of our R & D programmes: the work required to demonstrate safety of candidate products, and to satisfy registration and other regulatory bodies of their fitness for sales.

Let me be quite clear that I do not question the need for careful regulations, thoughtfully applied. Figure 12 shows what this means in the U.K., where for many years there has been the possibility of dialogue with the authorities to ensure that, for example, toxicological work is addressed to the real problems and carried out in an effective way. The timescale is still

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approximately 6 years. Looking at the total world picture, however, the situation becomes considerably less straightforward: regulatory protocols vary from one country to another, accessibility for discussion is sometimes greatly restricted, and a legalistic approach sometimes overwhelms reason. These are not the conditions under which willingness to undertake the future costs of innovation can flourish; indeed, the ability to do so within a prescribed budget

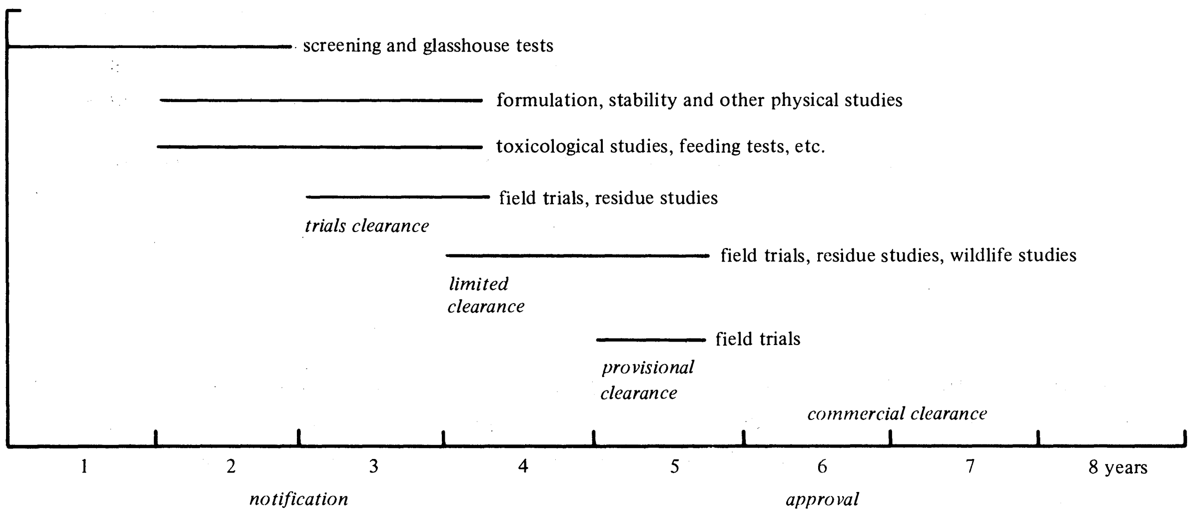

Figure 12. Registration of new chemicals in the U.K.

Table 10. Distribution of pesticide research costs (percentages)

synthesis and screening	20
biology (field testing)	23
safety	22
chemistry (process and formulation)	20
administration, etc.	15
total costs now estimated to bring a new product to market: $20M	

is being steadily diminished by growing proportion of costs accounted for by registration requirements. I estimate that this accounts for 25–30 % of the total R & D budget (table 10), significantly more than 5 years ago; long-term toxicological studies – three or more may be needed – cost around £0.25M each, and the whole package not much less than £1.5M for initial registration.

The continued growth of these costs is one trend that concerns the chemical industry greatly. The other, to which only passing reference will be made here, is the sometimes equivocal role of 'the expert' in guiding the process of pesticide regulation. Toxicology and industrial safety are highly complex matters, in which specific experts can be fallible, and they are certainly affairs in which the view of the informed layman must be heard; but if individuals or pressure groups are allowed to set aside or overrule the considered collective advice of properly appointed experts on a 'don't bother me with facts' basis, the whole regulatory process will become unmanageable.

Conclusions

This last section will be a strictly personal view of the likely techno-economic consequences of the uncertainties facing the agrochemical industry.

In its present form, the agrochemical business is a maturing industry in which, in aggregate, too much money is spent on R & D; of course, it is always the other man who has got it wrong! Nevertheless, pressures to merge or share activities are growing and there will be increasing evidence of this fact. Product acquisition or exchange is already the currently much in vogue in most major companies, almost all of whom are disappointed by the productivity of their research in relation to their ambitions – or even their need to run faster to stand still. As a maturing industry, agrochemicals will only prove highly profitable for those who are lucky; this implies those who are large enough and experienced enough to recognize luck when they see it. I believe that we shall see companies leaving the present business, and logic suggests that newcomers should not be buying their way in. I am not suggesting that there are no more big discoveries to be made; quite the contrary. One of the biggest contributions of the story of permethrin and its analogues may be the demonstration of commercial viability of complex molecules active at rates of a few grams, or tens of grams, per hectare. I believe that there will be a growing trend towards expensive but highly cost-effective materials requiring major advances in our application methods, and it is timely that such advances are now being made. This must be one of the most important developments in crop protection technology during the next decade, linked, I would expect, with the full impact of micro-electronics upon monitoring and control systems.

To relate these thoughts to future developments in our industry: there seems a real opportunity to promote the concept of selling an effect – a clean field or an undamaged crop – rather than kilograms of product in a can, and this could lead the industry in new directions and into new partnerships. This is especially true of the changes that could come about through the development of what I will loosely call integrated pest management. I have already indicated the dilemma with regard to providing highly selective chemicals; we must be even more uncertain about our contribution in the biological field. Formulated pheromones are recognizable as a possible article of bulk commerce, but will they ever attract the 'majors'? And if they do not, will they ever reach full and effective commercialization? In the truly biological area – production and use of pathogens and parasites – almost all the running is being made by small specialist organisations, and I would expect this to remain so for the foreseeable future.

I hope that I have managed to convey in this paper a mood, rather than a message, and it is a mood of uncertainty; not about the continuing existence of an agrochemicals industry, but about its future size, geographical diversity, technical profile and profit-fuelled ability to continue to spearhead innovation.

Discussion

C. Wall (*Rothamsted Experimental Station, Harpenden, U.K.*). The future of crop protection may well be clouded by our obsession with chemicals. Reference has been made by this morning's speakers to 'the agrochemical industry', 'chemical control measures', crop protection chemical and even 'behaviour controlling chemicals'. Surely we need efficient crop protection, which will involve the use of chemical agents and the manipulation of pest populations by a combination of several biological techniques.

Is there a realistic future for a crop protection industry which provides the farmer with a *complete* service – provision of monitoring procedures and equipment, interpretation of the results, advice on control strategy and tactics and supervision of control procedures?

The volume of chemical sales would not be of paramount interest, neither would patent considerations. The farmer would use the best services which he could afford. Open collaboration between the crop protection industry, government research institutes and universities would provide relatively cheap (for the industry) ideas and procedures; such an arrangement would give considerable stimulus to applied research workers in fields other than the generation of new conventional pesticides.

J. T. Braunholtz. I think there is general agreement that for the foreseeable future crop protection will depend upon the proper use of approved chemicals, in association with other good agricultural practices involving inputs from the agronomist, plant breeder, soil scientist, and so on. The development of more active chemicals, and of improved application techniques, may well contribute to a trend towards packaged systems and the sale of 'effects'. The crop protection industry already exhibits several of the features referred to by Dr Wall, and we see – for example – considerable activity in the direction of pest monitoring and advice on control measures. It is very unlikely that all these inputs would ever be provided by one organization. Collaboration between sectors of the industry of the kind suggested is in principle essential, and much of it already occurs; it can only be maintained fruitfully if it is to the ultimate benefit of both the users and providers of the products and systems in question, and this benefit must be provided without unacceptable risk to consumer and environment. Matters such as cost and industrial property considerations cannot therefore be dismissed as easily as the question suggests.

R. J. Cremlyn (*School of Natural Sciences, The Hatfield Polytechnic, U.K.*). Since, as Dr Braunholtz mentioned, it often takes a new compound 8 years from the test tube to the point of marketing, the increased demands by the registration authorities have extended this period so that there is now an induction period of about 12 years before a new compound starts to make any money for the company through sales. In view of these facts, is not the patent life of 16 years a severe deterrent to the introduction of new chemical pesticides by industrial companies?

J. T. Braunholtz. Patent life is of course not the only determinant of the useful commercial span of an agricultural chemical, but it is true that the prospect of only a few years of sales under patent protection is at least a significant deterrent in relation to the very high cost of innovation; in some cases, the timespan of the regulatory process could make it impossible to generate a fair financial reward from a new product. There are moves to recognize and alleviate this problem, by extension of effective patent life, in the U.S.A. and Europe; on the other hand, there are also changes in the opposite direction (e.g. in Brazil and India) which can only be described as extremely short-sighted, and in the long term potentially damaging to the chemical industry's will and ability to invest in R & D.

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