The Role of the Chemical Industry in Improving the Effectiveness of Agriculture [and Discussion]

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The role of the chemical industry in improving the effectiveness of agriculture

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The development and marketing of novel technology by the chemical industry has been a fundamental ingredient in the improvement of crop yields. Further advances will result from the continuing development of more effective pesticides. Improved application technology and better diagnosis of precise crop requirements will also lead to the more efficient usage of existing and future products.

New approaches to crop improvement based on chemical plant-growth regulators and genetic engineering of plants represent major technological opportunities for the future. Realization of these opportunities demands a substantially increased investment in basic plant research, a requirement already recognized within the chemical industry.

1. Introduction

Technological developments provided by the chemical industry have played a major role in the improvements in agricultural productivity that have taken place this century, especially since World War II.

In the future, it seems inevitable that the demands of an expanding world population will continue to require substantial increases in the efficiency of crop production, despite inequities in the distribution of agricultural produce. It is particularly appropriate in this symposium to review the application of chemical technology to crop production and, from current trends, to predict developments that will occur by the end of this century.

Current chemical inputs to arable agriculture comprise plant nutrients, of which fixed nitrogen is the most important, and pesticides, which shift the balance of competition between crop plants and their pests, pathogens and weeds in the farmer's favour. These inputs may be considered as producing an optimal nutritional and biotic environment in which crop varieites adapted to these inputs can produce yields limited only by their genetic potential. To the extent that many environmental constraints, can now be alleviated by the use of chemicals, future developments will concentrate on extending the potential performance of crop plants, either by increasingly sophisticated genetic modifications or by the discovery of chemical plant-growth regulators. In either event, there will be increasing emphasis on understanding the biological and biochemical processes contributing to plant growth and development.

2. Fertilizers

Where arable crops are intensively managed to produce high yields, fertilizer costs typically represent half the cost of the 'biological' inputs employed. The remaining inputs, pesticides and seed, each represent about one quarter of the input costs. The usage of fertilizers is thus a significant factor in the economics of crop production.

Fertilizers, by their nature bulk plant nutrients, are produced in large amounts (120 M t worldwide in 1983) at relatively low cost. However, as transport is a significant proportion of the total cost of usage, production and distribution is largely national or regional, with little export trade.

Fertilizer consumption figures for the United Kingdom since 1929, given in figure 1, show a rapid rise, particularly for nitrogen. However, since about 1960, usage of phosphate and potash fertilizers has remained approximately constant (figure 1). In general terms, phosphate and potash are strongly held within soils and accumulated reserves now provide optimum supplies of these nutrients. Application of phosphate and potash fertilizers is thus restricted to that required for the replacement of nutrients removed in harvested crops (Lidgate 1984).

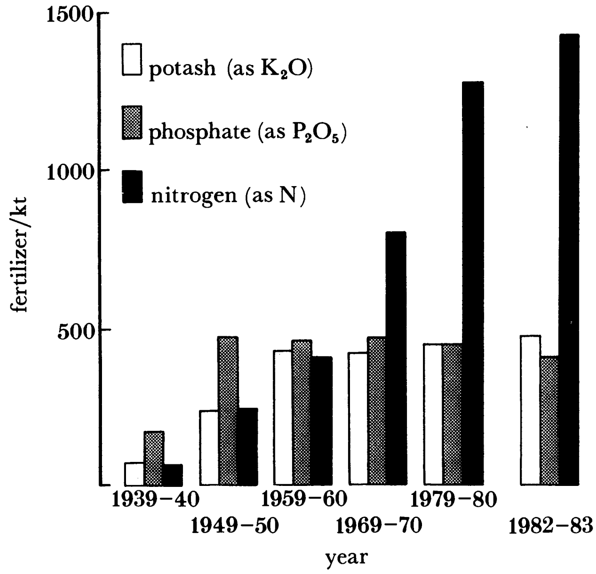

FIGURE 1. Usage of nitrogen (as N), phosphate (as P_2O_5) and potash (as K_2O) fertilizers in the U.K. since 1939–40. Data from Hood (1982).

Although soils contain considerable quantities of organic nitrogen (Lindsay & Crossett 1984), nitrate ions, which form the main source of soluble nitrogen for growing crops, are rapidly leached, at least under northern European conditions. As a result, the application of nitrate- and ammonia-based fertilizers, by increasing the pool of nitrogen readily available to the crops, produces dramatic increases in crop yield (see, for example, Lidgate 1984). The extent of fertilizer usage in practice is then related to the economics of the crop in general and the precise nitrogen response pattern of the crop varieties in use. For wheat growth in the United Kingdom, there has been a steady rise in total nitrogen application rates and in yields (figure 2) over the last 30 years. This reflects the availability of successive varieties with increasing yield potential and higher resistance to lodging, coupled with rising grain prices (Hood 1982). For higher value crops such as potato and sugar beet, where the financial benefits of high nitrogen usage have long been recognized, heavy dressings of fertilizers have been applied ever since these became readily available.

Most nitrogen fertilizer is now produced by the chemical fixation of atmospheric nitrogen in some variant of the original Haber process. The fact that industrially fixed nitrogen now

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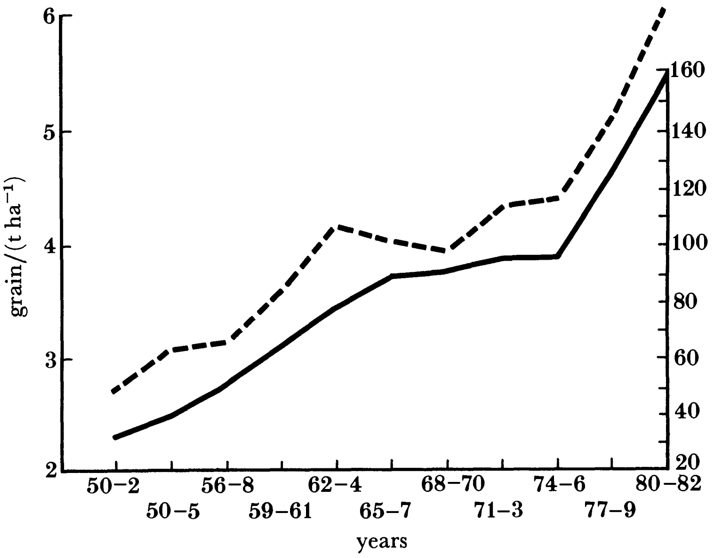

FIGURE 2. U.K. nitrogen fertilizer usage (solid lines) and wheat grain yields (broken line); three-year means 1950–2 to 1980–2. Data from Hood (1982) with additional figures from Ministry of Agriculture and Fertilizer Manufacturers Association statistics.

represents some 30% of the total world nitrogen fixation (Subba Rao 1980) bears witness to the success of this technology.

In looking to the future, the ever-increasing demands for food should ensure continued expansion of both production and consumption of nitrogen fertilizers on a world scale. As the chemical route is based on natural gas or oil feedstocks, it is to be expected that there will be continued attempts to improve the efficiency of the process. This may be achieved either through better design of chemical plant or development of better catalysts for the various steps in the process (King 1983). However, likely increases in the real cost of nitrogen fertilizers and concern about levels of nitrate in food and water (Lindsay & Crossett 1984) should lead to the development of more accurate techniques for forecasting crop nitrogen requirements. Such diagnostic techniques will then help to maximize the efficiency of fertilizer usage and reduce losses due to leaching.

At least half of the total world nitrogen fixation is currently contributed by biological (essentially prokaryotic) systems. The advent of gene-cloning techniques and more recently the demonstration that bacterial genes can be expressed in plants (Framond *et al.* 1983) has renewed speculation that nitrogenase genes could be used to provide crop plants with their own nitrogen fixation systems (Postgate & Cannon 1981). Although in reality transfer of the *Rhizobium* symbiosis to non-leguminous plants may be a more realistic goal, it is necessary to discuss the impact of this in relation to the usage of industrially fixed nitrogen.

In gross terms, the energy required to supply nitrogen to a non-legume (80 GJ t^{-1} of N) for fertilizer manufacture plus 215 GJ for uptake and assimilation of nitrate (gives 290 GJ t^{-1} of N) is roughly similar to that expended by legumes in biological nitrogen fixation (250 GJ t^{-1} of N) (King 1983). The dominant energy-requiring steps in these systems are the reduction of nitrate to ammonia in non-legumes and the fixation of nitrogen to give ammonia in legumes. Theoretical considerations suggest that the energy penalty of nitrogen fixation will be greater than that of nitrate reduction, leading ultimately to reduced yields in nitrogen-fixing plants

(King 1983). Practical comparisons of legumes supplied either with nitrate fertilizers or allowed to fix nitrogen symbiotically have indeed shown reduced yield under conditions of biological nitrogen fixation (Ryle *et al.* 1979; Silsbury 1979). Estimates of this yield reduction suggest values between 10 and 15% (King 1983) and, under current economic conditions, the value of this lost yield would exceed the value of savings in nitrogen fertilizer purchase.

These arguments considerably weaken the case for the introduction of nitrogen fixation into non-legume crop plants in intensive agricultural systems. It is possible (though unlikely) that these economic considerations will change in the future, but discussion of this is outside the scope of this review. More widespread use of biological nitrogen fixation seems an attractive goal in underdeveloped countries or areas where current economic and social conditions do not permit the use of high levels of nitrogen fertilizers. Alleviation of the nitrogen limitation to crop yield, for example by allowing cereal plants to produce nitrogen-fixing nodules in association with *Rhizobium* species then becomes an attractive scientific objective.

3. Pesticides

The development of high-yielding varieites of crop plants and their growth in large areas of monoculture has provided an enormous biological opportunity for competing species: weed plants, insect pests, fungal, bacterial and viral pathogens. Exact figures on crop losses due to these agents are difficult to measure, but in large-scale agriculture in developed countries, crop losses of the order of 30–50% would be typical. Severe infestation could still completely devastate local areas under unfavourable conditions. Not surprisingly, therefore, sales of chemical pesticides to control weeds, insects and pathogenic organisms generate large revenues worldwide, amounting, for example, to U.S. $13300 M in 1982. Sales of different types of pesticide vary widely between different countries depending on the predominant crop and pest problem but, overall, herbicides and insecticides make up most sales (table 1). Fungicides controlling the many fungal diseases of crops show lower sales, probably because of the success of plant breeders in producing disease-resistant varieties.

Table 1. Breakdown of world pesticide sales by type for 1982

pesticide type	percentage of total sales value
herbicides	47
insecticides	31
fungicides	18
others	4

The efficiency with which modern pesticides can control their target organisms and the resultant increase in crop yield is best demonstrated by a number of examples. In table 2, control of the major insect pests of cotton with synthetic pyrethroid insecticides is illustrated with reference to yields of lint. It is noteworthy here that effective insect control can be achieved with very low insecticide dosage rates, illustrating the potency of the pyrethroids, which in molar terms matches some of the most active mammalian drugs.

Whereas with insecticides the target organism is very different biologically from the crop, herbicides most often selectively kill a weed plant that is very closely related to the crop. This can now be achieved successfully for most important crop–weed combinations with resulting crop-yield increases. As an example, yield increases in wheat and barley resulting from control of wild oats (*Avena fatua*) by the Hoechst compound diclofop-methyl are shown in table 3.

The last example concerns the control of cereal diseases with fungicides (table 4). Here again, sequential treatments with the triadimefon fungicides manufactured by Bayer give substantial yield increases across a range of current winter wheat varieties.

Table 2. Effect of controlling cotton bollworm and tobacco budworm on yields of cotton in the U.S.A. (I.C.I. data)

treatment	lint yield/(kg ha^{-1})
control (untreated)	67
Cypermethrin 28 g (a.i.) ha^{-1}	402
Cypermethrin 56 g (a.i.) ha^{-1}	609

(a.i. = active ingredient.)

Table 3. Yield improvement in cereals resulting from wild oat control with Diclofop-methyl (O'Donovan & Sharma 1983)

treatment	plot yield/(g m^{-2}) wheat	barley
untreated control	143	251
treated with diclofop-methyl at wild oat leaf stage 2	366	500

Table 4. Response to fungicides (Plant Breeding Institute trials 1981 and 1982[a])

		untreated	treated
Huntsman	C	101	113
Armada	C	96	107
Aquila	C	103	120
Brigand	—	98	117
Avalon	C	101	120
Norman	C	100	121
Fenman	—	106	120
Longbow	—	103	127
Galahad	—	106	121
Moulin	—	105	121

Source: N.S.D.O. (1983). Fungicides: 1981, Bayleton BM(GS 30)+Bayleton (GS 57); 1982, Bayleton BM(GS 30)+Bayleton CF (GS 39)+Bayleton CF(GS 59).

[a] Yield expressed as percentage untreated mean of five control varieties, C (7.74 t ha^{-1}) mean for two sites in each of two years.

These three examples typically illustrate the way chemicals have been used effectively to overcome various major, long-recognized agricultural problems. In other spheres, chemical technology has had an even more profound effect on agricultural practice. In particular, the discovery of non-persistent total herbicides such as paraquat and glyphosate has allowed the complete replacement of traditional cultivations by the so-called direct-drilling technique. The elimination of ploughing as a weed control measure reduces fuel consumption and increases machinery work rates (Green & McCulloch 1976). It has added advantages in the maintenance of soil structure and the prevention of soil erosion (Allen 1975).

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Clearly, many of the more obvious agricultural needs for pesticides are already catered for in some degree. This is in marked contrast to the pharmaceutical business, the other major biological outlet for the chemical industry, where there is still no effective therapy for several major human diseases.

Future developments in the agricultural pesticide business will centre mostly on improvements in cost effectiveness of pesticides and in increased selectivity and ecological acceptability (Pickett 1984). Developments of this type are well illustrated by the changing characteristics of insecticides shown in table 5. The pyrethroid-based insecticides now replacing organophosphorus compounds such as parathion, show reduced mammalian toxicity but greatly increased toxicity against the target insect pest. With the successive generations of pyrethroids introduced over the last 11 years, a 35-fold increase in toxicity against the cotton pest *Heliothus* (table 5) has been achieved. There is also a continued need to develop insecticides when resistance develops to existing agents – one reason for the replacement of organophosphorus compounds by pyrethroids. In this case, the replacement compounds also had the advantage of displaying a much greater activity–toxicity ratio. Fungal pathogens also develop resistance to pesticides but it is interesting that there have been few problems from the emergence of herbicide resistant weeds, presumably because of the long generation times and relatively poor dispersal mechanisms of plants.

TABLE 5. DEVELOPMENT OF MORE ACTIVE, SAFER AND MORE EFFECTIVE INSECTICIDES AS EXEMPLIFIED BY THE I.C.I PYRETHROIDS

	higher activity against pest (e.g. cotton bollworm, *Heliothis*)		
compound	permethrin	cypermethrin	cyhalothrin
year of release	1973	1977	1984
relative control of *Heliothis* (permethrin = 100, based on LD_{50} (rat oral)	100	458	3505
	increased safety (lower mammalian toxicity)		
compound	parathion		permethrin
LD_{50} (rat oral)/(mg kg^{-1})	4		3800
	new mode of action (effective against resistant strains)		
compound	organophosphates		pyrethroids
mode of action	anticholinesterase		nerve membrane disruption

Clearly, in looking to the future, some comment must be made on the possibilities for developing biological control strategies, particularly for insect pests. In the past, biological methods have received little attention from the agrochemical industry as they gave less effective control of pests than chemical agents. However, in the quest for more ecologically acceptable control measures, greater attempts will be made to develop the technology for efficient use of biological methods.

As an example, it is well established that sex attractant pheromones can be used to control such pests as the pink bollworm moth (*Pectinophora gossypiella*) in cotton, by disrupting mating and lowering fecundity of the insect (Critchley *et al.* 1983). In the past, use of this approach has been limited because formulations for the necessary slow release of the compound under field conditions have been cumbersome and have necessitated specially modified application techniques. However, it has now been possible to develop a microencapsulated formulation compatible with conventional spray technology that produces a suitable controlled release of pheromone. With this technique, we have been able to control pink bollworm in cotton more effectively than with conventional insecticides (Critchley *et al.* 1983). No doubt similarly ingenious solutions will be found for the effective deployment of other biological control measures in the future.

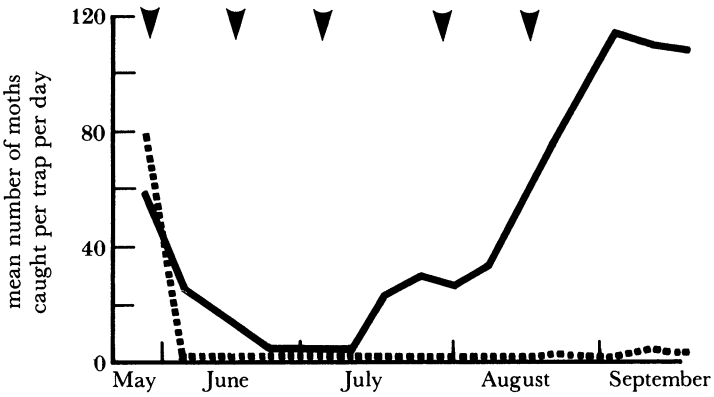

FIGURE 3. Mean daily catches of pink bollworm moths in pheromone traps located in large areas of cotton treated throughout the season with insecticides (solid line) or microencapsulated pheromone (broken line). Arrows indicate times of pheromone application.

Although this review has concentrated so far on the development of new chemical toxophores, major changes are also occurring in techniques for applying pesticides. The trend is to reduce substantially the volumes of liquid required to apply the active pesticide ingredient. This is partly a result of the energy and manpower requirements for transporting large volumes of water and partly a result of the much reduced application rates required by modern pesticides, as exemplified in earlier sections. Conventional spraying techniques have already been modified to reduce spray volumes considerably but current developments, pioneered by I.C.I., break new ground with the application of electrodynamic spraying techniques.

In the I.C.I. 'Electrodyn' system (Coffee 1981), the pesticide, usually in a specially designed non-aqueous formulation, flows under gravity through a nozzle containing an electrode maintained at a high electrical potential (typically 25 kV) relative to earth. The imparted charge disperses the liquid into droplets of precisely controlled sizes, repels them from one another and attracts them towards the crop, which is at earth potential. This allows a remarkably uniform coating of the plant with pesticide. For example, upper and lower leaf surfaces receive equal amounts of pesticide. Most dramatically, effective pest control can be achieved with as little as one hundredth of the conventional spray volume (i.e. 2 l ha^{-1} as opposed to the 200 l ha^{-1} of conventional techniques (Parham 1983)).

4. Plant-growth regulators and crop biology

An area of great promise for future development of agricultural effect chemicals is in direct modification of crop plant performance. A variety of such effects can already be achieved, most often by combinations of synthetic plant hormones or by antagonists to the biosynthesis of such hormones (Luckwill 1978). Salient examples would include the stimulation of parthenocarpic fruit growth by a variety of more or less specific gibberellin biosynthesis inhibitors (Humphries 1968; Dalziel & Lawrence 1984).

A more attractive target for plant-growth regulatory chemicals is a direct increase in crop yield. The requirement for such an effect is illustrated by the data in table 6 for the U.K. crops of wheat and barley. Although average yields are still only around half of record yields, record yields approach the theoretical maxima calculated from a consideration of light interception and photosynthetic efficiency (Austin 1978). Indeed, in the exceptional conditions of 1984, maximum observed yields of wheat have exceeded Austin's original predictions, giving values of between 13.1 and 14.1 t ha^{-1} (Lidgate, personal communication). Further increases in maximum crop yield must thus depend on enhancing the yield potential of crop species – a goal equally pursued by plant breeders.

Table 6. U.K. cereal yield statistics

	winter wheat	spring barley
estimated potential yield/(t ha^{-1}) (Austin 1978)	12.9	11.1
record yields obtained/(t ha^{-1}) (Hood 1982)	12	10
national average yield 1979–80/(t ha^{-1}) (H.G.C.A. 1980)	5.2	4.1

As a first approximation, crop yields are a function of the total plant biomass produced and the proportion of that biomass devoted to harvestable products (e.g. tubers, fruits, seed). For some root and forage crops, the harvest index is already around 85% and it is doubtful that it could be much increased in practice (Bingham 1981). Historically, yield improvement in cereals has been achieved mostly by increases in harvest index, to the current values of approximately 50%, with little or no change in total biomass (Austin *et al.* 1980). There may be further scope for harvest index improvements in cereals (Austin 1978) and indeed plant growth regulatory chemicals applied to cereals to prevent lodging (straw shorteners) do result in some improvements in harvest index and yield (Humphries 1968).

However, it seems inevitable that further improvements in cereal yield, as in other crops, must address the factors limiting total biomass production. Given optimum supplies of water and inorganic nutrients (see §2), biomass production closely parallels the total light energy received by the crop as demonstrated in figure 4 (Monteith 1977). The fact that four widely different crops show very similar dry matter: intercepted light relations perhaps indicates similarly limiting photosynthetic processes in these species. The potential for improving the efficiency of light utilization is best indicated by the observed partitioning of light energy into different processes. Table 7 contains data of this sort for a typical C3 crop taken from Holliday (1976).

Although C4 crops, by virtue of the absence of photorespiration, achieve an improvement in efficiency of light utilization (the actual figures are 2.7% for C3 crops and 4.0% for C4 crops)

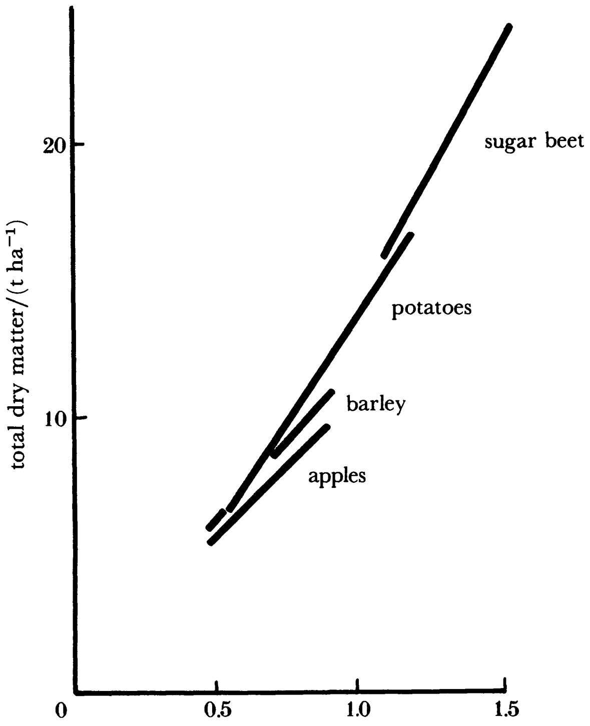

FIGURE 4. Relation of total dry matter accumulation to total intercepted solar radiation for crops of sugar beet, potatoes, barley and apples. Redrawn, with permission, from Monteith (1977).

TABLE 7. EFFICIENCY OF LIGHT-ENERGY UTILIZATION FOR CROP PRODUCTION (MODIFIED FROM HOLLIDAY 1976)

item	process	10^{-8} energy (J ha^{-1} d^{-1})	percentage of total energy
total radiant energy available to crop	energy input	1674	100
	50% photosynthetically active	837	50
radiant energy losses to crop	reflected, not intercepted or unusable at high intensities	228	14
energy available to crop	gross photosynthesis	609	36
efficiency of gross photosynthesis	energy required for carbon fixation in a 'C3' crop	509	30
respiratory losses	photorespiration and whole crop respiration	50	3
radiant energy appearing as crop dry matter	crop growth	50	3

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there would still seem to be plenty of scope for improving light interception, increasing the efficiency of the photosynthetic process or reducing respiratory losses (Austin 1982; Monteith 1981). There have already been some indications in fact that alterations in leaf angle produced by conventional plant breeding have resulted in greater light interception by the crop canopy and higher rates of crop photosynthesis (Evans 1975).

5. Conclusions – future prospects

The foregoing sections have demonstrated how development of novel technology by the chemical industry has led to increases in agricultural production through provision of plant nutrients and control of organisms competing with the crop. Continuing need for such inputs will ensure a role for the chemical industry in the foreseeable future although the precise solutions to agricultural problems may alter under pressure from environmental or economic constraints. For example, to reduce amounts of fertilizers and chemical pesticides released into the environment, there will be greater development of diagnostic techniques to monitor crop nutrient requirements and the incidence of pests and diseases. This will maximize the utilization of nutrients by crops and minimize the amounts of pesticide required to control weeds, insects and pathogens. The trends in pesticide design to separate toxicity to target and non-target organisms, together with techniques such as electrodynamic spraying, will similarly reduce the total amounts of pesticides used.

So far in this review, the benefits of chemical technology have been discussed largely in terms of crop yield and the efficiency of crop production. To the extent that the chemical industry, together with plant breeders, have been successful in providing the tools with which farmers can achieve high yields, the political problems created by crop surpluses may alter technological goals in the future. Although it must always be in the farmer's interest to produce maximum yields from minimum areas of land, quality criteria may become more important in the future. Fertilizers and pesticides have certainly played a role in this in the past, especially for horticultural crops, but for large-scale agricultural crops, characters such as breadmaking quality in wheat or oil composition in legume seeds have been largely the province of the plant breeder.

Current developments in areas such as plant tissue culture, gene cloning and plant transformation have lead to speculation that plant breeding will become a much speedier and more efficient operation (P. R. Day, this symposium). Though these techniques may aid the procedures of plant breeding, the extent to which they contribute to improved varieties will largely depend on the same basic understanding of plant physiology and biochemistry that is required to discover plant-growth regulatory chemicals. It would also seem advantageous to develop new crop genotypes with a close regard to the chemical inputs under which the crop will be grown. Examples of this are the evaluations by breeders of fungicide responses of new varieties (N.S.D.O. 1983 and table 4) and current interest in the genetic engineering of herbicide-resistance genes into crop plants (Arntzen & Duesing 1983). As the chemical industry has invested heavily both in basic plant-science research and in the development of the crop inputs described in this review, there has been a logical extension to investment in commercial plant breeding, a trend that will assume increasing importance in the future.

I am grateful to my colleagues M. W. Bayliss, B. W. Langley and D. K. Lawrence for their help in preparing this review.

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Discussion

B. D. Soane (*Scottish Institute of Agricultural Engineering, Bush Estate, Penicuik, Midlothian EH26 0PH*). Several of the previous speakers have illustrated their presentations with data showing the changing average yields of wheat in Britain over the past 50–80 years. During the past 15 years or so there have been spectacular increases in these yields, the curve approximating to a logarithmic relation, and the latest estimate for the 1984 crop, given by Professor Day, appears to lie very close to an extrapolation of the previous data. It seem pertinent to ask whether this trend can continue much longer in view of the concept, referred to by Dr Reece, of a finite potential yield determined largely by the incoming radiation level. Professor Buringh in his opening paper gave evidence for a marked upward turn to the crop performance index (100 × actual yield/potential yield). From his data it might appear that a 100% value would be reached within the 1990s, which is the period of relevance to this symposium. However, such an extrapolation seems to be unrealistic. Is it not to be expected that the shape of the average crop yield against time curve in future years will follow a sigmoid relation as the potential yield is progressively approached? Although there appears to be no evidence yet of any reduction in the rate of increase of yield, could it be that we are now at the inflection point?

P. R. Day (*Plant Breeding Institute, Maris Lane, Trumpington, Cambridge*). My breeder colleagues tell me that they are still obtaining an average increase in yield of winter wheat of at least 1% each year. Experience of F1 hybrids shows that gains of up to 15% or more are possible over the higher yielding parent. Biometrical experiments indicate that the hybrid vigour is mainly due to dispersed genes with dominance for high yield and can be fixed by inbreeding. Although the present interest in chemical hybridizing agents is to exploit this extra potential rapidly, it also points to the prospect of further improvement from pedigree selection. We do not believe we have yet reached the inflection point, and if F1 hybrids are unsuccessful for other reasons, we may not reach it until the end of the 1990s.

J. V. Lake (*Agricultural and Food Research Council, Letcombe Laboratory, Wantage, Oxon OX12 9JT*). Is it realistic to try, as Dr Reece suggests, to close the twofold gap between the average and best crop yields? Historically, the gap has always been there, mainly because some farmers choose to adopt relatively low-risk extensive crop production methods while others go for high-risk intensive schemes.

On a second point, I agree strongly with Dr Reece that direct drilling and simplified tillage methods still have much to offer arable agriculture both in the U.K. and developing countries. However, in the U.K. in particular, the trend towards increased adoption of these techniques has been checked by problems from straw residues because the public is increasingly objecting to straw burning. Does Dr Reece see a solution to this problem and a resumption of interest in simplified tillage.

C. H. Reece. If we could make agricultural systems more robust and hence able to grow plants effectively under a variety of stress conditions, this would help to bridge the gap between poor and best crop yields. It all depends on our skills in taking the risk out of intensive systems.

D. J. Greenwood (*National Vegetable Research Station, Wellesbourne, Warwick CV35 9EF*). Could Dr Reece give us an explanation of how he calculated that the introduction of nitrogen-fixing capacity to a cereal would reduce dry-matter production and thus yield by between 10 and 15%. My query is prompted by field studies on the growth of crops under optimum conditions. I would have thought these showed that the rates of growth of dry matter of the above-ground parts of at least some leguminous crops in the absence of N fertilizer are not detectably different from those of non-leguminous crops in the presence of N fertilizer.

C. H. Reece. This is a theoretical calculation based on the ATP requirements to fix the nitrogen. It assumes that the ATP would be otherwise available for carbon fixation.

D. Rudd-Jones (*Glasshouse Crops Research Institute, Worthing Road, Littlehampton, West Sussex BN17 6LP*). I was interested to hear Dr Reece's comments on gibberellic acid and that I.C.I. had done a great deal of development work on this plant-growth regulator in the fifties but had found very limited commercial outlets.

At about the same time we were working on griseofulvin as an antibiotic for the control of plant diseases. It proved to be extremely effective in laboratory and glasshouse tests, giving complete control of cereal powdery mildew at 1 $\mu g\ g^{-1}$. In the field, however, it was quite ineffective, although subsequently it has found a valuable use in medicine for the control of dermatophytes. I wonder whether Dr Reece sees a future for biological pesticides, or will they prove too expensive to produce?

C. H. Reece. Yes, biological pesticides will have a role to play and with modern biotechnological techniques it will be possible to manufacture them at a lower cost. However, it will be a highly selective role and it will take longer to prove the cost-effectiveness of such systems than the venture capital biotechnologists anticipate.

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