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HERBICIDES IN PERSPECTIVE - THE RESPECTIVE ROLES OF GOVERNMENT AND INDUSTRY

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INTRODUCTION

When your program chairman, Dr. Fryer, first asked me to speak at this conference, we had the great good fortune of being on a delightful rooftop patio overlooking a lovely beach on the north coast of Puerto Rico. In such a pleasant locale, and in the welcome company of Dr. Fryer, how could I possibly refuse? I must add that in my euphoric state, I was not troubled by the seemingly peripheral comment that an hour or a bit more was scheduled for this portion of the program. Reason and a bit of common sense asserted itself after my return to the cold winter of Washington, D.C. To run the risk of boring an audience for 15 minutes is permissible, one-half an hour perhaps pardonable, but an hour would be wholly unconscionable. Thus, I was elated to learn that this portion of the program could be shared. It is my good fortune that I have the privilege of joining with Dr. Glasser in addressing you at this 11th British Weed Control Conference.

The subject of this address is most timely. We have gone through in the U.S. an era of rapid growth in the use of herbicides. Now, because of widely based concern about the introduction of chemicals into the environment, we must analyze carefully the benefits and the risks related to their use. Can we expect that the use of herbicides will continue to increase in the future as rapidly as it has in the past? Can we expect that we will have as few problems with adverse aspects of herbicide use in the future as we have had in the past. Can we expect that requirements for registration of herbicides will be more exacting in the future than in the past? And finally, can we expect that the responsibilities for developing the data leading to registration will, in the future, follow the pattern established in the past?

These are questions we will discuss with you this morning. For some of them, there are adequate indications now of what the future portends. For other questions an uncomfortable bit of crystal-ball gazing is required. Hopefully, our interpretations of the historical events leading to the present will not lead us too far astray in projecting trends of the future.

TRENDS IN USE OF HERBICIDES

All of you are aware, I am sure, that there have been significant increases in the amount of pesticides used, particularly since the advent of synthetic organic pesticides. While the use of all classes of pesticides has increased, the increased use of herbicides in recent years has been far more dramatic than that of other classes of pesticides.

Between 1960 and 1968, U.S. Manufacturers' sales of unformulated chemical pesticides showed an annual average increase of 6.5 percent on a volume basis and 16.5 percent on a value basis, reaching a level of 950 million pounds valued at $850 million. Between 1968 and 1970, however, volume sales dipped 3.6 percent a year while dollar sales increased only slightly more than 1 percent annually. In 1971, chemical pesticides sales resurged, reaching a level of about $980 million. Herbicides had the largest annual sales gains during the growth period--about 22 percent in volume and 33 percent in dollars. Today herbicide sales in the U.S. account for about 60 percent of total pesticide sales volume.

Let's take a look at the data we have on herbicide usage for the years 1964 and 1966. It will be possible to project some values to the present situation; for others, projection to 1972 requires a much clearer picture in the crystal ball than I can obtain. Data for both years was obtained by surveying farmers. In 1966, 9,600 farmers in 417 counties throughout the 48 contiguous states were interviewed (Eichers et al. 1970). Projects for the nationwide situation were made from the interview sample.

As shown in Table 1, the farm purchase of herbicides went up 37 percent from 1964 to 1966, an increase from 84 to 115 million pounds. In 1966, herbicides accounted for nearly a third of the quantity of pesticide materials used on farms, but the proportion is probably greater now.

TABLE 1

Quantities of selected herbicides used by farmers in the U.S., 1964 and 1966

Type of Herbicide	Pounds x 10^6, active ingredient 1964	 1966	% change
Inorganic herbicides	10.4	4.9	-53
Organic herbicides	73.6	110.4	50
Arsenicals	1.1	.9	-18
Phenoxy	38.4	44.1	15
Phenylurea	1.7	3.7	111
Amides	Not available	5.9	
Carbamates	5.3	10.1	92
Dinitro group	3.2	5.0	55
Triazines	11.3	24.3	115
Benzoics	3.5	7.0	102
Other organics	4.2	9.5	126

Table 2 shows the farm use of herbicides by crops for 1964 and 1966. It is apparent that there was a dramatic increase in use of herbicides. Reductions were recorded in only a few instances.

Table 2

Farm use of herbicides by crops in the U.S., 1964 and 1966

Crop	Pounds x 10^6, active ingredient 1964	 1966	% change
Corn	25.5	46.0	80
Other field crops[1]	19.0[2]	10.8	-43
Pasture and rangeland	4.7	10.5	123
Soybeans	4.2	10.4	148
Wheat	9.2	8.2	-11
Cotton	4.6	6.5	41
Vegetables	4.8	5.7	19
Sorghum	2.0	4.0	100
Fruits and nuts	1.0	3.6	260
Peanuts	[3]	2.9	
Rice	[3]	2.8	
Summer fallow	1.3	0.9	-31
Nursery and greenhouse	0.05	0.1	100

[1] Tobacco, sugarbeets, alfalfa and other hay, plus others.
[2] Includes peanuts and rice in addition to other field crops.
[3] Included in other field crops.

Increased herbicide usage in terms of volume is also reflected in the percentage of crop acres treated. While only 11 percent of the corn acreage was treated in 1952, this rose to 27 percent in 1958, 43 percent in 1964, and 57 percent in 1966 (Fox, et al., 1968). We have reason to believe that as much as 80 percent of the corn acreage may be treated with herbicides now.

The same sort of acreage increase occurred for some other crops. For small grains, the acreage treated increased from 12 percent in 1952 to 29 percent in 1966; for pasture and rangeland, 0.3 percent in 1952, 1.2 percent in 1966; and for cotton, from 7 percent in 1958 to 52 percent in 1966.

The past increases in herbicide use cannot be as great in the future. Rate of use per acre has remained essentially constant for many years. For those crops on which most herbicide is used totally, I expect our recent survey will show that a high percentage of the acreage is treated now. Thus, the rate of increased herbicide use will begin to level off. A reduction in the use of hand labor as an energy source for weed control, and a continuation of the trend toward larger, more mechanized farms will favor increased herbicide usage. Another possibility favoring increased usage would be increased agricultural acreage resulting from demands for food and fiber for the higher population we will inevitably have.

The number of new herbicides being developed and registered for use in the U.S. appears to be remaining steady. Over a period of 6 years the number of new chemicals were: 1967, 1; 1968, 2; 1969, 3; 1970, 2; 1971, 1; and through August of 1972, 2. The total of 11 compounds for the 6-year period was 30 percent of the total for all pesticides. Of interest too, is the information that four of the 11 compounds were for use in corn, 3 for sugarbeets, 2 for soybeans, and 1 each for wheat and tomatoes. Thus, the developmental work by the agricultural chemical industry is concentrated on high acreage crops. Obtaining registrations for minor uses is a critically severe problem and will be discussed in greater detail in a later section of this address.

THE PROBLEMS ENCOUNTERED

The word "problem" is overworked -- perhaps to the extent that any precise meaning has been lost. But Webster's definition suggests that the word is appropriate despite its common usage -- "An intricate unsettled question, a source of perplexity." Thus, the problems to which I refer are not the common, easily solved ones such as occasional drift onto susceptible crops, but rather the much more difficult problems relating to the possibility of hazard to man's health or to the environment. These problems are indeed intricate, unsettled questions.

A common and widely used herbicide is 2,4,5-T. It was used for more than 20 years without suspicion that it might represent a possible health hazard. Our complacence was rudely shaken in October of 1969 with the announcement that 2,4,5-T had been shown to cause fetal abnormalities in mice. There was immediate furor. Shortly thereafter, the suggestion was made that the teratogenic effects may have been caused by a contaminant in 2,4,5-T. Analysis showed that the sample used in the mouse tests did indeed contain 27±8 ppm of the contaminant. Thus we came to know about 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). TCDD is an extremely toxic compound, having an LD_{50} of 0.0006 mg/kg for guinea pigs, 0.023 mg/kg for male rats, and 0.045 mg/kg for female rats. Subsequent tests showed that TCDD was indeed a teratogen (Aparschu et al, 1970). The 2,4,5-T from which TCDD was removed by recrystalization to an undetectable level, was shown to be teratogenic in the mouse, but not in the rat. Those findings led to the suspension of some uses of 2,4,5-T and the cancellation of others, including uses on food crops. The cancellation of 2,4,5-T registered for the control of weeds in rice was appealed. The case is now in a court of law, and a public hearing may be held next year. The use of 2,4,5-T is still permitted in forests, on rights-of-way, and on grazing land, but there is much public feeling against its use.

This despite a generally favorable report by the Office of Science and Technology, (MacLeod et al., 1971) and by a scientific advisory committee, which had one dissenting opinion (Wilson et al., 1971).

An economic analysis of restricting the use of 2,4,5-T showed that weed and brush control costs would increase about $52 million if all other chemicals remained available, and about $172 million if no phenoxy herbicides were available (Fox, et al., 1971). Restricting the use of 2,4,5-T for weed control in rice would cost about $3.5 million (Gerlow, 1972).1/

2,4,5-T was not the only phenoxy herbicide whose safety was questioned. The same study that implicated 2,4,5-T as a teratogen also implicated the butyl, isopropyl, and isooctyl esters of 2,4-D, although the concern about the latter compounds was at a lower level than for 2,4,5-T. You should be aware that the Environmental Protection Agency has a review committee whose function is to make a critical review of all pesticides about which there is a question of safety, either to human health or to the environment. They have started with those pesticides included in Recommendations 4 and 5 of the Mrak Committee Report

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1/ Gerlow, A.R., 1972. Unpublished data

(Mrak, et al., 1969). Recommendation 4 states, "Restrict the usage of certain persistent pesticides in the United States to specific essential uses which create no known hazard to human health or to the quality of the environment..." Included in that recommendation are aldrin, dieldrin, endrin, heptachlor, chlordane, benzene hexachloride, lindane, and compounds containing arsenic, lead, or mercury. Recommendation 5 states, "Minimize human exposure to those pesticides considered to present a potential health hazard to man." Included in this recommendation are aldrin, amitrole; aramite; avadex; bis (2-chloroethyl) ether; chlorobenzilate, p,p'-DDT; dieldrin, heptachlor (epoxide); mirex; n-(2-hydroxyethyl)-hydrazine; strobane; captan; carbaryl; the butyl, isopropyl, and isooctyl esters of 2,4-D; folpet; mercurials; PCNB; and 2,4,5-T. Some of these compounds have already been reviewed, others will follow. No restrictive action against 2,4-D is expected, but that will surely be considered when its uses are reviewed.

The uses of pesticides containing arsenic have been reviewed recently in the U.S., and some restrictive action in 1973 is not unlikely. You are aware that arsenical compounds have been used for many years, not only as herbicides, but for the control of many other pests as well. Although there is no new problem with arsenic, its toxicity and accumulation in soils where applied demand that we look at its uses critically.

The organic arsenicals are of particular importance to us. DSMA and MSMA are important herbicides for weed control in cotton, ornamental and recreational turf, rights-of-way and ditchbanks, industrial sites, and around brickwalks, stone patios, tennis courts, and similar situations. In terms of acreage and volume of use, weed control in cotton is of most importance. About 4 million acres of cotton are treated annually with 8 to 12 million pounds of DSMA and MSMA.

Arsenic acid is important to us as a preharvest dessicant for cotton. About 900,000 gallons are used annually on about 2 million acres in Oklahoma and Texas. No other economically satisfactory desiccant has been developed for this purpose.

Our principal concern about the continued use of arsenical compounds is that accumulation of arsenic in the soil, if treatments are continued long enough, will eventually cause phytotoxity, particularly for more susceptible crop species such as rice. A study in Mississippi (Schweizer, 1967) indicated that cotton tolerated 60 ppm in the upper 3 inches of soil, which is the equivalent of about 120 lb/A of DSMA. If that is indeed the critical level under field conditions, more than 50 years would elapse before residue levels reached the point of phytotoxicity to cotton, assuming that application rate remained at the current level. Phytotoxic levels for more sensitive crops would be reached sooner. Studies are underway to assess the practical significance of reaching phytotoxic residue levels by the current usage patterns of DSMA and MSMA. We have recommended that a diligent search be made for alternates to arsenical herbicides so that their use can gradually be phased out.

Propanil, an important herbicide used world wide for weed control in rice, has also been beset with problems. The isolation of a metabolite of propanil, 2,2'4,4'-tetrachloroazobenzene (TCAB)(Bartha and Pramer, 1967) stimulated concern because TCAB is chemically similar to some known carcinogens. Subsequent research showed that the uptake of TCAB from mineral salt solutions was insignificant and that no biosynthesis occurs in rice plants (Still, 1969). TCAB was detected in rice producing soils from Arkansas, however, in the range of 0.00 to 0.18 ppm (Kearney, et al., 1970). Shortly thereafter came the report that TCAB was not carcinogenic in the test animals (Bartha and Pramer, 1970). Despite this evidence, the spectre of possible hazard has again been raised on the basis that there are numerous metabolites of propanil about which we have little or no information (Pramer, 1971).

There are three important points to bear in mind regarding our problems with herbicides. Firstly, herbicides cannot be exempted from the possibility of posing a hazard. Secondly, because herbicide usage has increased so rapidly in the recent past and can be expected to increase in the future, we can expect that there will be more problems. Thirdly, and perhaps most importantly, research needed to prove or disprove the safety of a herbicide reduces the amount of research that would otherwise be done on the positive aspects of furthering our knowledge of weed control.

What conclusions can be drawn from the problems we have had with certain herbicides and problems that we will inevitably have in the future. Two conclusions appear to be of paramount importance.

With regard to the adverse aspects of certain herbicides, it is highly important that weed scientists are alert to potential problems, conduct their research critically, interpret their results with utmost objectivity, and publish their research in responsible, refereed journals, regardless of whether the research data are harmful or helpful to a compound. This applies not only to State and Federal scientists, but to those in private industry as well. Recognition and reporting of adverse aspects of herbicides, however painful, lends credibility to the objectivity of agricultural scientists, and offers greater freedom from the oft heard charge of bias.

Both public and private sectors must make their contribution toward resolution of problems engendered by newly discovered information that a pesticide may pose a hazard to public health or to the environment. That has been our pattern in the past and will be in the future. A good example is 2,4,5-T. Papers published since the presence of TCDD became public knowledge are quite evenly divided between the private and public sectors. We will also participate in the public hearing on 2,4,5-T when the time comes. Another example is DDT. We assigned two attorneys, a high level scientist and a reference librarian during an 8-month public hearing to develop a complete record so that all information on DDT would be available for use in reaching a regulatory decision.

REQUIREMENTS FOR REGISTRATION

Those who are responsible for sheparding petitions for registrations and establishment of tolerances must be patient and forbearing souls. If they have had that responsibility for 10 years or more, they have seen a great increase in the data requirements to support registration and in the time required to obtain an acceptable label.

Registration of a pesticide is a serious matter. Serious for the petitioner for registration as he views the effective patent life of his latest offspring slipping away. It is equally serious for the regulatory officials who have gone through a prior experience of approving a registration, only to find after the fact that some deleterious characteristic of the chemical dictated against its use as registered.

Both registrant and regulator have been plagued for many years by the lack of written guidelines that define the kinds of tests needed to support a petition for registration and the manner in which those tests are conducted. Without guidelines, it was always possible to ask for one more piece of information, or to question the validity of data obtained from a chosen experimental design. To do so is frustrating for a registrant and discomfiting for a regulator. The Environmental Protection Agency has now developed such guidelines. They are not cast in concrete. They are only guidelines and reflect the need to make adjustments as advancing knowledge dictates. This is a significant advance in the registration process in our country.

I mentioned earlier that both time and data requirements for registration have increased with time. I would like now to share with you the nature of some of those increased requirements. Upon first consideration, it did not seem there would be much of a problem in identifying the changes that have occurred. But remember that we had never had written guidelines. Thus requirements were imprinted in the collective minds of several groups of individuals, but were frequently not committed to a reviewable document. What I report here is the experience of one agricultural chemical company. It does not represent the epxerience of the industry as a whole, nor does it necessarily represent with exactness the policy and procedures of the regulating agency. An 11-year period, from 1962 through 1972 is involved in this analysis.

The time required for an initial registration for a non-food use was 2 to 3 months from 1962 thru 1966, and 4 to 8 months thereafter. Label revisions for registered non-food uses increased from 15 to 30 days through 1968, and 60 to 90 days thereafter.

For food crop uses, the time required for a label revision was 15 to 30 days through 1967, and 60 to 90 days thereafter. A seemingly simple matter such as label approval after a tolerance was granted required 1 to 2 weeks until 1966, but 4 to 12 weeks since then. The initial tolerance for a new product required 5 to 8 months through mid 1966, but as much as 12 to 30 months thereafter. Some new items required for registration came into being after 1962. Thus, in 1967, the concept of acceptable daily intake was implemented. In 1969 there was an increased concern about pesticides in the home environment, and satisfactory demonstrations of safety had to be provided by the registrant.

Pesticide residue data requirements increased dramatically during the 11-year period. In 1962 it was necessary to demonstrate residue stability during frozen storage; conduct studies in cattle to determine which metabolites, if any, were excreted in urine and feces, and whether they occurred in milk; and studies in plants to identify toxic metabolites in all fractions of plant extracts. Increased requirements were soon added.

1964 - show persistence in soil from applications made at proposed rates and from various geographic locations.

1965 - mammalian metabolism studies required to determine what toxic metabolites were likely to occur.

- compare plant and animal metabolism studies.

- determine the effects of pesticide residues on flavor of the consumed product.

1966 - prove that analytic methods for residues were specific for the compound and that similar compounds would not interfere with the analysis.

- conduct ten residue experiments, each from different locations, for each crop proposed for a tolerance.

1968 - feeding studies at excessive rates to demonstrate whether residues are transferred to meat or milk as a result of feeding crop forage or crop by-products.

- develop confirmatory methods for residue analysis.

1969 - soil runoff, leaching, and adsorption studies needed to meet environmental requirements.

- establish whether residues decompose in water if the proposed use would result in the chemical entering water.

1970 - 90 percent of residues must be accounted for in plants.

- Tobacco fermentation and processing studies to show persistence of residues in harvested tobacco.

- Metabolic studies in soil.

A similar pattern of increasingly greater stringency is evident in the requirements for efficacy data. In terms of extrapolation from one situation to another, the following developments occurred:

1962 - Data for a pest species on one crop could be used to support claims for the same pest on another crop. Only phytotoxicity data were needed for the second crop.

- Data for one formulation acceptable for another formulation of the same compound.

1966 - Drastic reduction of permitted extrapolation from crop to crop and formulation to formulation.

1969 - No extrapolation of data permitted.

A change also occurred in the experimental scale needed to demonstrate efficacy and phytotoxicity.

1962 - Data from small plots adequate.

1968 - Full scale commercial plots required.

Toxicity studies to demonstrate safety and for use in establishing tolerances are perhaps the most expensive tests required of the registrant. Intitially, if residues did not exceed 0.1 ppm, a product could be registered on a no-residue basis. Increasing sensitivity of analytic methods soon made that concept untenable and it was dropped in 1966. Now a residue of 0.1 ppm or less is called a negligible residue. The extreme sensitivity of present analytic methods has of itself created problems of interpretation for toxicologists. For example, a method has been developed for the symmetrical tetrachlorodioxin that detects 2×10^{-12} grams. What is the toxicologic significance of such a minute residue? The answer will require a much more sophisticated approach from toxicologists than they have used in the past.

The toxicity data required for tolerances in excess of negligible residue are as follows:

1962 - Acute toxicity.

- Rat subacute oral (90 day)

- Dog subacute oral (90 day)

- Rat chronic oral (2 year)

- Dog chronic oral (2 year)

- Rodent (three generation breeding study)

- Neurotoxicity (for O.P. compounds)

1963 - Subacute dermal (rats)

1969 - Teratogenicity

- Mutagenicity

- Carcinogenicity

Requirements for a negligible residue tolerance are less stringent.

1963 - Acute inhalation studies

1966 - Acute toxicity

- Rat subacute oral (90 day)
- Dog subacute oral (90 day)
- Rat subacute dermal

1969 - Neurotoxicity (for O.P. compounds)

Lastly, in terms of the requirements for registration, it is now necessary to provide data pertaining to effects on wildlife. The first of these requirements were imposed in 1968.

1968 - 96 hour LC_{50}, 2 fish species.

- Acute oral LD_{50}, 2 bird species.

- Simulated field studies with birds and mammals.

1970 - Subacute accumulation studies in fish.

- Bird reproduction studies (on request).

A simple listing of data requirements does not tell the whole story, however. The research protocols have become more complex and demanding, e.g. greater numbers of animals per dose level and more measurements of physical and biochemical parameters. Though only presented in summary form, I trust you realize that one does not approach the registration process with equanimity.

To this point I have not yet spoken of the requirements of time, money, and energy that are expended by a prospective registrant. The National Agricultural Chemicals Association (NACA) in the U.S. conducted a survey in 1971, the results of which are shown in table 3.

There are several statistics from NACA survey that give cause for some concern. We all know that the dollar costs for developing a new pesticide have risen sharply-60 percent from 1967 to 1970 - and that the elapsed time between discovery and marketing has increased - 28 percent for the same time period. As individual statistics, they are impressive, when combined they are cause for concern. If interest on the investment is compounded, the true costs are considerably higher.

Table 3

Pesticide Industry Scientific Research: A Profile[1]

Item	1967	1970	% increase
Average R&D For a New Pesticide	$3.4[2]	$5.5	60
R&D Expenditures	$52.4	$69.9	33
R&D Spending as % of Sales	8.2%	9.7%	18
Research Time, Discovery to Marketing	60 months	77 months	28
No. of Compounds Screened Per Product Introduced	5,481	7,430	36
R&D Man-Years Expended	2,368	2,768	17
No. of Scientists with PhD	539	662	23
No. of Compounds Screened	60,200	62,800	4.3

[1] From: 1971 Survey of 33 agricultural chemical companies by National Agricultural Chemicals Association. Survey results compiled by Ernst & Ernst.

[2] Dollars in millions.

Note also that the R&D costs as a percent of sales rose 18 percent during the 3-year period.

While the number of compounds screened rose by 4.3 percent, the number screened per product introduced rose 36 percent. Thus, there are relatively fewer chemicals that remain viable throughout the R&D process to finally achieve marketability. As of now, about a third of the successful chemicals are herbicides. It appears that more R&D emphasis is being given to those chemicals which, as a class, pose a lesser potential for future problems than do other classes of pesticides. We hope there will not be a diminution of effort on herbicidal chemicals. But precisely what the future holds cannot be predicted.

ROLES AND RESPONSIBILITIES FOR REGISTRATION

Historically, developing data needed for registration has been the responsibility of the manufacturer. We believe that responsibility has been properly placed and should continue to reside there. It is clear, however, that if the manufacturer has the sole responsibility, the needs of agriculture specifically, and the public generally, will not always be adequately served. To understand that, you must know that in the U.S., a pesticide is registered for a specific use. R&D costs by the pesticide industry have risen dramatically. As a consequence, there is an economic advantage to developing the data needed to register a product for use in corn, for example, but little economic justification to do likewise for onions, cabbage, or for some other crop where use of the pesticide would be minor.

Registration of pesticides for minor uses has been a problem in the U.S. for many years. In recent years, the problem has become more severe, and we believe it will become even more so in the future. Thus, the public sector in our society, the federal government and the states, will be compelled toward greater activity in developing the data needed for registration of chemicals for minor uses. In most instances, we will be seeking extended uses for pesticides that are already registered. We have no intention of initiating an R&D effort that would duplicate that of the pesticide industry. The U.S. Department of Agriculture is now in the process of developing guidelines to determine those instances in which we would expend public funds for the express purpose of developing data required for registration. There are two basic reasons for developing such guidelines:

(1) We must assure that needed technology is available to users, and

(2) We must be certain that the pesticide industry does not depend inordinately on the public sector to develop the required data.

There are specific situations, however, in which the public sector will do all of the R&D needed for the registration of a pesticide. I refer here specifically to viruses, pathogenic bacteria and fungi, sex attractants, and the like. Industry has not yet seen the opportunity for an economic return on investments in support of such pesticides. I call them pesticides advisedly because they must be registered in the U.S. just as do the conventional chemical pesticides.

Dependance on the agricultural chemical industry to snythesize and screen new compounds for biologic activity is not wholly comforting to us. When we consider that industry is developing only those chemicals having a high market potential, one must suspect that there may be numerous chemicals now on the shelf that would have utility for minor markets. We have not yet faced a situation of not having an adquate representation of herbicides to meet weed control needs. Hopefully industry will continue to provide an adequate number of new compounds. We are alert to the possibility that they may not do so at some future time. If that should occur, our present policy will have to be re-assessed.

The registrant and the agricultural community are not alone in their responsibility for registration. The Environmental Protection Agency, which is our regulatory arm, shares that responsibility. Recently, the EPA completed a second draft of "Guidelines for registering pesticides in the United States." The guidelines are intended to instruct applicants in a general way on the requirements for registration, while retaining the flexibility for application of judgment in individual cases. Such guidelines have long been needed.

The time required for review of data submitted for registration and then reaching a decision should be reduced so that an applicant for registration receives a decision at the earliest possible time.

FUTURE TRENDS

Earlier in this address, I showed data indicating that pesticides were used on only about 15 percent of the crop acreage in the U.S. in 1966. Herbicides were used on about 27 percent of the crop acreage, excluding pasture and rangeland. Today that figure is undoubtedly higher. Yet there is a significant portion of our acreage that is not treated with herbicides. With the demand for food and fiber by an increasing population, there seems little doubt but that agriculture will have to use all the technology available in order to produce food in sufficient quantity. New innovations in pest control are generally less adaptable to weeds than to other classes of pests. For example, we have essentially no experience in breeding crops for greater competitive potential with weeds, biological control cannot be expected to solve more than a few weed problems, and genetic control of weeds is only a faint light on the distant horizon. Thus we expect that herbicide usage will continue to grow, but at a slower rate than in the past.

We can expect more environmental and health related problems with herbicides than has been the case in the past. Although problems have been more severe with insecticides, herbicides are not immune from adverse effects. Weed scientists must be alert to potential problems and make adjustments before being compelled to do so by force of public opinion.

Finally there will come to be the development of systems of crop protection, and this is a topic I should like to dwell upon in somewhat greater detail.

The evolutionary development of weed control has a long history. Starting with occasionally pulling a weed -- not because of knowledge that its presence hindered the growth and development of the desirable plant, but simply because it was in the way -- through deliberate hand weeding, hoeing, mechanical cultivation, the use of inorganic herbicides, and finally the use of synthetic organic chemicals. Biological control was not mentioned because there has always been some natural biological control. Each step required more knowledge and a greater sophistication on the part of the farmer or other user.

At this point in time, with public pressure to slow or to stop the rapid rise in use of chemical herbicides, we are entering a new phase of weed control--a phase in which we will use a variety of methods from our total arsenal of pest control technology, considering also the interactions between various classes of pests, between the methods used for their control, and between the pests and their control, and the crop. The popular term for such a practice is, "integrated pest management." That term does not adequately express the direction of our pest management strategy, however, because it is most frequently applied to the management of insect pests only, disregarding the other classes of pests with which we must contend.

The concept being developed in the U.S. is better explained by the term, "systems of crops protection." Embodied within that concept is the requirement that protection of the crop is the objective in using a variety of integrated pest management strategies. We do not believe it is wise to have one scientist studying the control of weeds, a second insects, a third plant diseases, and a fourth nematodes, each having the control of only one class of pest as his objective.

These four scientists should have the same objective--protection of the crop. There are several reasons for moving in the direction of developing systems of crop protection:

(1) No single pest or class of pests exists in a vacuum--there are interactions among them and differential effects resulting from a given control method.

(2) Current public attitudes about pesticides compel us to look critically at our pest control practices.

(3) The increasing complexity of pest management requires more knowledge of a farmer than he can be expected to have. Thus a corps of crop protection specialists should be available to provide a service to farmers.

Our academic programs have become highly specialized. In many cases, if not most, the narrowly trained individual knows only his own field of specialization and does not appreciate the importance of other **classes** of pests. The highly trained specialists have been responsible for many technological advances and we will continue to need their expertise. Nevertheless, we critically need the generalist who has the ability to integrate pertinent knowledge from several fields and bring it to bear on a single function--that of crop protection. We are hopeful of stimulating some changes in the curriculum of our agricultural colleges to provide the broadly based academic training needed to address the objective of crop protection. Opportunities for employment of individuals so trained are excellent. Needs exist in State and Federal governments, the pesticide industry, and as private entepreneurs

We now have new pesticide legislation that became law in October, only a short month ago. Its title is the "Federal Environmental Pesticide Control Act of 1972." We needed this legislation. There are key differences between the new Act and the older Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). These key provisions are:

1. Classification of pesticides into general use and restricted categories.

2. Certification of applicators. A pesticide in the restrictive category must be applied by a certified applicator who has knowledge of adverse effects that may result from the application of a pesticide.

3. Indemnities for stocks of pesticides held at the time use of a compound is suspended.

The most important point is that the new Act provides for control over the end use of a pesticide through the mechanism of certified applicators who must be licensed. Without that authority, the outlook for pesticides in the U.S. would be bleak indeed - the reason being that our courts had interpreted the FIFRA in the sense that, upon a finding of substantial question of safety to man or the environment, the Administrator of EPA must file a notice of intent to cancel in order to initiate the administrative review process. Because the FIFRA did not provide for control over end use, EPA was constrained to issue broad scale cancellations. Our new legislation will permit selective cancellation when the need arises.

Obviously, we do not yet have experience under the new bill. We in Agriculture are happy to have it, as is the EPA. Only time will tell what our actual experience under the bill will be, but we are committed to making it workable, in such a way that the needs for pesticides can be adequately met while at the same time protecting public health and the environment.

CONCLUSION

I have spoken at considerable length on the subject of "Herbicides in Perspective." As I review what has been said, I have the feeling that I may have given undue prominence to the problems we face at a time when the pesticide issue is a focus of much attention. But the problems are before us and they can be best resolved by facing them squarely.

I am not pessimistic about the future of herbicides. They have carved an important niche in the total technology of agriculture. If I were to prepare a balance sheet of benefits and risks from their use, there is no question but that the benefits would far exceed the risks. There are those who feel that public concern about adverse effects of pesticides generally in the U.S. is so great that the true message of their benefits can never be sold to the public until deprivation of their use results in an inadequate supply of food. I'm more optimistic than that. Technology has, unfortunately, contributed to a host of environmental problems. But the solution to that is not a retreat from technology. It is only technology, resulting from research, that can solve the problems technology has wrought.

Sitting where I do, there are many problems that come to my attention. The positive reward I can find in such a situation is that the problems are at least varied. So I can appreciate the thought of Washington Irving when he said, "There is a certain relief in change, even though it be from bad, to worse; as I have found in traveling in a stagecoach, that it is often a comfort to shift one's position and be bruised in a new place."

The future for herbicides is bright. We are learning that cooperation on a broad front is essential to further progess - government (State, Federal, and International) pesticide industry, agricultural community, and environmentalists. There will always be some compromise, but that expresses life itself. Considering all factors, I'm comforted and humbled by the words of Socrates, "If all the world's problems were thrown in a common heap, whence each would draw an equal share, most would be content to take their own and depart."

Ladies and gentlemen, the privilege of addressing you has been a great pleasure. Thank you.

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HERBICIDES IN PERSPECTIVE - THE RESPECTIVE ROLES OF GOVERNMENT AND INDUSTRY * PART II

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INTRODUCTION

It is indeed a great honour to be asked to join with Dr. Tschirley in addressing you at this, the first session of the 11th British Weed Control Conference. The more so, because it provides the additional opportunity to be in your presence over the next three days which we deem of immense importance since you are the vanguard, both in the development of knowledge on herbicides and in its implementation for the benefits of our society.

As your session organiser has correctly indicated in the programme, we are at the stage when the requirements placed on the pesticide chemical industry by regulatory authorities are increasing. And also, at a time when there is an increasing surveillance by society in general of these respective roles of government and industry.

Contrary to the opinion often expressed, we in industry do consider ourselves responsible citizens. As such, we have a deep desire and strong motivation to improve the society in which we live through the development of knowledge and products to improve the life of man.

We meet here today to look at "Herbicides in Perspective and to Discuss the Respective Roles of Government and Industry". Placing herbicides in perspective requires that a proportional importance be given to all the component parts of the subject and we will try to accomplish this by focusing our attention on:-

(1) The trends in usage of herbicides;
(2) The problems encountered;
(3) The requirements for registration;
(4) The roles and responsibilities for registration; and
(5) The future trends.

TRENDS IN USAGE

First then, regarding trends in usage in the World outside North America:

The organised use of chemicals for pest control had its beginning in the 18th Century but the most important developments have taken place in the last 50 years. Before 1940, the pesticide industry was relatively small and supplied mainly inorganic compounds, organic preparations derived from plants and some by-products of the coal tar industry.

During the 50's the use of inorganic and naturally derived products levelled off and synthetic organic pesticide chemicals began a remarkable rate of growth, initially led by the insecticide products.

Graph 1., depicts herbicide product introduction world-wide, pre-1940 through 1971, and Table 1., shows the relation between herbicide introductions and those of insecticides and all pesticides, again on a world-wide basis.

Graph 1

Herbicides product introductions
(world-wide)

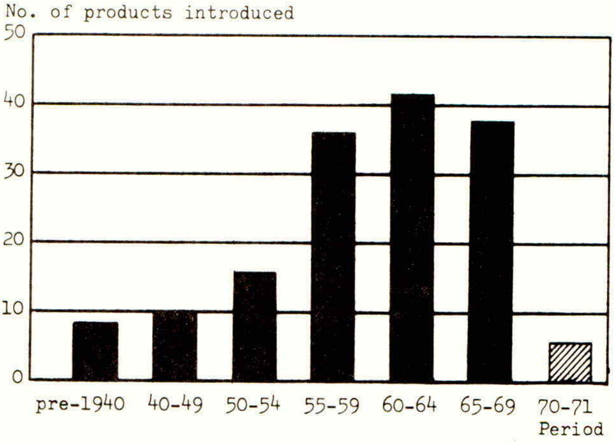


Table 1

Relation to herbicide introduction to those for insecticides and all pesticides (world-wide)

Year	Herbicides	Insecticides	All Pesticides
pre-1940	9	25	49
1940-1949	10	26	56
1950-1954	16	28	58
1955-1959	36	33	97
1960-1964	42	28	102
1965-1969	38	53	151
1970-1971	6	4	17
Cumulative Total	157	197	530

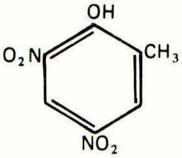
At the end of the 1940's, only about 19 of the 100 or so pesticidal products available to the farmer were herbicides. Now about 160 of well over 500 pesticidal compounds available are herbicides and, since the mid 1960's herbicides have been rapidly overhauling the formerly dominant position of insecticides as regards the number of active compounds.

This growth in number of available products has been matched by the expansion of herbicide usage. At the beginning of the 1960's the retail value of herbicides outside North America and East Europe was only about one eighth of the total market

Table 2

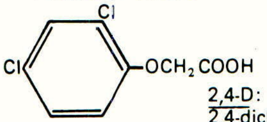
Herbicide product introductions – by class

PHENOLS

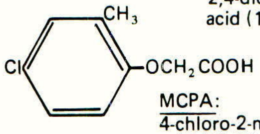


DNOC:
2-methyl-4,6-dinitrophenol (1932)

PHENOXY ACIDS

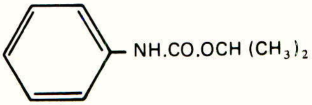


2,4-D:
2,4-dichlorophenoxyacetic acid (1942)



MCPA:
4-chloro-2-methylphenoxyacetic acid (1945)

CARBAMATES



propham:
isopropyl N-phenylcarbamate (1945)

for pesticides at that time. The herbicide sector now accounts for more than a quarter of the estimated 2 billion dollars (approximately 800 million pound sterling) now being spent on pesticides in countries outside North America. Considering that prices, generally, have tended to erode, this represents a phenomenal annual growth rate of over 20% - well above the average rate of the pesticide industry as a whole.

Many of you will already be familiar with the way the modern herbicide industry has developed. I suppose it is true to say that its real advent was marked by the independent development in Britain and the United States of the first of the phenoxy acids (MCPA and 2,4-D). Even at this early stage both industrial and government research organisations played essential roles in establishing the nascent industry and the foundation was laid for the now familiar patter of the respective positions of these two complementary activities. The first carbamate herbicide, propham, was also discovered in Britain at round the same time and these, with DNOC, were the forerunners of the present array of selective herbicides. (See Table 2).

The coincidental spread of mechanical harvesting in the 40's and 50's in Europe eliminated a major labour demand on the farm and opened the way for extended use of herbicides, which in turn led to a fundamental change in husbandry practicies. Crop rotation became less important as a means of reducing weeds; weeds could often be controlled selectively by the use of herbicides in the crop itself. Herbicide developments in the last decade have taken this a step further and now the necessity not only of crop rotation, but of cultivation itself as a means of weed control, is being strongly challenged.

Hand-in-hand with the development of organic herbicides went the development of application equipment. In the 1940's, MCPA and 2,4-D were largely used as dusts capable of application by means of the fertilizer distributor. The introduction of cheap, low-volume spraying equipment allowed a much more versatile use of the new products. The continuing development of specialist equipment and formulations now allow for the application of herbicides as granules, wettable powders, solutions, and emulsions by pre-plant, pre-emergence, post-emergence and lay-by applications on almost every major crop. There is no doubt that all these factors had a major role to play in the expansion of herbicide usage.

The phenoxy acids were probably the most important milestones in herbicide history; and, along with DDT and BHC may be considered the foundation of todays agricultural chemical industry. It is significant that although the market share held by the original and subsequent relatives of the phenoxy acid has been showing a slight decline in recent years, world-wide they still account for around a third of all herbicide used today.

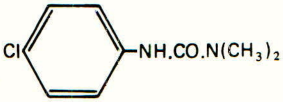
After the introduction of phenoxy acids, came the development in America of the substituted ureas in the 1950's. These compounds have never enjoyed the same scale of usage outside North America as in that region of the world but, they still represent a significant proportion of the selective broadleaf weed killer market.

At about the same time as the introduction of the ureas, TCA, a halogenated carboxy acid, was complemented by the development of dalapon, greatly extending the possibility of control of grass weeds on crop land. Dalapon still appears to dominate the selective grass killer market outside the United States. (See Table 3).

Table 3

Herbicide product introductions – by class

UREAS



monuron:
N'(4-chlorophenyl)-NN-dimethylurea (1952)

CARBOXY ACIDS

$CH_3CCl_2.COONa$

dalapon:
Sodium 2,2-dichloropropionate (1953)

The second half of the 1950's saw the development of a number of novel herbicides, amongst which the triazines were outstanding. The residual soil activity of the original compound, simazine, was obviously an asset where long term, non-selective action was required; and this was originally the main outlet for this product. As more and more analogues were developed including atrazine, ametryne, terbutryne, prometryne, cyanazine - the range of application has progressively developed to the point that they are second only to the phenoxy acids from the marketing point of view.

Another major development at the end of the 50's was the discovery, in the United Kingdom, of the bipyridyls which, with their novel mode of action, have contributed more to the philosophy of "zero tillage" than any other group. The substituted arsenicals, DSMA (particularly used for post-emergence control of grass weeds in cotton) and TBA (used in mixtures with MCPA to control many weeds resistant to the latter herbicide) and also aminotriazole which could control both graminaceous and broad leaved weeds in fallow land, industrial sites and in perennial crops, were also significant inventions at this time. (See Table 4).

The 1960's and onward have seen a dramatic increase in the number of products from research aimed at achieving greater selectivity. They embrace both refinements of known herbicidally active chemical groups and some completely novel compounds, for example, dichlobenil, propanil, tri-allate and more recently, nitralin and trifluralin - all with a diversity of selective applications. (See Table 5).

If one looks at the use of herbicides regionally outside the United States, Europe is by far the most important now, accounting for well over half the market outside the U.S.A. If the markets in Australia, New Zealand, Japan and South Africa are added to the European total, one arrives at the conclusion that more than three quarters of the market for herbicides is in the development areas and the trend has been, if anything, towards a widening of the gap between developed and developing areas. This is a reflection, of course, of higher labour costs in developed areas, their more intensive and mechanised agricultural systems and the larger number of industrial outlets for herbicides.

Even this does not represent the whole story. An important part of the herbicides used in developing countries is concentrated in large scale plantation agriculture, often itself primarily responsible for the introductory biological testing that was needed. I am reminded how some twenty years ago, my present deputy Dr. Tincknell, was working with West Indian sugar companies on the introduction of herbicides into sugar cane agriculture. It seems to me that much scope remains to develop the use of herbicides in non-plantation agriculture in these countries - and here might be an enormous field for scientists in official organisations and universities to increase their role, provided the basic economies are sound, and provided also that, the required skills are locally available.

As regards the use of herbicides in crops, temperate cereals account for no less than a third of all herbicides used and, if rice and maize are included cereals completely dominate herbicide outlets with over half the market. Other outlets are diversely spread, with pasture, plantation crops, potatoes, sugar and fodder beet and top fruit leading.

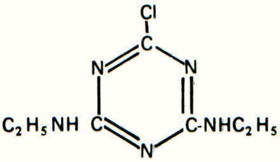
Clearly, in looking at trends in development of chemical weed control, several factors stand out and one can see that the use of herbicides has closely paralleled the move away from the land and increased mechanisation and intensification of crop husbandry in the developed regions of the world.

Significant in the history of this development, as with pesticides as a whole, has been the trend towards selectivity and specificity of end use.

Table 4

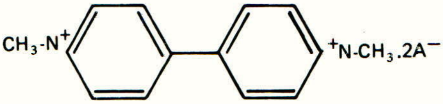
Herbicide product introductions – by class

TRIAZINES



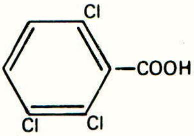
Simazine:
2-chloro-4,6-bis(ethylamine)-1,3,5-triazine
(1956)

BIPYRIDILS



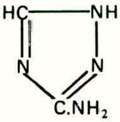
paraquat:
1,1′-dimethyl-4,4′bipyridilium (1958)

BENZOIC ACIDS



2,3,6-TBA:
2,3,6-trichlorobenzoic acid (1954)

AZOLES

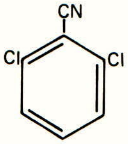


aminotriazole:
3-amino-1,2,4-triazole (1954)

Table 5

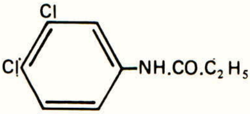
Herbicide product introductions – by class

BENZONITRILES



dichlobenil:
2,6-dichlorobenzonitrile (1960)

AMIDES

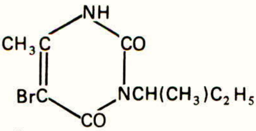


proponil:
N-(3,4-dichlorophenyl) propionamide (1960)

DINITROANILINES

nitralin:
4-(methyl sulphonyl)-2,6-dinitro-NN-dipropylaniline (1966)

DIAZINES



bromacil:
5-bromo-6-methyl-3(1-methylpropyl) uracil (1963

PROBLEMS ENCOUNTERED

I agree with Dr. Tschirley that the word "problem" has become one of the most common in everyday usage. Let us be sure that we distinguish between its application to different aspects of pesticides. Firstly, we have the technological problems which always arise during the development of a new compound. These are either resolved or the project is abandoned.

Then we have what I would prefer to call "problem situations" or issues. These usually develop only after a product has become successfully established and widely used.

Over the past ten years pesticide chemicals, mainly the organochlorine insecticides of which DDT has been the most cited example, have certainly had their share of problem situations to contend with, being subjected to a great deal of controversy, usually involving charges and counter charges that their use is uncontrollable, and that they are resulting in wholesale pollution of the environment, upsetting the balance of nature and finally, slowly poisoning mankind.

Herbicides, as a class, have been less involved in these situations perhaps the most notable exception has been the case of 2,4,5-T which has already been described for North America. Outside this area some fears have, of course been expressed and under pressure of public opinion and employee reaction, a few countries have temporarily restricted the use of this herbicide - withdrawing permission for use in forests, rights of way and other public areas. With the clarification of the situation in the U.S.A. as a result of further studies, it is expected that the use in forests will again be allowed.

Nevertheless, it is true to say that herbicides in the past have been subjected to fewer problem situations than insecticides. Primarily, I think this is so because their formulations have generally been shown to be of a low order of mammalian toxicity and as a result they have presented little, if any, hazard to the applicator when properly used as recommended. Also, their hazard to the food consumer has been adjudged as being somewhat negligible because they seldom leave more than traces of residues in the raw agricultural commodity.

What are now known as environmental studies have shown that most pesticides, including herbicides, are broken down in the soil, either by chemical or biological activity, or both; some quicker than others. Looking at the data on residues of soil applied herbicides has shown that they usually break down within a few months to amounts, as determined by highly sensitive analytical techniques, which are not considered, in our present state of knowledge, to be significant in respect of adverse effects on wildlike or soil fertility. Indeed, insofar as I have been able to ascertain, adverse effects on wildlife have seldom been observed even from direct exposure in the laboratory to much larger amounts than are customarily applied.

This is not to say we should become complacent - in my opinion soil carry-over investigations must continue to be an important area for study. Dr. Tschirley has already referred to the problems associated with the old arsenicals but our modern herbicides are organic molecules and although we might term them xenobiotic molecules, they usually breakdown fairly quickly so that succeeding crops are seldom endangered. At the present state of our knowledge, the experimental work needed to check this point is long term and well illustrated by the excellent studies carried out by scientists of the Weed Research Organisation at Oxford. In their study the herbicides MCPA, linuron, simazine and tri-allate, applied each year, showed that soil residue levels did not increase, even after 6 years - and I am told that this situation still prevails after 10 years. There was no evidence that successive applications were likely to cause any injurious effect on the ability of the soil to produce healthy crops.

One must always anticipate that there will be some pesticide chemicals - herbicides included - that can cause carry-over problems. In this regard we concur with those who believe there is a most urgent need to develop better techniques. There has been much discussion particularly here in the U.K. as to whether we may not check the effects of pesticide products on a series of soil parameters, notably the population numbers of certain commonly occurring soil inhabitants. If a population is reduced, this might be a danger sign. Unfortunately, at the moment we do not know how to relate these data to soil fertility - so I am told. As an aside on the point, many scientists have expressed the feeling that nitrification bacteria should remain unharmed, yet it is not so long ago that most useful effects on the soil's nitrogen supply were being reported when products were added to the soil specifically to inhibit nitrification and render inorganic nitrogen less liable to leaching, by keeping it in ammoniacal form.

Here is a case where programmes to discover indicator parameters are urgently needed and we are pleased to report that consideration is already being given to this aspect by the "Wildlife Panel: Soil Biology Group of the Scientific Subcommittee on Poisonous Substances used in Agriculture and Food Storage", and it is to be hoped that discussions between soil biologists and specialists in soil fertility regardless of their affiliation will work together to provide a valuable lead. What we must always be on our guard against is developing data which cannot be interpreted, so easily done and the real issues so easily obscured.

REGISTRATION REQUIREMENTS

The legislative and regulatory aspects of pesticides are complex. This is so, of course, because each country has its own unique pattern of legislation, registration schemes, and their enforcement. This complexity is further increased as a consequence of the large number of ways in which pesticides can effect the well-being of man. Consequently, not one but a number of different authorities (public health, agriculture, labour and transport) in a country, usually contribute to the legislative control of pesticides. For this reason I will be following with a great deal of interest that session of the programme dealing with the "Harmonisation of the Control and Regulation of Herbicides".

In terms of the world, outside North America, pesticide laws can be seen to have evolved, generally speaking, from early poison legislation; the practice is usually to include pesticides in the lists of poisons annexed to the legislation. With a more formalised development of the pesticide business and an increasing use of pesticide chemicals, national governments have taken steps to strengthen or to introduce new legislation in order to deal specifically with the control of pesticide use in their countries. Most of the legislation enacted over the last two years in our areas of responsibility (some 91 countries) has been straight-forward and workable and generally accepted by industry. A large number follow guidelines prepared by the Council of Europe and the Food and Agriculture Organisation and World Health Organisation wherein industry has been allowed to play a consultative role - or should I say advisory role on request.

In view of these developments, and to ensure that our pesticide products comply with these regulatory requirements, it has been found essential by most pesticide producers to have an organisation charged with responsibility of co-ordinating the collection of technical data and evaluating it to satisfy their own management that the information is sufficiently comprehensive and definitive for marketing to be considered. Only then will the data be submitted to government approval authorities for them to make an independent evaluation on which they can take a decision as to whether the product may or may not be sold and the conditions under which it can be sold.

This organisation, (in Shell this is named the Regulatory Affairs Division) along with its representatives in each marketing organisation, serves as a bridge between industry and the government in so far as the registration of individual compounds are concerned.

On matters of a wider concern; for example, on proposed changes in legislation and regulations, the Regulatory Affairs Division, or its local representatives, will be in a position either on direct request by governments, or through industry associations, such as the British Agrochemicals Association and the Groupement International des Associations Nationales de Fabricants de Pesticides to comment on government proposals. By and large, we have found this to be a very workable arrangement where mutual respect and trust assures that the needs of governments and industry are adequately met in serving both agriculture and society as a whole.

In terms of regulatory requirements, the most demanding aspect both on industry and government alike are that they should be able to satisfy themselves that the product proposed for registration can make a valuable contribution to agriculture without the danger of unacceptable side effects from the viewpoints of toxicology and residues in food and the environment.

Obtaining adequate biological performance data is usually accomplished in close collaboration with the official crop protection organisation in the country concerned. These local officials frequently play a dominant role in obtaining the scientific data to demonstrate the value of the contribution the product can make to the countries agriculture.

Toxicology data are obtained and evaluated to determine the dosage rate at which toxic effects occur in test animals. An estimate must then be made, by extrapolation, of the meaning of these data in terms of man. There are two main divisions of information:-

1. The effect of a single dose, acute toxicity;

2. The longer term effects of continued ingestion or chronic toxicity.

The acute toxicity is mainly of interest from the viewpoint of safeguarding the user. Tests are done to determine such acute effects when administered in the feed (oral), applied to the skin (dermal), or breathed in (inhalation). Often pesticides are classified in the regulations on the basis of acute oral LD50 (rat) data. From the viewpoint of safety to formulators and applicators the dermal rather than the oral toxicity has been shown to be the more important. Moreover data should refer to the formulation rather than the parent compound only. The dermal toxicity of formulations in field use can, of course, be influenced by several factors including concentration, dilution in the field, mode and frequency of use and probably most important, the ingredients of the formulation itself.

In general, toxicologists in the agricultural chemical industry have found that in assessing the hazard-in-use of a product, the toxicology of the formulation is most important. Likewise, government authorities, supported by their toxicologists are recognising this fact and where new regulations are being promulgated this is taken into account in setting up classification schemes.

Chronic data, for which two years is a typical study period, are of importance in assessing the risks which might arise from occupational exposure or to consumers of food from treated crops. These studies establish a level below which no toxic effect occurs in the test animal. As a means of extrapolating the data in terms of man, a series of safety factors are usually applied to estimate a safe level at which the pesticide can regularly be ingested by man over a lifetime. There is general agreement among toxicologists in industry, regulatory authorities and WHO about the safety factors used.

These toxicological studies are detailed and highly specialised, involving experts of the highest professional order who must be qualified to assess any potential effects especially those of a carcinogenic, teratogenic or mutagenic nature. They usually involve the study of the compound in at least two animal species.

Additionally, if degradation products are found to be present in significant amounts as a residue in food or feeds, these may also require toxicological studies.

Thus, comprehensive toxicological evaluations up to the point of marketing not only calls for the expenditure of many man hours, but is also very costly. Up to a quarter of a million pounds may have to be spent on a given compound before marketing begins.

Concurrently with toxicological evaluations, studies are also made to determine the levels of residues which will occur in the food commodity after the crop has been treated in field conditions and according to recommendations. The breakdown pathway of the pesticide must be determined and a decision made on what product or products should be analysed for in crop analysis.

The toxicological significance of the residues determined are evaluated in the light of dietary customs concerned on a world-wide basis and the toxicological evaluation of the compound. Tolerances are then proposed which, on evaluation, are shown to be compatible with residue levels which may arise from practical use conditions and yet, of course, cause no hazard to public health. This approach is preferred by industry since it takes into account the many factors of "good agriculture practice in the use of the pesticide" that actually influence the level of occurrence of residues, such as the pesticide itself, its formulation, the rate of application, method of application, time of treatment, the number of treatments and the interval between last application and harvest, climatic and agricultural conditions under which the crop is grown and the effect of post-harvest processes, for example milling, peeling, cooking, etc. We believe that this approach integrates all the pertinent factors and does not merely involve toxicological informations in isolation.

The cost for this work can also be formidible, reaching the neighbourhood of another quarter million pounds, depending on the number of different regions where it is proposed to market the compound and the number of outlets to be covered. With herbicides, the costs are usually somewhat less since the modern herbicide is designated for a few outlets only.

From a registration standpoint, studies of an environmental nature are just now beginning to be raised outside the U.S.A. A responsible industry will, however, be already including in their studies the determination of effects on wildlife, including birds and fish, and also, where appropriate, studies of the effect on factors such as rates and pathways of degradation, readiness to leach, possibility of run-off and accumulation in the biosphere.

Most industries divide the development process into several stages. What we have described above is more or less the picture for the one compound in 10,000 that has survived and is ready for marketing. Requirements, as demonstrated, to bring a compound through to the registration stage are very taxing. Additional requirements are likely to be called for in the future as new scientific knowledge and techniques are developed - it is to be hoped that industry will continue to play a major role in such developments.

Governments, I believe, will find the pesticide industry right along with them as long as additional requirements derive from sound, logical and objective reasons and have not resulted from emotive or political pressures.

It has been proposed in some quarters that in view of the increasing requirements for toxicological, residue and environmental data that some of these activites should be shared by government laboratories, thus lightening the load on industry. The philosophy being that this might allow the marginal compounds that might otherwise be shelved to find a place.

In fact, in one country which now has as part of their regulations that complementary data be developed in their government laboratories appears to be having in my view, the opposite effect; and in fact is proving to be more costly and long term could even discourage industry from entering into such a market.

Perhaps it is not fully realised that in the development of a new compound it is absolutely vital that all studies are closely integrated to a strict timetable which I think you will recognise as being one of the most important factors in determining the viability of the product.

From my point of view, and one which I believe is shared by those who must work with many regulatory bodies harmonisation of regulatory requirements offers much more hope - and we would welcome and look forward to the time when this is achieved at least in the European community.

ROLES AND RESPONSIBILITIES FOR REGISTRATION

We in industry believe that the responsibility for the safe use of pesticides, fall jointly on the manufacturer and on the government regulatory control authorities. For our part, we have a responsibility and are prepared to exercise that responsibility by supplying comprehensive data on our compounds firstly to be identified by the provision of adequate physical and chemical properties of both the compound itself and its formulation and secondly, to enable the composition of the formulation to be analysed to ensure that it meets the stated specifications, by the provision of analytical methods. We also believe they should demonstrate that the product will perform efficiently and should give a clear indication of optimum dosage rates and methods and time of application. These data should show clearly how the risk to applicators and to non-target species whether they be crop, domestic animals, terrestial or aquatic wildlife or soil organisms, can be minimised. We will continue to supply information to ensure that the compound can be safely handled during manufacture, formulation, packing, transport, storage, sale and use with proper warnings as to safe disposal of empty containers and what steps are to be taken in the event of an accident. The data should also show that the product, when used according to recommendations, will not have an adverse effect on the health of the consumer should residues of the compound or its metabolites, if any, be present in or on the commodity at harvest.

For the part of governments, it would appear to us that they have a very positive role to play in that they have to make the ultimate decision based on their scientific study of all the available data and to arrive at an early decision which will allow the product, if accepted, to be properly approved and labelled in such a way that an appropriate balance between safety and the needs of agriculture, public health and livestock production is achieved.

To exercise our respective responsibilities to proper effect it is, of course, essential that our activities be conducted with sincerity, frankness and in an atmosphere of mutual trust and co-operation. Fortunately, this atmosphere already prevails between most governments and industry regulatory people and in most countries of the world.

FUTURE TRENDS

And now what of things to come? I have heard it said that it takes a brave or reckless man to predict the future. Yet all of us in the pesticide industry have our views.

Harmonisation of pesticide legislation and regulations are still in a state of development. The manner and speed in which this can be accomplished, ensuring effective control by competent authorities and reasonable laws and regulations, is, in my opinion, of vital importance for the continued effective development of the pesticide industry and indeed of agriculture in general.

Novel herbicides, in the opinion of my colleagues who have their fingers on the marketing pulse, still present considerable challenge to our research associates; and there would seem to be considerable scope for improvement by concentrating development activities on compounds with more precise selectivity and greater flexibility as regards methods or timing of applications.

Again, I am told there is a great growth potential in the developing regions of the world, once these traditional rural economies become more industrialised and labour becomes scarce. With an expansion of the market southwards, this stage has already been reached in much of Europe. However, the rate at which herbicide usage outside developed areas will expand, would seem to depend on economic factors and Government strategy for local agriculture. These are difficult factors to predict and are essentially long term.

Neither am I brave nor reckless when I suggest there is little doubt that the world will continue to require crop protection agents. Novel and exclusive herbicide products will be in the forefront among these agents and the pesticide industry must be given the opportunity to develop these in order to survive and prosper.

CONCLUSION

From these discussions, which have called for a look at "Herbicides in Perspective", firstly we hope that you will have obtained a more complete and thorough understanding of the current status of the respective positions of Government and Industry in respect of herbicides in particular, and pesticides in general, and of the scientific and administrative matters surrounding them.

Secondly we hope that we have demonstrated how essential it is to have a policy of complete co-operation by industry with Governments and other International bodies who have a joint interest and responsibility in dealing with the scientific aspects involved in the continuing studies with existing herbicides and the development of new pesticide products. It is only through such a policy that the public, with their increasing awareness of our activities, can be properly informed.

And thirdly, we hope that resulting from our contacts made today, in future as in the past, you will feel free to work with us on any and all matters pertaining to herbicides and other pesticide products in your area of scientific interest, knowing that in so far as possible, we will keep you informed about our products and that, as with government regulatory authorities and other International bodies, such as FAO and WHO, we will co-operate with you as members of a responsible scientific community, in arriving at sound conclusions.

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OBJECTIVES OF WEED CONTROL IN CEREALS

Principles and Practice

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INTRODUCTION

The aim of the study group was to examine the objectives of weed control in cereals and to indicate how technological progress has affected the need for weed control. The findings of the group are presented in this and the four succeeding papers.

Routine spraying with chemical weedkillers has been practised on a large proportion of the cereal acreage in Britain for over 20 years, but the overall effect of this treatment on weed populations is not clear. Pfeiffer (1968) stated that few scientific facts were available to prove that changes in weed populations had taken place. From a survey of available data, Fryer and Chancellor (1970) concluded that radical changes in composition of weed flora had occurred in Britain over the past 25 years. Their evidence suggested that during the near future weed populations would continue to decline numerically, but not necessarily in diversity of species, so that any future laxity in weed control might be exploited by former problem species.

WHY CONTROL WEEDS IN CEREALS?

Cereals and their attendant weeds form a dynamic ecological system in which the competitive balance between cereals and weeds may fluctuate during the growth period or as environmental factors alter. If weeds are harmful in cereals, the farmer needs to shift the balance in favour of the crop by using methods which are effective and financially acceptable.

The purpose of weed control in cereals, therefore, is to offset physical and financial crop losses which may occur, due to the presence of weeds, in the following ways:

a) By reduced crop growth and yield due to competition for mineral nutrients, water, light and possibly carbon dioxide.

b) By necessitating the use of control measures which may themselves injure the crop and reduce yield.

c) By interfering with harvest and thereby increasing harvest costs and yield losses.

d) By lowering the quality of cereal grain through contamination with weed seed and foliage, by increasing the moisture content of the harvested grain, and by preventing uniform cereal maturation.

e) By reducing yield and quality as a result of adverse effects of diseases and pests associated with weeds.

The five main effects of weeds in cereals listed above will be examined critically in the four succeeding papers. In the present paper it is proposed to consider wider and more general aspects of weed control in cereals and particularly factors which motivate farmers to control weeds.

DEVELOPMENTS IN WEED CONTROL IN CEREALS

In the 19th century, farmers kept their crops clean by using clean seed, cheap labour and simple horse-drawn machines. At the end of the century, in most of Britain, competent farmers following traditional concepts of 'good husbandry' had no serious weed problems. Later, as labour became dearer and scarcer, cereal production became increasingly mechanised, more specialised and more intensive and different weed control problems emerged.

The introduction of selective weedkillers and the widespread adoption of the combine harvester in the 1950's made possible a very significant increase in cereal acreage in Britain despite a much reduced labour force. The need for weed control in cereals at this time did not seem to be questioned (Evans, 1969).

In present mixed farming systems, weeds may be kept in check by the combined effect of herbicide applications and cultural operations carried out at very different times throughout the cropping sequence. Under these conditions, with competent farming, little opportunity is provided for serious weed problems to develop. But on farms where intensive cereal production is practised there is a tendency for some weed species, especially annual and perennial grass weeds, to reach significant levels of infestation.

The old established practice of stubble cultivation has been revived to deal with weed problems in cereal production after harvest. In this way weed seeds and shed corn are stimulated to germinate and established plants are either destroyed or weakened by exhausting their food reserves or through dessication. Within cereal crops, weeds are now controlled as far as possible, almost entirely by application of chemical herbicides.

WHY DO FARMERS CONTROL WEEDS IN CEREALS?

It is clear that most farmers believe that weed control in cereals is desirable and necessary. Their reasons for this are likely to be based on the kind of objective and subjective considerations on which the success of their business depends.

The benefits expected, which provide the motivation for weed control in cereals, may be (a) direct, (b) indirect, and (c) personal and social.

Each of these three potential benefits will now be considered.

(a) Direct benefits

The most important direct benefits are associated with an increase in yield and quality of grain, and freedom of cropping.

(b) Indirect benefits

The main indirect benefits are associated with ease of harvesting, drying and storage, cleaner grain, and reduced risks from diseases and pests spread by weeds.

Direct and indirect benefits from weed control in cereals are considered critically in the four succeeding papers but opinions from a small survey of farmers will be given later in this paper.

(c) Personal and social benefits

Personal considerations may provide important reasons for controlling weeds in cereals. The concept of 'good husbandry' persists and farmers take pride in the appearance of their cereals. Just as a clean crop gives much satisfaction, a foul crop causes much disappointment and sometimes embarrassment. These attitudes are reflected in the extra attention given to roadside fields and to those adjacent to neighbouring farms. Contractors are instructed often to give priority to such fields, and more sophisticated sprays may be used on these sites than on fields on the same farm hidden from public view. Poor weed control after spraying fields exposed to public view often causes particular distress to the farmer concerned.

Belief in the merits of 'good husbandry' may also influence methods of weed control in cereal production. The rapid acceptance of stubble cultivation by cereal growers reflects the confidence that farmers have in cultural methods of weed control.

The effects of stubble cultivations are clearly visible and easy to appreciate and the mechanical techniques are well understood. By contrast farmers are uncertain about the use and effects of chemical herbicides. Moreover, compared with herbicides, cultivations are considered to be inexpensive since they utilize available labour and power resources and do not involve extra expenditure on sprays.

Many farmers still believe that 'one years seeding leads to seven years weeding' and are determined therefore to keep weed populations in check throughout the cropping sequence.

A further personal and social reason for weed control in cereals is fashion. Progressive farmers especially like to keep abreast of developments and may be keen to try out the latest chemical herbicides as 'leader farmers'. Their initiative may be followed quickly by neighbouring farmers.

A farmer's assessment of benefits from and new methods of weed control in cereals is based frequently on the opinions of farming friends and relatives (sometimes acquired in 'auction gossip'). Thus after a period of using, due to optimism or parsimony, a relatively cheap simple spray, a farmer may be influenced by his associates to try out a more expensive and complex spray mixture to deal with a particular weed problem.

The general aspects of weed control in cereals considered above will now be supplemented by information from a survey of about 30 farmers and their advisers in the West Midlands, on the practical reasons for weed control in cereals.

All the farmers sprayed their cereals unless prevented from doing so by seasonal weather conditions. Troublesome broad-leaved weeds included Matricaria spp.L (mayweeds), Chrysanthemum segetum.L (corn marigold), Polygonum aviculare.L (knotgrass) and Tussilago farfara.L (coltsfoot), but most farmers were satisfied that the sophisticated range of herbicides now available could give satisfactory control of broad-leaved weeds. The annual grass weeds Avena spp.L (wild oats) and Alopecurus myosuroides L.(blackgrass) remained a problem, and perennial grass weeds were a constant threat.

Damage to cereals was reported sometimes even when recommendations for application of herbicides had been strictly followed, and seemed to be associated with crop growth stage and seasonal weather conditions.

It was accepted generally that stubble cultivation was a cheap, useful, and effective method of controlling perennial grass weeds and some annual weeds. Basically, after harvest, cultural treatments were considered to be more valuable than chemical treatments because in addition to weed control they could improve soil condition and facilitate ploughing of stubbles.

The main practical reasons for spraying, resulting from the survey, are summarised below:

1) Yield response

Farmers considered that yield responses were obtained, generally, from spraying cereals but estimates varied from nil to 20%. Yield response was related to specific weeds and weed populations.

2) Ease of harvesting

There was general agreement that spraying was very beneficial in relation to speed and efficiency of combine harvesting, and in view of the cost of labour and power and weather risks, this benefit was considered to be paramount.

3) Clean grain

Farmers and advisers stressed the value of spraying in relation to cleaning, drying and storage of grain, especially in relation to seed crops, milling and malting samples.

4) Cost benefit

This was difficult to assess but it was reckoned to be anything from double the cost of the herbicide used to £10 per acre.

The main personal reasons for weed control in cereals arose from a conviction of the merits of 'good husbandry' and the satisfaction and pride associated with clean crops. In this connection, timeliness and skill in cultivations were regarded as important factors in weed control but there was increasing dependence on chemical herbicides. Provided that the latter were properly applied, weed control was usually satisfactory.

The survey in the West Midlands of farmers' reasons for weed control in cereals confirms the view of Evans (1969) that the main practical benefits were ease of harvesting and clean grain.

Other considerations which may justify the cost of weed control in cereals include a long-term desire to reduce weed populations and the avoidance of possible social stigma incurred by weedy cereal crops.

CONCLUSIONS

The main reasons for controlling weeds in cereals are to reduce competition, facilitate combine harvesting, and to improve quality of the grain.

After more than 20 years of routine spraying of most cereal crops in Britain, the effects of spraying broad-leaved weeds on cereal yield are still not clear. The limited available scientific data suggests, generally, that only marginal benefits in yield are likely to be obtained from spraying, and that sprays have phytotoxic effects on cereals. In practice, farmers believe that some yield benefit accrues from regular spraying of cereals.

Farmers consider that weed control in cereals is desirable and necessary. Their reasons for this are based on objective and subjective considerations relating to their overall business.

The most important benefit from spraying, in commercial practice, is to facilitate combine harvesting, but this advantage is due to a complex of physical and financial factors and is difficult to quantify.

Improvements of grain quality, due to weed control, is particularly important from the merchant and the farmers viewpoint in relation to cleaning, drying and storage of grain.

Apart from financial considerations, personal reasons may have an important bearing on a farmer's approach to weed control in cereals. Farmers have a deep-rooted sense of pride in clean crops and a desire to keep weed populations in check throughout the cropping sequence. It is apparent, despite recent technological advances and increasing financial pressure, that most farmers still believe firmly that the tenets of 'good husbandry' apply to weed control in cereals.

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THE OBJECTIVES OF WEED CONTROL IN CEREALS - AN AGRONOMIST'S POINT OF VIEW

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INTRODUCTION

The overall objective of weed control from the farmer's point of view must be, in part, a sense of pride and order but, in the main, economic. We could define this economic objective as being "to ensure the continued profitability of a chosen system of cropping". By this is implied a system chosen in response to economic pressures and a farmer's personal preferences not a system imposed by the demands of weed control.

The agronomist's role in this is to study and analyse the effects of weeds and weed control so as to provide guidance to farmers and their advisers on the range of techniques and overall strategies by which this objective can be achieved.

This implies a strong and continuous interaction between biological and technical factors and the economics of cereal culture. Without the financial element there would seem to be little need for the involvement of agronomists; all that would be necessary would be herbicide technology. In this present brief review I shall try to concentrate on the technical and biological factors as far as possible but it is impossible to escape this overall economic background.

There are two contrasting ways in which the objective of ensuring continued profitability can be achieved; by preventing seed or vegetative propagules building up to a level which could give rise to damaging weed populations, or alternatively by treating only those weed populations likely to be damaging or to respond economically to treatment. The biological and agronomic factors involved are of course virtually the same but it does seem worth, at the outset, differentiating between two broad lines of approach to the common objective. I shall refer to them as the preventative approach and the curative approach without wishing to compare them at this stage. Before discussing strategies it is necessary to review the harmful effects of weed populations and the extent to which these can be predicted and should be considered when planning control strategies.

Four of these harmful effects are discussed below, namely; the effects of weeds on potential crop yield, the effects on attainment of potential yield, the production of seed and vegetative propagules, and weeds as alternate hosts of pests and diseases. Other harmful effects are discussed in the four related papers.

The effects of weeds on potential crop yield

In the simplest concept, competition between species could be regarded as a struggle for space. A plant uses nutrients, moisture and light in proportion to the space it occupies and the time that space is occupied and these resources are then unavailable to other plants. If one accepts this it could be said that any level of weed infestation will result in a reduction of potential crop yield. If, in experiments, this does not appear to be so then either the experiments are not sufficiently sensitive or the crop is not being grown in such a way as to exploit all the space available to it.

In practice this concept may be too simple to be of value in many cases. The studies of cereal growth at Rothamsted - Watson, Thorne and French (1963) and Thorne (1966) suggest that the mechanisms of competition may vary in importance at different stages of crop development. Such change would be continuous but I would suggest that the growth of temperate cereal crops could be divided into three basic phases; The development of a young tiller population; The establishment of a mature tiller population and the final phase of ear growth.

In the first phase a high tiller population is produced and a dense canopy of crop or crop and weeds is established. In the very early stages ample resources are available to all plants so there can be very little direct interference. However the relative speed of growth of the competing elements in a population has a direct bearing on their ability to survive the onset of the second phase.

The early stages of the second phase are characterised by a high degree of mortality among crop tillers. Tiller mortality commonly exceeds 50% but varies with plant density, arrangement and variety - Kirby (1967). Competition for light is critical at this stage (Watson et al, 1963) but, as the season advances, the probability of deficiencies of moisture and/or mineral nutrients becomes greater. These deficiencies are highly subject to variation between sites and between seasons.

The third phase is concerned with the growth and maturation of the seeds. It appears that most of the carbohydrate in the grain is produced during this period by photosynthesis in the flag leaves and ears of the crop. At this very late stage weeds are unlikely to interfere very much with the reception of light by the crop flag leaves, but competition for moisture and mineral nutrients could still play an important part in the determination of crop yield.

The above is an over simplification in that the phases would, in practice, run into one another and in that some aspects have been ignored altogether. The production of biologically active exudates by weeds for example could influence crop growth at very early stages - Osvald (1947) and Wellbank (1963). It can do no harm however to stress the dynamic nature of crop and weed growth before considering the possibilities for relating weed growth and cereal yield response.

The weeds are intruding into a situation in which, in phase two, there is intense intra specific competition, notably for light. It is to be expected therefore, that weed plants will be affected by this competition and their success as competitors will be influenced by it. This counter competition from the crop has been noted in respect of a range of widely differing weed species. Mann and Barnes (1948) (1949) working on two rhizomatous grasses Agrostis gigantea and Holcus mollis reported that barley had a greater effect on the growth of these grasses than vice versa. My own work (Cussans 1968, 1970) confirmed this for Agropyron repens and showed that the counter competition from spring barley was greater than that from spring wheat, both cereals being much more competitive than field beans. These results were closely comparable to those obtained with wild oats in these crops (Thurston 1954, 1956).

Some weed species are more successful than others but there have been few critical comparisons of species of contrasting habit. Blackman and Templeman (1936, 1938) showed that Raphanus raphanistrum was much more competitive than Papaver rhoeas, but with both species there were large fluctuations from site to site in yield responses to the removal of these weeds.

It would appear however that duration of growth can, with some species be as important as growth form and vigour at early stages. A study of the competition between barley and Polygonum lapathifolium - Aspinall and Milthorpe (1959), Aspinall (1960) showed that the crop was dominant, as was the case with the grass species described earlier. It was also noted that this weed, although dominated by barley in the early stages, retained its ability to make vegetative growth after crop growth had ceased. This is similar to the behaviour of A. repens and stresses the importance of the time factor in critical analyses of competition. Cussans (1970) postulated that a late maturing crop could be influenced to a greater extent by A. repens than an earlier maturing crop even though the two were of similar competitive ability in the early stages.

The high site to site variability commonly experienced in competition experiments could be due to a number of factors influencing the speed of growth and ultimate size of individuals within a weed population. Soil type must be important and occasionally specific restraints such as soil pH or a disease infestation will influence competition (Thurston 1956).

This brief personal account has not attempted a complete review of the subject of competition. It may have helped, however, to illustrate some of the difficulties and to explain the wide diversity of results obtained in field experiments. This variation makes it difficult to predict the level of crop reduction resulting from a stated level of weed infestation. The difficulty has not prevented people trying and with Avena fatua there have been many attempts to calculate a threshold level. In the United Kingdom populations of 10 or 12 plants or panicles/yd^2 have been said to be the level at which increased yields would cover the cost of spraying. Current work at the WRO however (Wilson and Peters - private communication) suggests that the threshold level is likely to be higher and to be subject to at least a three to four fold variation from site to site. The behaviour of mixed weed populations may, of course, be even more difficult to predict.

Nonetheless as our knowledge of the mechanics of competition grows it should be possible to devise such threshold levels. It seems likely however that, in addition to weed numbers and species, account would have to be taken of the relative times of emergence of crop and weed and a prediction of crop counter competition would have to be made.

Effects on attainment of potential yield

In addition to reducing potential yield, weeds influence the attainment of that yield by interference with mechanical harvesting. This will be dealt with elsewhere in the session but the following points may be made.

In temperate cereal crops the output of a combine harvester is limited not by acreage or grain yield but by the total bulk to be handled. That is to say, in clean crops, the limiting factor is throughput of straw (Arnold - private communications, Hebblethwaite and Hepherd, 1961). In weedy crops the throughput of straw and weeds would be limiting. At the higher levels of throughput, any increase results in higher threshing losses.

One could postulate therefore two very broad groups of weed species, with a number of intermediate species, in respect of effects on harvesting.

The first group would comprise species which mature and senesce at the same time as or before the crop and which would not normally be expected to cause discontinuous effects (blockages) on speed of harvesting e.g. Alopecurus myosuroides and Papaver rhoeas. Such weeds would be expected to reduce the speed of combining in direct proportion to the bulk of weed present at harvest and in proportion to the degree of competition suffered by the crop. The latter relationship would not be a direct one because bulk at harvest may not be related to the degree of competition. However, taking this very simple model, it might appear that a population of these weeds which reduced yield by 10% would be expected to reduce the combine speed per ton of grain harvested by around 8-10; the combine speed/acre being virtually unaffected. This it must be said, is an outrageous cockshy for I can find no evidence that this subject has ever been studied in depth.

The other extreme group would comprise perennial weeds and annual species which have the ability to continue vegetative growth after the crop has senesced; some examples have already been mentioned and one could include such species as Cirsium arvense and Convolvulus arvensis as classic examples of this type. The effect of such weeds on combine output would be extremely difficult to predict, being weather dependant, but it would certainly be greater than the effect on crop yield. Moreover the effect of increasing weed population on combine speed per ton of grain recovered would almost certainly not be a linear relationship. This is because the greater the proportion of weed to cereal straw the greater would be the tendency for the mixture to mat together on the straw walkers and reduce combine efficiency. There would also be a greater risk of blockages. If we supposed therefore, an even more outrageous cockshy, that a moderate level of Agropyron repens, which reduced potential crop yield by 4%, reduced combine speed per ton of grain by 6%, then under the same climatic conditions a severe infestation, reducing yield by 20%, might reduce combine speed by 40-50%/ton of grain or up to 20%/acre. In practice an uneasy compromise would probably be reached in which the driver would attempt to maintain his speed over the ground at the expense of even greater loss of attained yield. In addition, weeds of this type would, under some conditions, increase the moisture content of the harvested grain by delaying the process of drying out. We have ourselves recorded differences of 2% in moisture content between barley with moderate or severe levels of A. repens harvested under marginal conditions.

This characteristic is most marked with laid crops. These may dry out as quickly or even more quickly than standing crops if weedfree but the presence of weed or secondary crop tillers will prevent drying.

The intermediate group of weeds hardly needs definition. This group is of course the most liable to behave differently under different conditions. Avena fatua for example might be placed in the first group in late maturing crops on sandy soils. However, on moisture retentive soils or in wet seasons this species continues vegetative growth appreciably longer than most varieties of spring barley and the resulting bulk of unripe wild oat straw may have a marked effect on combine performance. Prudence forbids any attempt to predict the effects on combine output of this group.

The production of seed and vegetative propagules

The traditional saying "one years seeding, seven years weeding" gives an indication that prevention of build up was one of the main objectives of weed control in the days before the advent of chemical weed control. It is a less fashionable objective now but is still relevant to most situations and critically important for some. An obvious example exists where cereals are grown in rotation with some more demanding crop. Some weeds such as Viola species or Veronica species may not be considered competitive in cereals and others such as Sinapis arvensis may be considered so easy to control that a certain amount of seed return is permissible. However, if the Viola and Veronica subsequently appear in sugar beet drilled to a stand or the Sinapis appears in oil seed rape then these weeds could acquire an importance vastly out-weighing their effects or lack of effect on the cereals in the rotation. Other weeds, notably Avena fatua and Chrysanthemum segetum, may be difficult and/or expensive to control in cereal crops so that return of seed of these species must add to future management problems.

Unfortunately, although Roberts has studied some aspects of the seed economy of weeds under horticultural conditions, very little work has been done in an agricultural context. Some difficult weeds have been studied and further work is in progress. Some recent work at WRO (Wilson and Peters, private communication) has recorded seed return of Avena fatua and the yield response of spring barley to removing this weed. At high population levels colossal quantities of A. fatua seed may be produced; 22,000 seeds/m^2 is the highest estimate so far in a spring barley crop. Even where the yield response would not justify the cost of chemical treatment seed production of 200 to 2000 seeds/m^2 has been recorded. Some of this seed would be removed with the grain or straw, and not all of the remainder would survive to produce plants. Some current WRO work on factors influencing seed survival is reported elsewhere in these Proceedings (Cussans and Wilson 1972, Wilson 1972).

In studies of Agropyron repens (Cussans 1968, 1970) populations which have not affected yield of spring barley have built up high levels of rhizome reserves. Over 10 fold increase in rhizome weight per unit area has been recorded, even in vigorous and competitive barley crops, leading to levels of over 600 viable rhizome buds/m^2. Not all of these buds will produce shoots to influence the following crop, of course, and more ad hoc measurements indicate that populations of A. repens will usually increase by a factor of x 3 - 4/unit area/annum with considerable variation around this value due to climate etc. This is closely analogous to Selman's (1970) observations of the increase in populations of Avena fatua at Boxworth. He noted a mean increase by a factor of about x 3/annum with a range of x 1.3 to nearly x 6.

The main factors controlling the degree of seed and rhizome growth would appear to be the same ones that influence the degree of crop loss due to the presence of weeds. Crop counter competition and the factors controlling it are the most important but some weeds are, as discussed earlier, capable of continued growth after the senescence of the cereal crop and therefore partly, but not wholly, recovering from these effects.

Clearly, factors such as crop species and variety, seed rate and plant arrangement, relative time of emergence of crop and weed etc. will affect the degree of crop loss and the potential increase in weed population to a similar extent. Studies of crop competition which lead to some means of predicting crop losses should therefore also be useful in predicting these potential increases.

So far as treatment is concerned, the two effects of weed populations must be considered separately. Crop loss can only be avoided by killing the weeds before competition has occurred to any extent. Production of seed or vegetative propagules can be reduced or prevented by attacking the weeds at any stage up to maturity or by attacking the propagules and not the competing population at all. Thus with A. repens, for which selective treatments are not available at the present time, all control systems in cereals are based on attacking the weed after crop harvest, thus reducing the current stock of rhizome and preventing further rhizome formation during the autumn. With A. fatua one means of control has traditionally been hand roguing, now it is possible to use a chemically impregnated glove for the same purpose. In addition, many acres of straw are burnt each year, not with the primary aim of weed control but frequently with the hope that seeds of A. fatua will be destroyed. Some of our current experiments are designed to determine the extent to which such hopes are justified.

Weeds as alternate hosts of pests and diseases

Space does not permit detailed discussion of this aspect of the objectives of weed control. The subject was reviewed at length at the last British Weed Control Conference by Moore and Thurston, Franklin, Heathcote and van Emden. These reviews were extremely helpful to our general understanding of the subject but could help very little with the difficult but central problem. To what extent is pest control through weed control a valid and economic objective compared with the more direct aims of weed control?

One case does seem to be generally accepted. The volunteer cereals can only be regarded as weeds by virtue of their role in disease carry over. These plants rarely have any other deleterious effect but are considered to play such an important part in the epidemiology of cereal leaf diseases that they must be considered in planning autumn cultural and herbicide programmes. This is an example, not unique, in which the prime technical objective of weed control is the prevention of a secondary effect of a weed; totally unconnected to the primary effects discussed earlier but very much a part of our central economic objective.

DISCUSSION

A discussion of the objectives of weed control in cereals implies a need for planned approaches to the subject. Analysis of the current situation would seem to support this need. Limited resources of manpower and money are available for crop protection but the demands on these resources are increasing. Difficult weeds are tending to increase; some, such as Agropyron repens and Avena fatua are obvious, others such as the Mayweeds and Polygonum species are not so obvious as problem species but exert a powerful influence on herbicide programmes. In addition the use of crop protection chemicals other than herbicides is beginning to increase the problems of choice and of management at critical periods of the year.

Before weed control strategies can be planned we need basic data on weed population dynamics and on the economic effects of weeds. We should know the probable effects of weed populations on yield, harvest ability and produce quality and be able to relate these effects. Unfortunately the objectives of weed control in cereals remain easy to define but difficult to quantify. More accurate predictive ability is necessary and must be sought, however. Evans (1966) and Hughes (1966) indicated that farmers were not, on average, increasing crop yield by spraying for control of broadleaved weeds in cereals. This average response, however, included situations in which yields were increased by spraying and others where marked yield decreases were recorded. It was not possible to define the situations in which spraying would be justified due to the range of conditions encountered in the survey; varying accuracy of spray application, different weed populations, the range of products used etc. At the present time, six years after the great debate on spraying against broadleaved weeds, we still cannot define with any precision the benefits likely to accrue from such spraying. Nonetheless, recent survey data (Phillipson, Cox and Elliott 1972) indicates that about 90% of our cereal acreage is treated with herbicides for broadleaved weed control. This would suggest that most farmers decide that the level of cost of these sprays justifies a preventative approach. This is in contrast with the use of chemicals for control of wild oats; here it seems that only around 10% of the infested areas are being treated.

The curative approach to weed control would appear to be very much a 'farmers risk' operation at the present time. Our ability to predict the effects of weed populations on cereal yield is poor and, despite the dubious mathematics in earlier sections of this essay, our knowledge of the effects on harvesting is poorer still. Moreover, some of our most serious weeds such as wild oats and blackgrass may in some cases best be controlled by a pre-emergence herbicide. In such cases our prediction of weed effect would have to be added to a prediction of weed population such as that suggested by Naylor (1968). Even this complex calculation should not be ruled out as completely impractical although it requires more knowledge than we have at the moment. Certainly in respect of some of the most serious weed species we should be in a much better position when current research programmes reach fruition.

The problem is to reconcile these difficulties with the fact that it appears farmers cannot adopt preventative approaches to weed control regardless of cost. This is most obvious with the weeds which are expensive to control but the principle may apply to other species. Economic circumstances and herbicide technology may change but it does seem at the moment that weed eradication is rarely a practicable goal. Most of the broadleaved species seem surprisingly resilient and have survived 15-20 years of spraying in many cases. Other weeds such as wild oats and couch grass are, in theory at least, susceptible to eradication but the economics of doing so may be unacceptable, and a relentless vigilance would be necessary to prevent re-infestation.

If eradication is accepted as impracticable, we seek methods of maintaining weed populations at low and harmless levels, at minimum cost. The choice of target populations should not present too many problems; in theory at least, the maintenance of a more or less constant level of weed population should for any one species, cost the same whatever level was selected. One suggestion which has the advantage of allowing for a degree of guess work is as follows: The maximum level of any weed which should be tolerated is the lowest population level likely to cause an economic effect, be it on crop yield, harvestability or produce quality, divided by the highest likely rate of annual population increase. This would result in a much lower tolerance level than only spraying for immediate return but would provide some yardstick for assisting decision. A more serious problem arises, having selected an arbitrary level of weed population, in deciding how to attain it and subsequently maintain it.

One positive and valuable contribution which has been made by many students of competition has been to stress the paramount importance of crop vigour or counter competition. Vigorous, healthy, optimally spaced crops reduce the competitive effect of weed populations and the potential for population increase of those populations. If we are to make progress in predicting the effects of weed populations then it seems that such progress will be more certain against a background of consistently vigorous crops. It may not always be easy to achieve such standards and some factors may not be entirely compatible. It seems for example that increasing crop seed rates may be one of the most consistent ways of increasing crop counter competition. Such increased seed rate may be costly, however, and could create conditions favourable for the spread of powdery mildew. However, it does seem certain that if we wish to employ more planned approaches to weed control and thus maintain standards while reducing costs then such approaches must be accompanied by closer attention to detail in respect of some of these other aspects of husbandry.

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WEED CONTROL IN CEREALS
A MANUFACTURER'S VIEW OF FARMER BENEFITS

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INTRODUCTION

The cereal crop represents the biggest individual market for herbicides in the U.K. and accounted for nearly 50% of total farmer expenditure on pesticides in 1971. Like the farmer, the manufacturer has a direct financial stake in ensuring the benefits of herbicide use are successfully and profitably achieved.

Unfortunately firm and reliable data on all the possible benefits of weed control in cereals are scarce compared with the mass of technical information published on chemical products and crop husbandry in general. This is primarily because herbicide use in cereals is part of an integrate programme of production from which it is extremely difficult to isolate and cost each component part.

U.K. farmers spent more than £8 million on weed control in cereals in the season 1971/72. This is a measure of the need for herbicide use as assessed by the farmer even though much of the benefit cannot be quantified in economic terms.

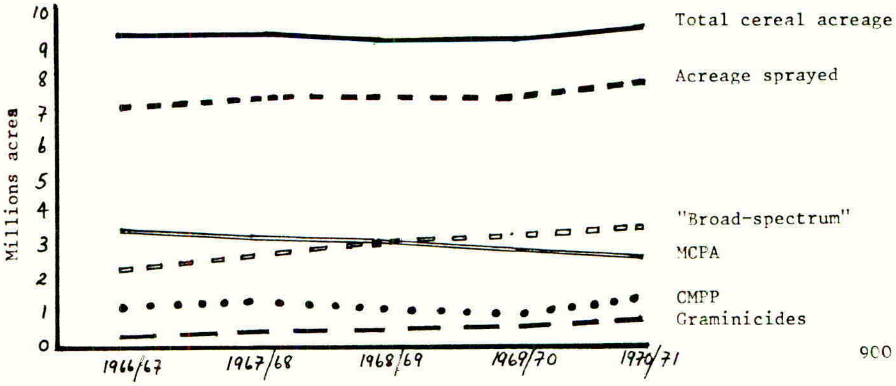
This paper outlines some of the potential "direct", "indirect" and "subjective" benefits from herbicide use in cereals.

PRESENT STATE OF WEED CONTROL IN U.K. CEREALS

For background information the approximate use of herbicides in U.K. cereal crops over the past five years is given in figure 1.

Figure 1

Weed Control in U.K. cereals - approximately



The percentage of the total acreage sprayed has remained fairly static (about 85%) over the 5 year period. MCPA shows a continuing decline relative to "broader spectrum" herbicides, despite its lower cost, reflecting the change in weed flora to species more difficult to control. However MCPA is still a very important constituent of most hormone mixtures.

Although the acreage sprayed for the control of grass weeds has more than doubled over the period shown it still represents a relatively small percentage of the infested area. During the past 3 years the major increase in grass weed control has occurred in the blackgrass (Alopecurus myosuroides L.) sector.

The sprayed acreage of cereals undersown with legumes is not shown separately but has remained relatively constant at about 0.3 million acres/annum. With the increased emphasis on grass it is probable that more herbicides will be used in this sector in the future.

BENEFITS OF WEED CONTROL IN CEREALS

For convenience of discussion the potential benefits are divided into 3 categories viz "Direct" (related solely to the crop being sprayed, and capable of increasing the output or decreasing the costs); "Indirect" (benefits to the cropping system overall); and "Subjective". All benefits will not necessarily occur simultaneously.

DIRECT BENEFITS

1. Prevention of yield loss

a. Grass Weeds

The magnitude of the grass weed problem in U.K. cereals is obvious to any observant traveller. Wild oats (Avena fatua L; Avena ludoviciana Dur.) have "exploded" into a National problem as was indicated possible under intensive cereal growing in experimental work (Rademacher et al 1964; Selman 1968). The acreage infested with blackgrass (Alopecurus myosuroides L) is also showing significant and continuing annual increase especially where the rotation involves a high proportion of winter crops. Estimates of the U.K. arable acreage heavily infested with these weeds, based on data from Fisons' weed surveys in 1967 and 1972 are given in Table 1.

Table 1

000's acres Heavily Infested

	Wild Oats	Blackgrass
1967	530	197
1972	920	280

The yield depressing effect of wild oats and blackgrass on U.K. cereals is well documented. Cultural techniques of control alone are generally inadequate or inconvenient under intensive cereal growing systems. However much, if not all, of the potential yield loss can be prevented by the application of herbicides as shown in Table 2.

Table 2

Typical Yield Increases from Controlling Moderate to Severe Infestations of Grass Weeds in Winter Wheat and Spring Barley

	WINTER WHEAT		SPRING BARLEY
	AVENA SPP	ALOPECURUS MYOSUROIDES	AVENA FATUA
Number of trials	14	13	26
Mean % yield increase	25.9	24.4	26.0

The above data was obtained from experiments with barban (wild oats) and metoxuron + simazine (blackgrass).

The applied cost to U.K. farmers of wild oat and blackgrass control with these chemicals is approximately £3.50 (wild oats) and £5.50 (blackgrass) per acre. Using the 1972 guaranteed prices (wheat £1.72 per cwt; barley £1.56 per cwt) the 'break-even' yield increase required per acre from wild oat control is 2.1 cwts. wheat and 2.25 cwts. barley. For blackgrass control an increase wheat yield of 3.2 cwts. per acre is needed. Based on the mean percentage yield increase due to spraying of 25% given in Table 2, compared with an unsprayed crop of wheat of 30 cwts. per acre, spraying would increase yield by 7.5 cwts. Similarly a barley yield of 25 cwts. per acre would be increased by 6.2 cwt. It is obvious therefore that control of moderate to heavy infestations of grass weeds in cereals shows considerable financial benefit.

Most farmers would expect to obtain higher average yields of wheat and barley than those used above and in many cases therefore the benefit of herbicide application may be greater. Evidence from the control of blackgrass in winter wheat suggests that in potentially high yielding crops the benefit of grass weed removal is relatively less than in crops of low potential yield (North and Livingstone 1970; Griffiths and Ummel 1970; Naylor 1972). Similar information on wild oat control does not appear to have been published but it is likely that the same response occurs. However the level of yield at which financial benefits do not result from spraying is considerably above the yields of unsprayed crops consistently obtained by most farmers.

Despite the economic benefit of grass weed control by chemicals shown above it is estimated that less than 25% of the cereal acreage infested with grass weeds was sprayed in 1971. This suggests that manufacturers and advisers have failed to convince farmers of the benefits of control. The data given in Table 1 calls for much greater efforts in this respect or severe yield losses will result.

Advisory yardsticks for recommending at what level of infestation herbicide application is justified need further refining but this is a complicated task depending on many inter-acting factors. For wild oats 10 plants per m^2 and for blackgrass 50-100 plants per m^2 are considered sufficient to depress yields in excess of the equivalent cost of herbicide plus application. In conjunction with this farmers need also to have a measure of the probability of success. With post-emergent treatments where infestations can be assessed before commitment the probability of success is high. It is less easily predicted with pre-emergence treatments but these are generally used only where significant weed infestations are anticipated. Recent work on Weed Predictive Indices for blackgrass (Naylor 1970) may ultimately help the farmer in his decision-making and perhaps this technique can be extended to cover other annual grass species.

The very obvious appearance of wild oats and blackgrass (temporarily) above cereal crops means that farmers can make a visual assessment of the benefit obtained after spraying. However, this measurement of success alone can be misleading in that considerable yield benefit may be obtained despite poor visual control. It is extremely difficult for farmers to make such comparisons but, wherever possible, the benefit of treatment should be judged on the basis of yield rather than appearance.

b. Broad-leaved weeds

Although yield increases can occur from the control of broad-leaved weeds in cereals they are generally less significant and occur less frequently than from grass weed control. Some experimental work in the intensive cereal growing areas of the south and east of England in recent years has shown small or negligible yield increases from spraying (Evans 1969). In these areas (where the highest percentage of the crop is sprayed for broad-leaved weeds) factors other than yield increase motivate the farmer to spray.

It should not be assumed that lack of yield benefit necessarily applies to other areas of the U.K. even though the weed spectrum may be fairly similar (Scragg 1970). Soil type also has an influence and significant yield increases are more likely to occur from controlling weeds on high organic soil than on mineral soils. These differences may merely reflect the vigour of weed growth on organic soils and in high rainfall conditions but they might also be related to the farming systems. In the North and West of the U.K., as on soils high in organic matter, the rotation is less dominated by cereals.

Increased yields may result not only from preventing weed competition but also by ensuring minimum losses during the harvesting operation. Even in an average year the main grain loss at harvest occurs at the combine cutter bar and the presence of weeds can increase this loss. Although most farms may have an adequate "combine capacity" if harvest runs smoothly, some crops are frequently harvested late. ADAS experiments have shown the high level of grain loss from combining under late conditions and have suggested increasing the forward speed to minimise these losses. (MAFF 1969). The presence of weeds (e.g. *Polygonum spp. L.*; *Galium aparine L.*; *Sinapis arvensis L.*; *Chenopodium album L.*; *Stellaria media L.*) would make this a difficult recommendation to carry out.

2. Ease and Speed of Harvesting

Difficulties at harvest are related to weather conditions and the weed species present. In general grass weeds do not interfere significantly with harvest but wild oats can make the crop more liable to lodging as their straw is usually weaker than that of the crop. They can also tangle in the combine reel when the latter is adjusted for short strawed barley varieties.

Tall growing broad-leaved weeds e.g. Polygonum persicaria L., Chenopodium album L., Matricaria/Anthemis/L. spp Tripleurospermum maritimum L., Sonchus oleraceous L., slow the rate of combining as mentioned above. They can also reduce the number of "combining hours" per day by holding moisture and delaying the morning start and necessitating an early finish. Stellaria media L. can also be important in this respect especially if the crop is laid. The cost of delayed combining can vary enormously but has been estimated at about £1 per ton harvested (Pertwee 1968).

3. Reduction in post harvest losses

Weed seeds and flower heads in the grain can increase drying and cleaning costs and simultaneously reduce the quantity of saleable grain owing to the harder cleaning processes required. Possible average losses attributable have been estimated to cost the grower more than £3 per ton (Pertwee 1968).

Losses at the marketing stage due to weed contamination can be particularly severe especially if this involves the loss of premium paid for a seed crop. Herbicide use cannot be guaranteed to eliminate all the losses due to weeds, or to ensure acceptable seed crops, but can contribute significantly towards this objective.

INDIRECT BENEFITS

1. Cropping flexibility

Intensive cereal production is widely practised in the U.K. This simple form of "rotation" would be impossible in many parts of the country without herbicides for the control of wild oats and blackgrass. Although not 100% effective, herbicides prevent these weeds becoming the limiting factor which dictates the rotation and causes abandonment of systems which suit the farmer. This flexibility which herbicides permit obviously has an economic value but it is difficult to quantify.

There appear to be no really profitable alternative crops to which intensive cereal growers can readily change. Grass/livestock enterprises are frequently cited as a possibility but the high capital expenditure necessary for such change will prevent rapid movement in this direction. Any reduction in the intensive cereal acreage therefore will only occur very slowly. Given this situation, and the level of grass weed infestation in cereals, herbicides provide the intensive cereal grower with the means of remaining in business.

2. Operational fluency

For consistent profitable growing of successive cereal crops, hygiene and 'timeliness' of operations are of paramount importance. The period between the harvest of one crop and the sowing of the next is an important opportunity for 'cleaning' the land, (especially if Agropyron repens is present) and can be very short especially between consecutive winter wheat crops. Any delay in harvest obviously reduces this opportunity for 'cleaning' and can mean a delay in drilling beyond the optimum time. For effective control of blackgrass in winter wheat and wild oats in spring barley using cultural treatments only, delayed drilling is almost always necessary. However, potential yield losses from delayed drilling have been clearly demonstrated in winter wheat (Mundy & McLean 1965) and Spring barley (Selman 1968). The availability of selective chemicals for control of these weeds in the growing crop has therefore allowed more timely drilling and thereby helped the attainment of maximum yields. They also aid the overall management of the farm in permitting a smooth drilling schedule rather than necessitating very intensive activity over a short period which is therefore more subject to the vagaries of the weather.

3. Reduced weed populations in succeeding crops

In the early 1960's the control of weeds in cereals which were difficult to control in other crops in the rotation (e.g. *Polygonum spp* in sugar beet and peas) had a beneficial carry-over effect. Today most weeds can be controlled chemically in most crops and this benefit is slightly less relevant. But in the overall "weed management" of the farm successive reductions in the grass weed population are very important steps towards the goal of eradication.

SUBJECTIVE BENEFITS

Apart from the obvious requirement to make profit farmers look for satisfaction in the method of achievement. Pride in appearance of the farm can be a strong motivating factor for herbicide use but the benefit eludes quantitative assessment. Like all businesses some decisions in farming are likely to be made on subjective judgements based on past experience. Thus if the clean crops which results from herbicide use give satisfaction to the farmer and his men it is likely that the whole organisation will run smoother and more efficiently. These benefits, although intangible, are none the less real.

GENERAL DISCUSSION

The benefits of grass weed control in cereals are relatively easy to measure and have been quantified earlier in this paper. However, the acreage of cereals now infested with grass weeds shows that much more attention must be focused on their control in the future. The benefits of broad-leaved weed control are much more diffuse and spraying is generally considered as an insurance against adverse harvesting conditions. The cost of this insurance in wheat and barley respectively is approximately equivalent to ½ - ⅔ cwt. per acre for MCPA and 1 - 1¼ cwts. per acre for most "broad-spectrum" products. This represents only 3-5% of the average total cost of production.

Based on published statistics (HMS 1970) the number of combine harvesters and grain driers in use in England and Wales in 1969 was 60,220 and 45,350 respectively. Assuming these numbers are still appropriate in 1972, and using a very conservative estimate of their value, a minimum of £150-200m is tied up in machinery specifically for cereal production. This valuable machinery is used for short periods of the year only and herbicide use contributes to its efficient operation. By comparison therefore the £6m spent on broad-leaved weed control in 1971/72 is a relatively small safeguard for the total investment. This is not to imply that the cost of weed control is unimportant, but by comparison with other costs it appears to be reasonable. In fact cereal weedkillers have remained a relatively cheap input over the past decade compared with other costs as shown in Table 3.

Table 3

Comparative Cost/Price Indices

	1962	1972 (to June 30th)
Herbicides (1)	100	116
Retail Price Index (2)	100	161
Labour (3)	100	192
Land (4)	100	368

(1) Based on the retail price of 3 widely used herbicides marketed since 1962.
(2) Derived from Trade & Industry, August 1972, Vol. 8 No. 8 page 349.
(3) Derived from Statutory minimum agricultural wage (MAFF statistics).
(4) Derived from Statistics published by the Institute of Agric. Econ. Oxford.

When one remembers the fall in value of the £, (as indicated by the retail price index) in real terms, weed control is now cheaper than in 1962.

The benefits of significantly improved reliability of broad-leaved weed control in cereals from specific combinations of several ingredients was demonstrated in the early 1960's. The past decade has clearly proved the advantages of this approach in that most herbicides for the control of broad-leaved weeds in cereals are now mixtures of 2 to 4 ingredients. In the future a similar situation is likely to develop for the control of grass weeds. Having achieved the control of specific target weeds e.g. wild oats and blackgrass, broadening of the products' weed spectra is now required for maximum farmer convenience. This target is most likely to be obtained by combinations of active ingredients already available. This will improve further the opportunity for effective overall weed control under U.K. weather conditions with consequent benefit to the farmer.

CONCLUSION

During the 1960's low cost cereal production was an objective of many farmers. Today costs of cereal production are already high and likely to increase further in the future. The major costs involved are in the 'fixed' element, especially land labour and machinery, and are determined mainly by factors outside the control of agriculture. The opportunity for cost cutting will therefore be minimal and to balance the increased costs farmers will need maximum production to sustain profits. Herbicides can assist attainment of this objective by reducing losses due to grass weeds and by improving the efficiency of the total operation. Against this background it is not cheaper herbicides that are required (cheaper can only be in terms of pence anyway) but rather a range of products which increase the farmers opportunity for reliable weed control.

Compared with other elements contributing to the total cost of cereal production the current cost of herbicide appears very reasonable. It is clear from the benefits outlined in this paper that chemical methods of weed control make a major contribution to successful cereal growing and are therefore a significant benefit to U.K. agriculture in general.

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OBJECTIVES OF WEED CONTROL IN CEREALS

The need for clean seed

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Summary This paper deals specifically with the objectives and effects of weed control in cereals grown for seed purposes. It demonstrates the problem that exists at the present time with weed seed contamination in cereal seed and goes on to show that, under the new E.E.C. Seed Regulations, the problem is likely to increase rather than decrease. The causes for the contamination are then examined both in Merchants' seed and also separately in farmers' "home-saved" seed. The losses that occur in extracting weed seeds when cleaning for seed purposes are examined and an attempt made to quantify.

Finally the legal aspects of selling seed containing weed seed are set out and some conclusions made about the trend and its effect.

INTRODUCTION

What is going wrong with Weed Control in Cereals grown for seed purposes? From the evidence that follows, it could well be argued that chemical control might just as well not be used at all for the good it is doing - 36% of merchants' seed affected with weeds and over 89% of farmers' home-saved seed affected. Why is this? How is it that vast sums of money are being spent to eliminate weeds and yet we are actually drilling sufficient weed seeds to cause a high infestation in a large percentage of crops? Worse still, the situation could deteriorate. Evidence shows that the admixture of weed seeds is far greater in farmers' own seed and the likelihood is that the proportion of farmers' own seed as compared to that supplied by merchants will increase.

The ideal crop grown for use as seed should be dry, (certainly below 17%), containing a minimum amount of screenings (i.e. small grains, half grains, straw, chaff, etc.) and completely free from weed seeds. This enables the parcel of grain to be cleaned quickly and easily at minimum cost. The fact that this ideal parcel is comparatively rare, especially as regards freedom from weed seeds, seems to point to the need for action and this paper examines the situation and the likely reasons for the problems in greater depth.

PRESENT ANNUAL TONNAGE OF SEED USED BY FARMERS

Unfortunately there is no accurate way of assessing the total usage of seed because there is no requirement for farmers to keep records of seed planted. However, the results of the most recent survey carried out by the Ministry of Agriculture from returns from merchants showing how much seed they sold to farmers (quantity return of home-grown cereal seed sales by variety in the United Kingdom for the twelve month period 1st June 1970 to 31st May 1971), together with the official annual agricultural statistics of crop acreages, give a good idea for estimates :-

	Total seed used	600,000 tons
of which :	Merchants supply	450,000 tons
and :	Farmers' Own	150,000 tons

ESTIMATED FUTURE USAGE OF SEED

Various estimates of the future likely trend of usage have been given by different individuals and committees. That given by the National Institute of Agricultural Botany working party, comprising members from the National Institute of Agricultural Botany, National Farmers Union, British Association of Grain, Seed, Feed and Agricultural Merchants Limited, and Plant Breeders has been taken as a good guide.

They felt that the amount of seed farmers produced themselves for their own use would be likely to increase from the present figure of approx. 150,000 tons to approx. 250,000 tons, leaving approx. 350,000 tons to be supplied by the trade. Some members of the working party thought that the initial resistance by farmers to buying seed at the new high levels of price would get less after a year or so of the introduction of the new requirements, especially when they feel the effects of making a sharply increased price for their grain crop, and that there might be a return to the approx. 150,000 tons of farmers' own seed. The more frequent changes of variety together with more sophisicated seed treatments would also possibly prevent a larger percentage of farmers' own seed being used.

However, any tendency of this sort immediately spotlights a major problem. If, as is thought, an extra 100,000 tons of farmers' own seed is going to be used and if over 70% of this contains weed seeds to a greater or lesser extent, (see paragraph headed "The Presence of Weed Seed in Drills"), then it appears that we are likely to see a sharp increase in weed contamination.

THE COMMON MARKET RULES FOR SEED

The E.E.C. directives as a whole represent a departure from the philosophy underlying our own present seeds regulations. In the context of this paper the main implications from the Marketing Directive for Cereal Seed are as follows :-

(a) A variety must be on the Common Catalogue (a list of all varieties in current use).

(b) As from July 1976, all seed offered for sale must be certified - i.e. above minimum laid down standards for purity in the field and in the recleaned sample.

(c) The Directive requires member countries to adopt a generation scheme of production and marketing of cereal seed.

(d) The Directives stipulate minimum standards for varietal purity, germination, freedom from weeds, etc.

(e) A farmer may use his own seed, but any purchased, from whatever source, must conform to the above regulations.

The significance of these changed conditions can be summarised in two words - increased costs, especially caused by the restrictions on generation. This increase in costs, and therefore in price, will have one major effect, it will increase the temptation for farmers to use their own seed.

THE PRESENCE OF WEED SEED IN DRILLS

In Spring 1970, the A.R.C., Weed Research Organisation organised a survey on a random selection of farms in the U.K. to establish the proportion of weed seeds that were being drilled in cereal seed. Samples of cereal seed of about 7 lbs. weight were collected from 620 drills operating in fields, the primary objective being to study the presence of wild oat seeds. The results of this survey were, to say the least, perturbing.

Merchants supplied 73% of the seed from which samples were taken while the other 27% was from seed saved on the same farm or on another farm. Wild oats were present in 11% of the samples from seed supplied by merchants and in 41% of those from farmers' own seed. None of the seed supplied by merchants showed more than 20 wild oats per sample, but 14% of samples from the farmers' own seed contained more than 20 per sample.

An analysis of the presence of all weed seeds showed that 36% of the samples supplied by merchants and 89% of those from farmers' own seed were contaminated. Only 4% however of the samples from merchants' seed contained 20 weed seeds or more, compared with 70% of the samples from farmers' own seed. Of the samples of farmers' own seed 18% contained more than 1,000 weed seeds in 7 lbs. In one sample there were more than 16,000 weed seeds representing 27 species and in another sample there were more than 25,000 weed seeds representing 22 species.

Seven species were found in 10% or more of the samples: Polygonum convolvulus (black bindweed) in 24%, Galium aparine (Cleavers) in 21%, Avena spp (Wild Oats) 19%, Polygonum aviculare (knotgrass) 18%, Polygonum persicaria (redshank) 18%, Agropyron repens (couch grass) 15%, and Polygonum lapathifolium (pale persicaria) 10%.

The remarkable feature of this report is the extraordinarily large numbers of weed seed in some of the samples being sown. This indicates that there are many farmers (about 22%) who in their own cereal seed or in seed obtained from other farmers, are sowing a wide variety of weed seeds in addition to wild oats at rates high enough to cause serious weed infestation.

Weed contamination in cereal seed was also the subject of two papers at the 1968 B.C.P.C. Conference by Tonkin who confirmed, from an analysis of samples tested by the Official Seed Testing Station at Cambridge, that this problem is a general one. The reports do not in fact differentiate between samples from merchants' seed and those from farmers' own seed, but show that a very large proportion of those tested contained weed seeds to a serious infestation level.

As yet unpublished data, from a survey of cereal samples tested at the Official Seed Testing Station during the 1971/72 season, shows that weed seed contamination of samples, both as a whole and for individual weed species, is very similar to the pattern of ten years ago, and certainly does not show any significant decrease.

WEEDS IN MERCHANTS' SEED

Having established that there is already a serious problem, and that this problem is likely to increase because of the tendency for farmers to use a higher proportion of their own farm saved seed, it is necessary to establish why these infestations are occurring. The reasons for the occurrences in merchants' seed as opposed to farmers' own seed are in the most part distinctly different and therefore are treated separately.

(a) In the field:

Of the approx. 450,000 tons at present sold by merchants, about half has been grown under a field inspection scheme, such as the British Cereal Seed Scheme. A crop that is entered for the scheme will undergo, amongst other things, a thorough inspection for weed infestations in the field, and if successful is therefore unlikely to have weed contamination in the final recleaned sample.

In the British Cereal Seed Scheme for field inspection standards are as follows :-

Wild oats in Oats	nil	plants	per	acre
Wild oats in Barley and Wheat	3	"	"	"
Cleavers (Galium aparine)	50	"	"	"
Runch (Raphanus raphanistrum)	3	"	"	"
Wild onion (Allium vineale)	nil	"	"	"

However, as already noted, over 200,000 tons of seed supplied by merchants is what is normally described as "Commercial" seed which can vary from parcels that have failed schemes such as the above, to other parcels that have been bought purely on sample. The chances of serious weed infestation in these lots is therefore considerably greater.

The major significance of the new seed regulations is that, in future all seed sold by merchants will have to be "Certified" which is equivalent to saying that it must be grown under a scheme and also means that it must be sampled and found free from weed seeds. This fact alone should help to eliminate the majority of weed contaminated merchants' seed.

(b) From cleaning:

There is some variation amongst the seed trade regarding equipment used for seed cleaning purposes. A specialised seedsman will normally have a collection of cleaning machinery which includes a pre-cleaner, a de-awner, a standard dressing machine containing a series of aspirations and screens, and one or more cylinders (or a table separator). The most efficient seed houses will have as many as three cylinders per cleaning plant to ensure a weed free sample and seed of even size. These cylinders are highly important for cleaning out weed seeds as they separate on length and the depressions on each cylinder will be of different sizes to cater for the different impurities. If a merchant therefore does not possess cylinders or an equivalent machine, such as a table separator, he stands a very much higher chance of having weed seeds in his final product, especially wild oats. If a standard dressing machine is used on its own, however slowly the machine is run, it is not possible to clean out wild oats and runch completely, especially from Barley, and it is quite impossible to clean out wild oats from Oats.

WEEDS IN FARMERS' SEED

Most farmers who use their own home-saved seed will choose fields that are relatively free of wild oats. However, as can be seen from the survey in paragraph headed "The presence of Weed Seed in Drills", over 14% of these samples contained more than 20 wild oat seeds in a 7 lb. sample. Most farmers like to think that their dressing plant will remove the wild oats, and indeed it does remove a proportion, but, whereas nearly all farmers would agree that wild oats are a serious problem to extract, he would be unlikely even to notice seeds of other weeds in his selected parcel of grain, unless in very large proportions. As is stressed in para. 6 under the heading of merchants' seed cleaning machinery, it is a practicable impossibility to clean out wild oats completely without adequate machinery. Some farmers do have their seed cleaned by their local merchant, but of those who prepare their own, weed contamination comes from three major causes :-

(i) Use of grain already containing weed seeds (and possible non-recognition of this by the farmer).

(ii) Putting grain over their cleaner at a rate far above that recommended for efficient results.

(iii) The acceptance of a level of weed impurities in the final sample because they will be spraying the crop anyway.

WEIGHT LOSSES IN SEED CLEANING

One of the major effects of weed contamination in seed is the grain loss when extracting these impurities, especially wild oats. With premiums of between £4 and £8 per ton paid by a merchant to the farmer for growing seed, it is essential that the merchant minimizes his loss of grain when cleaning, because any seed so taken out will only be valued at milling/feeding value, i.e. it will lose the value of the premium.

Small weed seeds including cleavers do not create much loss in weight outside of the normal loss expected in seed cleaning, because up to cleaver size the impurity is lost anyway when removing the broken grains, i.e. half grains. Therefore, wastage on a parcel of raw material containing say five cleavers per 1 lb. would be in the order of up to 15%, which is an average loss anyway when cleaning seed.

Heavier losses in seed cleaning, however, occur when there is a wild oat contamination or an admixture of one cereal in another.

With wild oats, these are only a problem when their weight and length is near to that of the sample of grain which they contaminate. Five immature wild oats per pound are no problem, as these being much lighter are easily lost in aspirations, see (note (a)), and represent no great weight loss in cleaning.

The heavy losses in cleaning are not so much affected by numbers of weed seed as their size, for example to remove one wild oat per pound, which is near to the seed size, also means that all of the seed of the same length and weight would also be lost. Should the number of wild oats be 5 instead of one, the only different in loss would be that of the extra 4 wild oats.

There is no hard and fast rule as to how much is lost due to the number of wild oats present, but on average the following losses would be normal :-

5 wild oats per 1 lb. in Wheat	-	25%/30% loss
5 wild oats per 1 lb. in Barley	-	30%/50% loss
Barley in Wheat) Wheat in Barley)	-	25%/30% loss

The only other larger weed seed that is a real problem in cleaning is wild radish which can break up into similar lengths to the cereal grain and becomes almost impossible to remove.

THE LEGAL REQUIREMENTS

Early legislation in the U.K. aimed to prevent the sowing of weed seeds and the 1922 Seed Regulations prohibited the sale or sowing of seeds containing more than 5% by weight of five injurious weeds :-

docks and sorrels (*Rumex spp*), cranesbills (*Geranium spp*),
wild carrot (*Daucus carota*), Yorkshire fog (*Holcus lanatus*)
and soft brome grass (*Bromus mollis L. & spp*).

The 1961 Seed Regulations introduced a requirement for the declaration of the number of seeds of specified injurious weeds found in a sample of 8 oz. viz wild oat (*Avena fatua and A. ludoviciana L*), dodder (*Cuscuta spp*), docks and sorrels (*Rumex spp*), blackgrass (*Alopecunus myosuroides*) and couch grass (*Agropyron repens*). The Act also requires a declaration of the percentage of all weed seeds present, (i.e. including injurious weed seeds) where such percentage exceeds 0.5%).

In practical terms, it is very unlikely that a merchant would knowingly offer seed with even a small admixture, except in times of extreme shortage of a particular variety, but unknowingly, or because the impurities did not occur in the purity test, or in the case of the injurious weeds in the 8 oz. sample, there is still a proportion of seed sold by merchants which contains weed seeds.

CONCLUSIONS

Pointers for the future are not good - the proven high incidence of weed contaminated seed being sown, especially in farmers' own seed, the likelihood of this increasing, the lack of new and better seed cleaning machinery to eliminate the prolems at lesser cost all lead one to suppose that there will be a necessity for an even greater reliance on chemical weed control in the future. However, even the new E.E.C. Grain Regulations (concerning the use of the crop for milling purposes) impose restrictions on the maximum weed contamination in grain (a maximum 0.5% in Barley and maximum 1% in Wheat) and although this may not in practical terms be very severe, it does mean that attempts must be made to correct one of the causes - that from drilled seed. Further publicity on recognition of the weeds to look for and on the necessity to have all parcels of grain intended for seed tested for impurities by the Official Seed Testing Station would go some way towards helping. Some evidence of research by the machinery manufacturers on new techniques and new types of machinery to clean seed would also be very welcome. It is essential for all those concerned with the well-being of agriculture to give constant education to the farmer to use known clean seed.

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Notes

(a) "Aspirations" in seed cleaning machinery is the term used for the use of air, either by blowing or sucking, to extract light material and admixture.

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OBJECTIVES OF WEED CONTROL IN CEREALS

A Farmer's Viewpoint

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A cereal farmer tries to produce as much as possible compatible with the continual improvement of his land. He also has a certain sense of pride in his crops - the thin line of poppies which goes the whole length of a winter barley field indicating where the spray has missed is enough to make him see red. He cannot afford an unlimited labour force, and the weather is nearly always against him at some vital time in the year. Farmers have to get the most out of the men they employ and the machinery available. Before chemical weed control was possible, nearly all the weeds in cereal production were controlled by hand work or by cultivations. Now there is neither time nor labour for this work. Few are the farmers who can afford to keep a man on a cultivator all through harvest, let alone employ him chopping thistles in the spring and pulling wild oats in the summer.

To get the best out of the situation there are four rules which a farmer must obey:

1. The land must be free from weeds which carry over disease.
2. The land must be free from weeds which compete with the crop and therefore reduce the yield.
3. The land must be free from weeds which delay and complicate the harvest.
4. The land must be free from weeds which will contaminate the final product.

A farmer ought to walk his fields and consider each type of weed in relation to each of the four rules. If the weed breaks any of the rules, he must do something about it, but if not, then there is no point in wasting money trying to get rid of it.

Many weeds may be controlled by cultivation, but if this cannot be done and the weeds show signs of getting the upper hand, then a selective herbicide must be used. I use the word 'selective' advisedly because, looking at the subject from a cost point of view, a chemical must be chosen which will control the weeds which matter, leaving the crop to suppress those of little consequence.

RULE 1. Freedom from carrying over disease

The most common weeds coming under this rule are the grasses - couch (*Agropyron repens*), bents *Agrostis* spp., possibly the ryegrasses and most certainly shed cereal, particularly wheat and barley.

I do not know of any common broadleaved weeds which come under this heading.

Methods of control are well known, cultivations immediately after harvest are essential. There is a lot to be said for good ploughing which leaves no trace of green above the surface, while paraquat can be used as a rescue operation, but it is expensive if used in sufficient quantities to be relied on, by which I mean that the operation will cost at least £2.50 per acre.

RULE 2. Freedom from competition

This subject is much more controversial. In general all grass weeds, whether they be couch, bents, blackgrass Alopecurous myosuroides or even the remains of a ley, not properly killed before the cereal is planted, will compete with a cereal crop if present in sufficient quantity. It is surprising how a small amount of couch will reduce quite considerably the yield of corn.

In winter wheat poppies Papaver spp. will grow into quite large bushes. They are a distinct problem because after a mild winter they are not as responsive to herbicides as many of us would like them to be, in fact during this last year I have found conditions where they seemed to be immune to MCPA. Hempnettle Galeopsis tetrahit takes up a lot of room and thistles Cirsium arvense grow taller than the crop. Charlock Sinapis arvensis usually germinates in the spring with the result that it will be smothered by a strong growing crop as will other lesser weeds such as forget-me-nots Myosotis arvensis, pansy Viola arvensis and even the small red deadnettle Lamium purpureum. A vigorous crop of winter wheat will usually grow away, and finally suppress chickweed Stellaria media. I think it is seldom worthwhile spraying winter wheat with mecoprop if MCPA will kill everything present except chickweed.

Winter barley being a smaller plant is more likely to be affected by competing weeds and it is here that poppies Papaver rhoeas give the most trouble and chickweed will need to be taken more seriously.

Spring cereal presents a different set of problems. The seedbed is usually fine with the result that a mass of little weeds, usually far more than in winter corn, all start and grow together with the crop. Charlock then becomes a menace as does redshank Polygonum persicaria which grows into an enormous bush. These two, together with other Polygonum spp. must be stopped. Spring germinating chickweed will cause trouble in spring barley.

Finally under this heading comes the question of wild oats Avena spp. One school of thought maintains that since barban is not always reliable and cannot always be used at the optimum moment, and since tri-allate is unsuitable on some types of soil, we have to learn to live with a low infestation, that is low enough not to give obvious competition. I disagree with this idea. Wild oats must be stopped altogether, if only because every plant that is allowed to grow produces so many seeds, that, if they lodge in the combine harvester and come out in the dung of cattle undamaged, they will inevitably spread on to clean land.

The real problem is that there is no chemical that can be relied on to take all the wild oats out of cereals, while those chemicals that we do have are expensive to use costing upwards from about £3 per acre for the material. They cannot even be mixed with MCPA or 2,4-DP.

Identification of wild oats at the 2 leaf stage is more difficult in practice than in theory. Many times have professionals walked my fields and told me that they cannot find sufficient to justify the expense of barban, although when July comes, there are far more plants than can be rogued.

Taking the cost of employing a man at about £5 per day, it becomes clear that if he can clear wild oats from more than 1½ acres in a day, it is cheaper to do it by hand than by spraying and infinitely more reliable. Generally speaking an average of one wild oat plant to 10 sq. yds. over a whole field is well worth pulling out by hand, but the cost of a man pulling out twice this number should be less than by spraying.

RULE 3. Weeds that delay and complicate harvest

These are the weeds which create an entanglement, such as Cleavers Galium aparine and chickweed when they grow through a crop of laid barley. There are also the weeds which carry a green leaf when all the corn is clean and ripe - black-bindweed Polygonum convolvulus, Hempnettle Galeopsis tetrahit and the mayweed Matricaria spp., sowthistle Sonchus oleraceus and fat hen Chenopodium album are cases in point.

If the driver of the harvester does not slow his combine when he meets these patches of green, cereal is lost over the back of the machine.

Grass of any kind will necessitate a smooth knife instead of a serated one. It will prevent an early start in the morning, and stop the combine early in the evening when the damp starts to rise.

Under this heading of delays to harvest I would also include the weeds which complicate grain drying. For instance redshank Polygonum persicaria or knotgrass Polygonum aviculare can produce a vast quantity of mushy seed which will make a crop of wheat or barley need much more drying than it would if there had been no weeds. These weeds also have to be dried before they can be blown out of the grain, at extra expense. Also corn sometimes needs extra drying because there are small wet green leaves mixed in or even green poppy heads. In my own case, these green poppy heads reduced the through-put of the drier by about half.

RULE 4. Weeds that contaminate the final product

These are the weeds which the seed merchant finds difficult to remove such as cleavers and runch Raphanus raphanistrum in wheat, wild oats in barley or even white campion Silene alba and docks Rumex spp. in clover.

Wild oats will of course contaminate any sample of feed corn. They will go, undamaged through a mill rolling barley and I doubt whether they would come to any harm being rolled with good quality feed oats.

Barley straw fed to animals can easily contain large quantities of wild oats when anyone would think that they had either shed before harvest or gone into the combine tank.

Although not strictly used in cereal crops there are uses of chemicals which might be called 'Rescue Operations' and these I think fall within the ambit of the objectives of weed control.

First, I am referring to the use of paraquat to prevent a situation getting out of hand when it is not possible to plough or cultivate at the right time. I believe dalapon is worth considering in small doses for the same reason. Secondly I refer to minimal cultivations and direct drilling where paraquat is used to kill every green leaf when it is not intended to plough.

As a farmer these are the objectives in controlling weeds in cereal crops. By concentrating on the weeds which I know will cause problems, I find I can always manage with straight chemicals such as CMPP, MCPA, 2,4-DP and 2,4-D and the ioxynils. These are much cheaper than proprietary mixtures. It would be helpful if manufacturers would sometimes forget their trade names and state clearly what chemicals their products contain and in what quantities. Control of wild oats will be greatly improved if a chemical like tri-allate can be found to be sufficiently persistent to control spring germinating wild oats in autumn-sown corn. From a practical point of view such a chemical must be in liquid form so that it can be put on using a farmer's existing equipment. Life would be made easier if all herbicides were available in liquid form. Much time is wasted dissolving TCA, while desmetryne can be guaranteed to block the filters on the sprayer.

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OBJECTIVES OF WEED CONTROL IN VEGETABLES

A review

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INTRODUCTION

The term 'vegetables' covers a wide range of crop species, of which the edible portion maybe almost any plant part. There are, however, a number of aspects of husbandry and weed control in which, collectively, they differ from the cereal crops described earlier.

1. They are increasingly being grown to meet strict 'customer' requirements using specifically designed production systems.
2. They depend on residual herbicides for a major part of their weed control.
3. They are often less competitive with weeds.
4. They may be sown or planted over a much wider time scale, thus encountering different seasonal patterns of weed emergence, weather and soil conditions.

In compiling this report, the panel looked in detail at 5 aspects of weed control in vegetables and concentrated largely on crops grown for sale either to processors, supermarkets or chain-stores. I am indebted to Messrs. Arthur Elliott of Birds Eye Foods Ltd., David Harrison of the Agricultural Development and Advisory Service, John King of the Pea Growing Research Organisation, and Dr. Peter Salter of the National Vegetable Research Station for the hard work they put into preparing their individual papers, which form the basis of this report

(A) Effects of weed control practices on systems of production

The 'customer' whether processor, pre-packer, or supermarket buyer demands crops of specific size and shape, quality and maturity, which can be delivered in the required quantity at the right time. Maximum total yield is no longer the sole objective of the farmer, since his profit is largely determined by the weight of crop falling within the desired size and quality range. Much research has been devoted in the last 10-15 years to devising systems of production for vegetable crops grown to customer specification. Dr. Salter has reviewed for the panel the way in which these systems have developed, and the limitations placed on them by present day weed control practices.

Plant size is controlled by plant density and spatial arrangement. It has been found possible with many crops to manipulate these factors in such a way as to obtain not only higher total yield, but also high yields of the desired size and quality for specific markets. Optimum row spacing often means that the crop has to be grown in rows closer than the minimum distance needed for inter-row cultivation. Continuity of production may be obtained by use of different varieties and staggered sowing dates. Evenness of maturity is obtained by precision sowing, uniform seedling emergence and unrestricted growth to harvest. Mechanised single harvesting is becoming of increasing importance and this requires quite different production techniques compared with crops which are intended for hand-harvesting over a period of weeks.

Precision systems of crop production are by definition vulnerable to alterations in plant density and uniformity, such as may be caused by the presence of weeds or injury by herbicides. It will therefore be necessary to retain inter-row cultivation even at the expense of maximum crop efficiency, if safe and reliable herbicides are not available. Despite the rapid development of new herbicides in recent years, the number of crops in which the cultivation option can be disregarded is remarkably small. Inter-row cultivation itself can of course cause crop injury, and is unlikely to be tolerated in vegetable production systems for any longer than is absolutely necessary.

Accurate figures of the percentages of various crops grown in close rows as opposed to wide rows are not readily obtained, since agricultural statistics do not differentiate. Peas and carrots for processing are all grown in close rows. Onions, and red beet are examples of crops whose row spacing may vary according to the processing market for which they are grown. Most brassica crops are still transplanted in this country. One, but by no means the only, reason is the relative scarcity of safe herbicides for drilled crops. Fortunately, optimal row spacing for most brassicas still permits a restricted amount of inter-row cultivation.

(B) Effects of weeds on harvesting and processing

Peas and beans are the crops for which information is most readily available and which probably represent the most advanced degree of mechanisation and handling of any of the vegetable crops. Mr. Elliott has given us a very useful paper with many factual examples of the ways in which weeds can upset the efficient planning and operation of a pea or bean harvesting and processing schedule.

Because the crop has to be cut at a specific maturity level, the factory's programme is carefully planned to allow sequential harvesting of crops over a period of a very few weeks. The capital investment in harvesting machinery is vast, and if weeds delay their operations, e.g. by fouling cutting blades, or by creating extra bulk, this costs valuable time as well as money. The output of a pea viner in tons of peas per hour is governed by the bulk vegetation passing through. Attempts to cope with extra bulk caused by weeds by increasing the speed of vining have proved unrewarding. At higher than optimum speeds, the percentage of damaged peas rises sharply. A similar situation applies with French beans. Since the harvesting operation is often a race against time to catch each crop at the correct stage of maturity, seasonal pressures may well mean that weedy crops are by-passed in favour of clean ones and may in fact not be harvested at all.

Most growers realise the problem of weedy crops in terms of harvesting efficiency and cost, but do not appreciate that weed vegetation taken to the factory in the vined crop slows down the processing throughput there also. This in turn means that the field harvesting rate may have to be slowed down because the factory cannot cope.

Mr Elliott has produced flow charts to show the various cleaning operations carried out on peas and beans at the factory. The vined crop may be contaminated with weeds, or with stones and earth clinging to the weeds as well as with bits of pot and haulm. About 90% of this is removed by mechanical cleaning operations. There are further chances for cleaning during the later operations of washing the crop and air cooling it following blanching. After this stage, the removal of unwanted vegetation has to be by manual inspection. Since the final objective is a consumer pack completely free from unwanted vegetation, to comply with the Pure Food and Drug Act (1955), all rubbish appearing in the inspection lines must be removed. Manual inspection is expensive and may account for nearly 30% of all man hours involved in the processing operation. Costs can be greatly increased by the presence at this stage of parts of weeds which resemble peas in shape and size e.g. flower heads, berries, seeds etc. and have therefore escaped removal. Even more important are poisonous weed berries e.g. nightshade (S. nigrum).

Since weeds can thus pose problems and increase costs at all stages of harvesting and processing, it is obviously in the processor's interest to make sure that only clean crops are vined. This places the responsibility firmly on the shoulders of the farmer to produce weed-free crops or risk their rejection.

(C) Weed control and farm management

Mr. Harrison has looked at the problems of the farmer - the man in the middle - and how weeds and weed control affect and are influenced by the overall management requirements of the farm. To the farmer weed control is just one of many facets of management for which he has to find time and resources. He must achieve sufficiently good results to ensure that weeds do not interfere with his management programme for the crop, or with his planned allocation of men, machinery and time to do other essential farm operations.

He has to weigh up the benefits and risks of the latest growing systems in terms of his own farm situation. He has to bear in mind the requirements of his customers and he must try to grow the crop in a sufficiently efficient and profitable manner to give him a reasonable return for his investment.

Effective weed control management is made easier if (1) the farmer knows the weed flora of his fields and takes steps in the rotational context to ensure that problem species do not become dominant. (2) He learns enough about herbicides to choose the best treatments for his weed and crop situation, and ensures that they are accurately applied at the correct growth stages of crop and weeds. (3) He chooses growing systems appropriate to his weed situation and the ability of herbicides to cope with it. (4) He maintains an effective two-way communication with his farm staff so that developing weed situations can be reported and dealt with in a timely manner.

In theory, if the farmer pays attention to all these points, be should be able to grow his crops without undue interference from weeds or injury by herbicides. Unfortunately other factors may easily upset his weed control operations. Adverse weather can make herbicides ineffective, cause them to injure the crop, prevent timely spray application or cultivation, cause erratic and prolonged emergence of weed and crop. The farmer may have to decide that timely weed control operations in one crop have to be sacrificed to the more pressing needs of another task on another crop. Being human, he may, due to the pressures of a difficult job, neglect or forget to carry out certain operations at the right time. As Mr. Harrison points out, the skills of farm management, although increasingly based on scientific premises, remain very largely an art. The farmer has continually to make decisions and compromises based on the overall needs of the business and the methods at his disposal.

How does the vegetable grower make his weed control management decisions? What are his sources of advice? Is there any information on the extra time and labour needed to clean up weedy crops and the cost, not only to that crop, but to overall farm efficiency? We have not been able to find any factual information on these questions. We can assume that farmers will not stay in business if they make the wrong decisions too often, but we do not know to what extent they are making the best decisions and whether they are sufficiently aware of weed control priorities.

We were also unable to find reliable information on what decided the farmer that certain levels of weediness in a particular crop were unacceptable and must be dealt with. We do not know to what extent he bases his decision on possible competitive effect, interference with harvesting, the demands of the processor, general tidiness, the prevention of weed seed dispersal, or some combination of all these factors.

(D) Effects of weeds and herbicides on crop growth and yield

Mr. King had the difficult task of reviewing the available literature on crop/weed/herbicide relationships and deciding to what extent conclusions useful to the farmer could be drawn. The situation is a most complex one due to the range of crop types and edible plant parts involved and the diversity of weeds and herbicides to which they are exposed. Add to this the complexities of within crop interactions and the effects of changes in crop spacing or density and it may be seen how difficult the problem is. There is no time to quote at length from Mr. King's comprehensive paper, but I think it is important to consider his main conclusions in some detail.

1. There is not nearly enough information on weed/crop relationships in vegetable crops. Much of the work done has investigated (of necessity) artificial relationships, often with single species weed infestations. It is therefore very difficult to translate the findings into practical advice for farmers dealing with the multi-species weed problems and variable soil and weather conditions common to vegetable production in Britain.
2. The most common weed problems in vegetables today are weeds, resistant or otherwise, which have escaped initial herbicide treatment. Farmers need guidance in deciding which situations require removal of these weeds, and those where the weeds can be safely ignored. Competition studies are therefore needed on weed populations selected by herbicide treatment, to establish their importance in terms of crop growth and harvest.
3. More information is needed on the effects of weeds and herbicides on crop growth factors other than yield. This is particularly important in planned production systems where size, quality and time of maturity are major factors.
4. The effects of weather and soil conditions on the weed/crop/herbicide relationship need to be studied more fully, since there can be no place for unreliable performance in the controlled vegetable production systems of the future.

One or two other points are worth stressing:

(a) Although weeds may act as hosts of pests and diseases we could not find any evidence to justify in economic terms the control of weeds for this reason. There was similarly no data to show how the farmer could forecast an interaction between herbicides and disease incidence. These problems may well become more important as production systems become more sophisticated.

(b) The incidence of 'off flavours' or 'taint' in treated vegetable crops is much lower with herbicides as a class than with insecticides and fungicides.

(E) Herbicides for vegetables

There is no doubt that in the last 10 years, developments in chemical weed control have revolutionized vegetable growing. It is now possible to use pre-emergence or early post-emergence residual herbicides in almost every crop, to allow it to become established free from interference by seedling weeds. This has resulted in a considerable increase in the efficiency of crop management and a marked decrease in the amount of soil cultivation required for weed control. However, the improvement in vegetable technology made possible by these advances are also imposing much greater demands on herbicides themselves. All the panel members are agreed that the full exploitation of modern growing systems is dependent on improvements in the safety, efficacy and most important, reliability of herbicides.

There are many crops in which a wider choice of herbicides is needed and several weed species and soil types for which satisfactory treatments are not yet available. In particular, there is a need for residual herbicides less vulnerable to soil and weather conditions, herbicides safe to apply between crop emergence and the young plant stage, and selective, contact or translocated herbicides to control weeds in the later stages of crop growth or before harvest.

New herbicides will certainly come along, but unfortunately they cannot be produced to order or developed solely for vegetable crops. They will appear totally at random, as a result of the search for additional uses of new herbicides developed for major world crops. It may be that with ever-increasing costs and the more stringent testing required of herbicides to be used in 'blue-print' vegetable systems, manufacturers may not even find it economic to develop these minor uses for their agricultural herbicides.

It is therefore highly desirable that the vegetable industry should make the best possible use of those herbicides already available, by developing programmes of weed control based on treatment with mixtures or sequences of herbicides with complementary weed spectra. These give the farmer more options and greater flexibility, and reductions in dosage rates may also be possible. This raises a difficult problem. Chemical manufacturers and distributors are very reluctant to become involved with herbicides from rival organisations. The chances of one firm manufacturing or retailing a range of herbicides suitable for programmed use in the same crop are small, especially since there is no planned search for complementary herbicides. It is therefore very difficult for the farmer to obtain commercial backing for programmes of weed control. Farmers have to some extent taken matters into their own hands and worked out combinations of existing herbicides suited to their own requirements, but these are applied very much at their own risk. This situation cannot be allowed to continue. Manufacturers must come to terms with the fact that in modern vegetable crops, two or as many as four herbicides may be needed to maintain satisfactory weed control from sowing until harvest, and that no single herbicide can be expected to give the increasingly high levels of weed control required.

Equally, those involved in weed research and development in vegetable crops must relieve the farmer of the onus of devising weed control programmes, by exploring all possible combinations of existing herbicides and evaluating all new herbicides to see if and where they could fit into the system.

CONCLUSIONS

The findings of the panel may be summed up as follows:

The main objectives of weed control in modern systems of vegetable growing are to ensure that weeds or the techniques used for their control:

1. Do not restrict the objective of producing high yields of the required part of the plant of the desired size and quality at the right time.
2. Do not affect the speed, efficiency or costs of harvesting and processing.
3. Do not interfere with the efficient management or profitability of the crop or of the farm enterprise as a whole.

In compiling this report the panel has found that although considerable progress has been made in recent years, the attainment of these objectives is still a long way off, and the problems are likely to become increasingly complex as vegetable growing systems become more sophisticated. The panel therefore brings to the attention of Conference the following recommendations:

1. Adequate surveys of vegetable growing practices and herbicide management are needed, so that research and development priorities can be decided on the basis of factual information on the farmer's problems.
2. More research is needed into crop/weed/herbicide relationships in modern vegetable growing systems. In particular, there is a need for information contributing to practical weed control recommendations.
3. More herbicides are needed for many vegetable crops. Their major characteristics must be crop safety and reliability of performance.
4. More effort must be devoted to designing programmes of weed control based on groups of herbicides, to give the farmer the maximum flexibility of operation in coping with variations in weather, soil conditions and weed flora.

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OBJECTIVES OF WEED CONTROL IN VEGETABLES
The effects of weeds & herbicides on the growth & yield of vegetable crops

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INTRODUCTION

In a 'weed free environment', crops would not suffer from the various adverse effects of weeds and there would be no need for information about the nature and importance of these effects. There are few crops and seasons, however, when farmers are able to attain this ideal with the herbicides at present available to them and in spite of the continued use of an ever increasing 'battery' of herbicides there are no obvious signs that the potential weed infestations in our crops are being markedly reduced. The question of cost benefit is also of importance since the law of diminishing returns must apply to weed control as it does to other agricultural operations, and the cost of removing the last 10% of the weed flora may be very much greater than that of controlling the other 90%. From both these points of view, therefore, the farmer needs to know what effects weeds can have on his crop, so that he can decide whether or not to attempt to remove them. Herbicides can and do injure crops under certain circumstances and this risk must be weighed against the need to control weeds. In crops with dense stands of weeds, slight herbicide injury may be acceptable in order to prevent loss of crop or greatly reduced yield. Treatment of light weed infestations or species resistant to earlier herbicide application may not be justified, however, if the herbicide does more harm than the weed population to the crop.

This paper reviews the information available on the effects that weeds and herbicides applied for their control, may have on the growth, yield and quality of vegetable crops. The aspects of ease of harvesting, processing requirements and rotational weed control are covered in other papers in this Session.

Competition between weeds and crops

Both weeds and crops require certain things from the environment for growth and development. Light, gases from the atmosphere, water and nutrients from the soil are essential for growth and development of any plant. Shadbolt & Holm (1953) suggested that light played a major role in competition and in their work with beet, carrots and onions, measurements were made of light intensity in the presence of different levels of weed infestations, the predominant species being Amaranthus retroflexus. Light intensity at the level of the crop plants was reduced by as much as 85 per cent at the higher levels of weed competition and the measurements were inversely proportional to the injury observed. It was also noted that the decrease in light intensity was greatest between 3½ and 4½ weeks after emergence, which again was consistent with the effects on yield. Weeds may not only compete with crops for nutrients, but may also utilise them more efficiently. Granström (1957) found that Chenopodium album and Avena fatua utilised nitrogenous fertilizers more efficiently than peas and linseed, but not as well as barley. Competition for water may favour weeds with deep root systems at the expense of more shallow rooting crop plants and their water requirements may also differ (Derscheid 1952).

The competitive ability of crops

The growth habit of the crop is an important factor in competitive ability. Crops which are able to produce efficient ground cover early in their development have the best chance to compete with weeds and conversely crops such as onions which produce relatively little ground cover are particularly prone to the effects of weed competition. Low-growing crops such as red beet can also be severely affected by competition from tall vigorous weeds such as Chenopodium album and Philp (1953), quoting work carried out at Wellesbourne by Roberts, showed that populations of 14 and 38 plants of this species per ft.^{2} allowed to remain in the crop until harvest, reduced the marketable yield of beet by 97% and 100% respectively. As few as 3 plants per ft^2 reduced the weight of beet by 44%. In recent work at Wellesbourne, Hewson (1971) has shown that a weed population in which Chenopodium album predominated, reduced yields of dwarf beans by 92%, but yields of broad beans by 80%, illustrating the differences in reaction between a compact and a tall-growing species. Peas can effectively smother most species with a prostrate growth habit, but are susceptible to the effects of tall fast-growing weeds such as Avena fatua, Chenopodium album and Sinapis arvensis. In work reported by Armsby & Gane (1964) the use of a herbicide which gave 92% control of an Avena fatua infestation of 50 plants per yd^2 increased the yield of vined peas to 29.1 cwt/ac compared with 17.8 cwt/ac on the untreated plots. Also reported is an infestation of Avena fatua of 150 plants per yd^2, the total weight of which exceeded 12 tons/ac when measured at harvest.

The effect of distribution pattern on the competitive ability of the crop

Most vegetables are still grown as row crops, either because of the need to supplement the weed control from herbicides, with some form of mechanical cultivation or because of restrictions imposed by harvesting equipment. Peas are one exception and increasing use is being made of 'bed' systems in other crops such as carrots. The ability of the crop to compete with weeds can be influenced by its distribution over the ground. Several instances have been cited of increasing crop density reducing weed weight. Marx & Hagedorn (1961) showed that by increasing the population of vining peas, sown in 7 in. rows, from approx. 250,000 to 600,000 per acre the weed weight was reduced from 30% to 7% of the total green weight, in a year when abundant moisture encouraged weed growth. Roberts (1963) illustrated the effect of more even crop distribution on weed growth by sowing peas in 18 in, 9 in and 4.5 in rows at a population of 5 plants per ft^2 The mean weed weights from plots which had not received any herbicide treatment were 13.4, 4.0 and 0.9 lb per plot for the three row widths respectively and even on those which were treated with a herbicide the weed weights were reduced, the figures being 1.5, 0.2 and 0.02 lb per plot respectively. It is unfortunate that with such obvious advantages to be gained, that the use of more efficient distribution patterns cannot be applied to more vegetable crops.

The importance of the relative date of emergence of crop & weed

The importance of this is well illustrated by work carried out by Nelson & Nylund (1957). They found that a population of 3 plants per ft^2 of Sinapis alba emerging three days before peas reduced the vigour of the crop to a greater extent than did 9 plants per ft^2 which emerged four days after the peas. When 9 plants per ft^2 emerged before the crop, yields were reduced to 48% of weed-free controls, but in plots in which pea emergence occurred first, yields were well up to those of controls. The time of weed emergence in relation to the crop may or may not be under the farmer's control and the 'stale seedbed' technique relies upon the farmer being able to encourage the weeds to emerge before the crop. The bipyridyl herbicides have provided a means of dealing with weeds which emerge before the crop and in practice the farmer's main worry is those which emerge at the same time or after the crop.

The relative competitive ability of different weed species

Nelson & Nylund (1957) drew attention to the differences between a fast-growing weed such as Sinapis alba and one which develops less rapidly, such as Polygonum persicaria, in their ability to compete with the crop. This point was also illustrated in comparisons between Sinapis alba and Setaria italica, and they concluded that populations of 27 plants per ft^2 of the latter were required to produce the same effect on the crop as a population of 3 plants per ft^2 of the former. The relative competitive ability of different weed species has also been reported on by Welbank (1963). Whilst such information is valuable it does not provide a complete answer to the farmer's questions, when faced with a multi-species infested crop. It indicates those species which are likely to be the most competitive, but since the data is almost wholly based on competition studies with stands of single species it cannot be readily applied to mixed-species stands. Its value increases in situations where previous herbicide use has resulted in one or two resistant species being left, but there is still the problem of measuring likely competitive effects, size of the weed being just as important as numbers of plants.

'Critical periods'

Various workers have established 'critical periods' during which weed competition exerts an irreversible effect on the final crop yield (Nieto 'et al' 1968). The presence of weeds before this period does not apparently reduce crop yield, provided they are subsequently removed. Weeds that emerge and develop after the 'critical period' likewise may not affect yield. Hewson (1971) found that weeds could be left in red beet for approximately 4 to 4½ weeks after emergence without reducing yields, while in other experiments the period was 3½ weeks for broad beans and 2½ weeks for dwarf beans. Conversely, provided red beet was kept weed-free for 1½ to 4½ weeks, dwarf beans for 1½ weeks and broad beans for 1½ to 3 weeks after emergence they were unaffected by any subsequent weed development. Onions appeared to have a critical period for weed competition lasting for about two weeks, while the crop was developing the third true leaf.

Increases in weed density can considerably affect the time at which competition begins, as too can the crop density, and the composition of the weed population will also have a bearing on when they begin to exert a detrimental effect on crop development.

The fact that most crops appear able to tolerate weeds in the first few weeks after emergence helps to explain the apparent discrepancy which appears when comparing the effects of pre and post-emergence herbicides. Theoretically the treatment which prevents weeds emerging before or with the crop would allow it to develop more effectively and result in higher yields than the treatment applied some weeks after crop and weed emergence. In practice this difference seldom occurs, unless the post-emergence treatment is delayed too long.

The information available suggests that late weed infestation, which occurs after the 'critical period', does not affect final yield and this could be put to good use by farmers, who would only need to remove weeds in crops where they might interfere with harvesting. Unfortunately there is still insufficient critical data available concerning the conditions likely to be encountered on the farm, to make use of this knowledge.

The effect on crop growth & development

Although the gross effect of weed competition may be reduced total yield, there may also be effects on size grade distribution within the harvested crop which greatly reduce the 'marketable' yield of the crop. Shadbolt & Holm (1956) found that increasing weed competition caused progressive reductions in the diameter of carrots, onions and red beet, and the underground portions of the plant were the first to be seriously affected by competition. Similar effects were recorded by Hewson & Roberts (1971), who in addition reported an increased proportion of thick-necked onions. Lawson (1972) found that competition from weeds at a critical time of growth produced greater internode distances in spring cabbage, resulting in loose, unmarketable, heads.

Competition from weeds can affect the maturity of the crop and in work reported by King & Handley (1972) vining peas matured more rapidly in the presence of a dense stand of *Stellaria media*. Weed infestation may also alter the micro-climate within a crop and Rademacher (1967) found a higher incidence of *Ascochyta pisi* in weed-infested pea plots, although there was a lower incidence of *Mycosphaerella pinodes*. Weeds may also act as hosts for pests and diseases, e.g. vetches (*Vicia spp*) are hosts of pea root eelworm (*Heterodera göttingiana Lieb*). The stem nematode (*Ditylenchus dipsaci*) can infest *Stellaria media*, *Galium aparine*, *Taraxacum officinale*, *Vicia sativa*, *Hypochaeris radicata* and *Avena fatua* (Seinhorst 1956; Salentiny 1959), while Peterson (1961) recorded several weed hosts of crop diseases including *Sinapis arvensis*, *Raphanus raphanistrum* and *Brassica campestris* infected with club root fungus *Plasmodiophora brassicae*. Moore & Thurston (1970) mention *Senecio vulgaris* as a host for at least five important pathogenic fungi and also a host for several viruses, while Matta & Kerling (1964) showed that this weed is readily infected with wilt fungus *Verticillium albo-atrum*, which infects several horticultural and agricultural crops. The fungus was shown to be seed-borne in *S. vulgaris* and so this weed could be responsible for its widespread dispersal. Kristensen (1966) demonstrated that *Stellaria media* became infected with many air and soil-borne viruses of economic importance e.g. cucumber and lettuce mosaic viruses, beet yellows virus and tobacco rattle virus, which infected up to 39% of the *S. media* plants in Denmark. Overwintering weeds have long been known as hosts for vectors, for example the pea aphid *Acyrthosiphon pisum*, overwinters on *Medicago*, *Trifolium* and *Vicia spp*, which are the source of bean leaf roll and pea enation mosaic viruses which spread to leguminous crops (Cockbain, 1969).

Effects of herbicides on crops

In considering the possible adverse effects of weeds on crop growth, it is necessary to bear in mind that herbicides may also have effects on the crop. Ideally herbicide treatment ought to remove the weeds without crop injury, but this is by no means always achieved in practice. Most herbicides have reasonable safety margins in the crop, but it is virtually impossible to be confident that the vagaries of weather, soil conditions and application efficiency will not result in crop injury in certain circumstances. Rates of pre-emergence materials are selected for various soil types according to the percentage of sand, clay or organic matter present, but heavy rain or shallow drilling may result in the chemical being leached into the root zone of the crop. Faulty application may lead to overdosing, with consequent adverse effect on the crop. The weather can also affect the safety margins of herbicides, for example phenmedipham on beet and dinoseb in peas. Apart from the effects of temperature on the herbicide, wind, hail or blowing sand can predispose the pea crop to more injury from herbicides such as dinoseb, by damaging the protective leaf wax on the plant. The British weather tends to be less settled than in many other countries and consequently this makes the crop safety of herbicides less reliable. The effects on the crop differ according to the type of material e.g. carbamates generally delay crop emergence, leading to stunting, while triazines interfere with photosynthesis leading to chlorosis or necrosis and in severe cases death of the plant. Herbicides which 'thin' the plant stand can have serious consequences not only on the yield, but on the 'marketability' of the crop, due to the size of the produce being affected by the change in planting density. Red beet and carrots may be too large for canning and cauliflowers of the wrong curd size. Materials which cause uneven emergence and stunting of some plants can cause serious problems in pea crops to be harvested at the green stage. Lawson & Rubens (1970) found that in Scotland a pre-emergence treatment of a mixture containing chlorpropham caused irregular emergence, stunting of some plants and encouraged secondary tillering. This not only resulted in marked unevenness in maturity of the peas at harvest, which is a very undesirable effect on quality from the processors point of view, but there was a higher proportion of haulm to peas in the treated crops thus reducing harvesting efficiency. The problems of crop injury are increased when herbicide 'programmes' are employed, and there are several known instances where the use of one herbicide can lead to damage from a subsequent herbicide treatment, as for example TCA reducing the leaf wax of peas and thus making them more susceptible to injury from dinoseb. An increasing number of crops receive more than one herbicide application and there is little critical data on the effects of this practice. Herbicide use may also predispose the crop to greater infection from diseases and it is generally accepted that any factor which weakens or puts the plant under stress may increase the risk of pest or disease attack. Grümmer (1963) demonstrated that treatment of broad bean plants with simazine resulted in increasing infection of Botrytis fabae. A possible explanation of such effects is that the treatment reduced the protective nature of the leaf wax and Proctor & Armsby (1958) reported increased attack from downy mildew (Peronospora viciae) on peas grown on soil previously treated with TCA.

There is also the possibility that roots of plants affected by soil-applied herbicides become more susceptible to soil-borne fungi such as Fusarium solani which commonly affects legumes, although no positive information appears to be available on this point.

Beneficial effects of herbicides have, however, been observed in peas. Plants or leaves affected by downy mildew lose much of their leaf wax and are thus killed by applications of dinoseb (Anon. 1971). This can often considerably reduce the spread of the disease.

Herbicides can obviously affect crops in many ways and the possibility of flavour changes occurring in the produce following their use cannot be ruled out. However, in the considerable number of tests carried out by The Campden Food Preservation Research Association, on produce from crops treated with herbicides, the incidence of 'off flavours' or 'taints' is much lower than is the case for similar tests with fungicides and insecticides. Arthey & Adam (1963) suggest that taints occurring in crops treated with MCPB, when it was first introduced, were due to impurities such as cresols and it is generally accepted that impurities present in TVO and white spirit used as herbicides in carrots, can cause flavour changes.

Conclusions

The relationship which exists between weeds and vegetable crops is obviously very complex and the effects of weed competition should not only be measured in terms of total yield. Similarly the effects of the herbicides used in these crops are not always predictable, particularly in our changeable climate. The more sophisticated the growing technique or the processing operation the more we need to know about the weed/herbicide situation and the part the crop can play in controlling weeds and we find that there is not nearly enough information available. This must be the main conclusion to be drawn. Before we can plan more effective and economic weed control programmes we require much more information on the following aspects:-

1. There is not enough information on the weed/crop relationship for the wide range of species involved in vegetable production. Too much of the reported data

deals with artificial relationships rather than 'in field' situations and too little has been undertaken under U.K. conditions.

2. The most common of today's weed problems are those of weeds, resistant or otherwise, which escape the original herbicide treatment. There is a need for guidance so that farmers can recognise the situations where it is essential that they are removed, and those where they can safely be left. Linked with this is the need to know the possible effect of a multiple herbicide programme on the crop and in many vegetable crops there are insufficient post-emergence herbicides suitable for dealing with such situations.

3. More information is required on the effects of weeds and herbicides on crop growth other than yield. This is particularly relevant in vegetable crops where quality is of equal if not greater importance than yield. With development costs escalating there is a definite danger of herbicides being marketed before all the details of their effects on the crop have been fully established.

4. The effects of weather and soil type on the weed/crop relationship and on herbicide performance need to be studied more fully, as there is little doubt that they can be of overiding importance.

The complexity involved in the planning and execution of herbicide programmes in vegetable crops and the interpretation of the numerous variables associated with weed and herbicide effects, will require a high standard of management, probably far higher than is commonly found at present.

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OBJECTIVES OF WEED CONTROL IN VEGETABLES

The effects of weeds on vegetable crops grown for processing

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INTRODUCTION

In the agricultural districts supplying the food canning and freezing industry, traditional harvesting methods have rapidly given way to mechanical harvesting and bulk transport systems, which allow high volume throughput and quick despatch from field to factory so as to retain optimum quality in the produce. A major effect of increased mechanisation has been increased crop specialisation by growers involved with vegetable contract farming. Mechanisation has allowed full exploitation of group machinery operations in the field to minimise production costs and this has meant a dramatic increase in the acreage contracted per grower, per specialised crop over the last ten years. Processors have also been replacing hand labour by machinery and streamlining their operations in order to remain competitive and efficient. This has involved heavy investment in capital, processing and cold storage facilities, which can only be justified by round-the-clock production over the longest possible harvest season and by dove-tailing in sequence the variety of crops to be handled throughout the summer, autumn and winter.

Weeds, through their effects on growing crops and their interference with harvesting are one of the most important problems facing the vegetable grower. Until recently the level of weed control accepted by the grower has been based on his estimate of possible effects on crop yield or harvesting speed. However, the processor is nowadays finding that small amounts of weed vegetation can have an important effect on the cost and efficiency of the whole processing operation. As a result, he is forced to set a much higher standard for weed control than that required solely to allow normal crop growth and maturity. Peas and beans are examples of vegetable crops which undergo a lengthy processing operation and in which weeds can affect the crop in a variety of ways. The types of problems encountered in these crops are used to illustrate how weeds interfere with efficient management of a factory operation.

EFFECTS OF WEEDS ON HARVESTING EFFICIENCY

The processor has to make an intensive effort to plan and control his pea campaign, since the entire year's production must pass through the factory in a few weeks. The time of harvesting this crop is critical and there is a strict need to follow the advance plans very closely, since the next grower's crop is planned to reach harvesting maturity at precisely the correct time to ensure continuity. In hot summer weather, crops may follow one another so quickly in reaching maturity that some must be harvested dry. At such times there is a tendency by the processor to maximise the harvesting capacity of the machinery by selecting the most suitable crops. Before being processed the crop must pass through viners whose capacity is governed not by the yield of peas but by the bulk of plant material. It follows that the degree of weed control achieved has a direct bearing on harvesting rate and that the processor will concentrate on clean crops, those crops with severe weed infestations stand a greater risk of being left unharvested (Gane A.J. 1968). Quite apart from any effect of weeds on crop yield or on the speed of vining, extra bulk due to weeds may result in greater damage to peas in the viner. Tests have shown that in order to restrict the percentage of peas damaged during vining to a maximum of 4% a viner throughput of approximately 8.5 tons of plant material per hour should not be exceeded (IMC/FMC Ltd. 1969). Also, as the density of plant material in the field increases, the percentage ratio of peas to plant bulk weight decreases. Thus, if the quantity of material in the field is increased due to the presence of weeds, to maintain the same yield of peas per hour, the viner throughput would need to be raised above the desirable speed and excess damage to the produce could result. The effect of weeds on the bulk of plant material and on the ratio of peas to plant bulk was illustrated in a series of field tests. The average ratio of peas to plant bulk over fourteen tests in different conditions was found to be 25.5%, but this dropped to 17.0% in a field slightly infested with wild oat (Avena fatua)- a common weed of pea crops in East Anglia. This compares with a figure of just over 30% in comparatively weed-free crops (Ensor H. 1966). The presence of weeds therefore materially affects vining efficiency. As well as slowing down actual vining throughput, weeds may also directly affect the cutting efficiency. In particular such weeds as knotgrass (Polygonum aviculare) and black bindweed (Polygonum convolvulus) may wrap themselves around the cutting blades, causing stoppages and loss of valuable time.

Efficient harvesting of dwarf beans also suffers in the presence of weeds. The method of harvesting in this case involves the removal of the pod from the plant by a picking reel. The presence of tough, branching weeds such as fat hen (Chenopodium album) can easily cause damage to the reel, which will reduce the efficiency of the mechanical harvester and increase the time taken for harvesting. Knotgrass and bindweed also disturb the harvesting efficiency by wrapping themselves around the picking reel and jamming the harvester, causing delays. Extra crop damage is caused by the presence of tough-stemmed weeds such as fat hen at harvest time. In these circumstances a higher percentage of the harvested pods are broken and become unsuitable for slicing. As with peas, the pressures of the season may mean that weedy bean crops may have to be abandoned by the processor.

The problem of weeds in spinach from the processor's point of view is much more serious, particularly where the crop is machine harvested, as the only way of removing the contaminent is by hand and, consequently, if the level of infestation is above 1%, this can well mean the rejection of a load, or even a complete field. The main weed problem in this respect is chickweed (Stella media). With Brussels Sprouts the trimming of the sprouts from the stalk and initial grading is now carried out almost exclusively on the farm so that in general any problems arising from weed infestation are dealt with away from the factory by the grower and do not impinge on the efficiency of the process operation. The same is largely true with potatoes taken for processing which are currently purchased ready graded to the appropriate Potato Marketing Board Standard.

The time taken for the crop to mature is of great significance to the processor while planning the necessary continuous harvesting schedule. The presence of weeds and the varying effect of herbicides can quite considerably affect the rate of maturity, throwing the harvesting sequence off plan. This aspect is more fully dealt with in the associated paper by J. M. King.

In the main growers are very conscious of the effect of weeds on the harvesting efficiency and costs, but are slower to appreciate that increased amounts of extraneous vegetable matter in the raw material necessitate a slower processing rate in the factory. This in turn means that the harvesting rate in the field has to be reduced below the optimum so as to ensure that it does not get out of line with the processing rate at the factory. Since a series of fields will be harvested at any one time, one weedy crop can affect the vining efficiency of many other clean crops in the area.

EFFECTS OF WEEDS ON PROCESSING EFFICIENCY

In addition to the economic pressures on the processor and grower to ahdere to the harvesting schedule and to maintain quality in terms of maturity, there is also the problem of contamination of the finished product by extraneous vegetable matter. The Pure Foods and Drug Act of 1955 states that the content of a packet must be declared on the outside and that it must not contain any extraneous vegetable matter of any kind. Whilst a Public Health Inspector might take a lenient view with regard to contamination of peas by such things as pod he would definitely take stringent action if the product was contaminated with weed material. Thus the processor must aim to have his product completely free of such contamination. In practice this is not possible and tolerance levels have had to be introduced. Our aim is a tolerance level of one piece of extraneous vegetable matter in 320 ounces of produce at the bulk pack stage. Since the factory's machinery for removing the extraneous vegetable matter from the crop is not 100% efficient it is obvious that here lies further pressures on the processor and thus on the grower, to ensure that each crop is as weed-free as possible.

Contamination of peas by soil and stones is particularly common. Apart from causing damage to machinery, both in the field and the factory, this can cause discolouration of the crop while it is in transit. Contamination by soil is increased by the presence of chickweed (Stellaria media), which is easily uprooted by the cutter and brings soil and stones with it, or by knotgrass (Polygonum avicular) which becomes entangled in the cutters and causes a build-up of soil around the cutter blades. More serious contamination problems are caused by the buds, flowers and berries of such weeds as mayweed (Marticaria Spp.), creeping thistle (Cirsium arvense), black nightshade (Solanum nigrum) and poppy (Papaver Spp.) The buds, seeds and seed heads of these weeds are roughly the same size, specific gravity and colour as the pea, making detection at the factory very difficult and removal almost impossible.

Finally, there is the very serious problem caused by weeds of an obnoxious or even poisonous nature. These, for obvious reasons, must not be allowed to get into the harvested crop. If they do, any load so contaminated would be rejected at the factory. The most important of these species in the United Kingdom is nightshade (Solanum nigrum), generally found on light land, which is late germinating and can affect in particular the later-sown pea crops. Detection of the berry is difficult because it is dark green and the same size, shape and density as a pea. The second major species is Bryony (Bryonia Spp.) found in particular on headlands and on the site of old hedges or boundaries where two fields have been joined.

The processing method allows various stages at which unwanted material can be extracted from the raw material. These are illustrated using diagrammatic examples from a typical factory operation (Figs. I,II). Initially the intake at the factory is tipped into bulk hoppers. As it is fed out from the base of the hoppers it is subjected to a process of pneumatic and screen cleaning. The former blows off the lighter extraneous vegetable matter such as leaves or small pieces of pod, whilst the latter allows the peas to filter through a screen, leaving pods, sticks and lengths of stalk behind to go to waste. It is at this stage that most of the extraneous vegetable matter is cleared - about 90% by weight, though a considerable number of the smaller pieces of extraneous vegetable matter, together with stones and soil do get through with the vegetable crop.

The peas or beans then pass on to flotation washers via a stone trap where most of the larger stones and heavier extraneous vegetable matter still present is extracted. The washers themselves remove the lighter extraneous vegetable matter which will float off as the vegetables pass through and also contain a weir on which the smaller stones still present are trapped. Then on to the blancher, after which an air cooler also removes any light extraneous vegetable matter still present - especially any splits and skins which become detached in the blanching process. After this stage of the process the peas or beans are frozen, bulk packed and put into cold store, ready for repacking at a later date.

At this later time the processed product passes along manual inspection lines and any extraneous vegetable matter left is removed by the inspectors. The efficiency of this final operation is about 83% (Birds Eye Foods Ltd., 1969) and the cost is very high. In fact nearly 30% of all manhours involved in the processing operation are concerned with cleaning and inspection. In trials comparing the effifiency of groups of inspectors, the relative efficiencies of inspecting for groups of 2, 3 or 4 inspectors were 74%, 83% and 93% respectively (Birds Eye Foods Ltd. 1970).

The final standard required is a consumer pack which is completely free of extraneous vegetable matter of any kind. If this standard was not obtained the first time through, a re-cycling procedure would have to be used, either back along the inspection lines alone, or through some of the mechanical cleaners as well as the inspection lines, obviously involving considerable extra time and expense.

It should be noted that although the process has been approximately described for both peas and beans at the same time there are important differences, especially in the fact that inspection lines are included in the bean processing operation before the freezing and bulk packing stage as well as at the later time of repacking. All of these can only maintain at best 80% - 90% efficiency, with the final manual inspection methods probably the least efficient of all. Thus, as it is the processor's aim to finish with a completely contamination-free final product, the acute importance of ensuring that crops are as weed-free as possible is self-evident.

CONCLUSION

The economic pressures on the industrial processor and the ever increasing demand for improved quality control are forcing him to apply increased pressure on the grower so that the whole harvesting programme may run as smoothly and efficiently as possible. The presence of weeds in the crop is detrimental to this operation, both in hampering the mechanical harvesting operations and in increasing the cost of the processing operation at the factory. With the present trends to introduce even more machines of even greater capacity into agriculture nearly all the problems described here are likely to become even more acute and the demand from the processor for weed free crops will grow stronger. It is anticipated that by the 1980's half of all Britain's food will be prepared or will be in the form of convenience foods and by this time the frozen food market could be double its present size. Emphasis must be placed on machines which can eliminate waste in the field, reducing raw material to minimise transport and disposal costs and minimise damage to the usable product, preventing post-harvest deterioration and retaining quality. These machines will require a weed-free environment in which to perform if their future and their success is to be assured. At the factory, speed of throughput and costs of labour will become increasingly important. Rather than suffer the inconvenience and extra costs of upsetting the smooth operation of the processing line by handling weedy crops, the processor will be forced to demand that farmers present him with virtually weed free crops.

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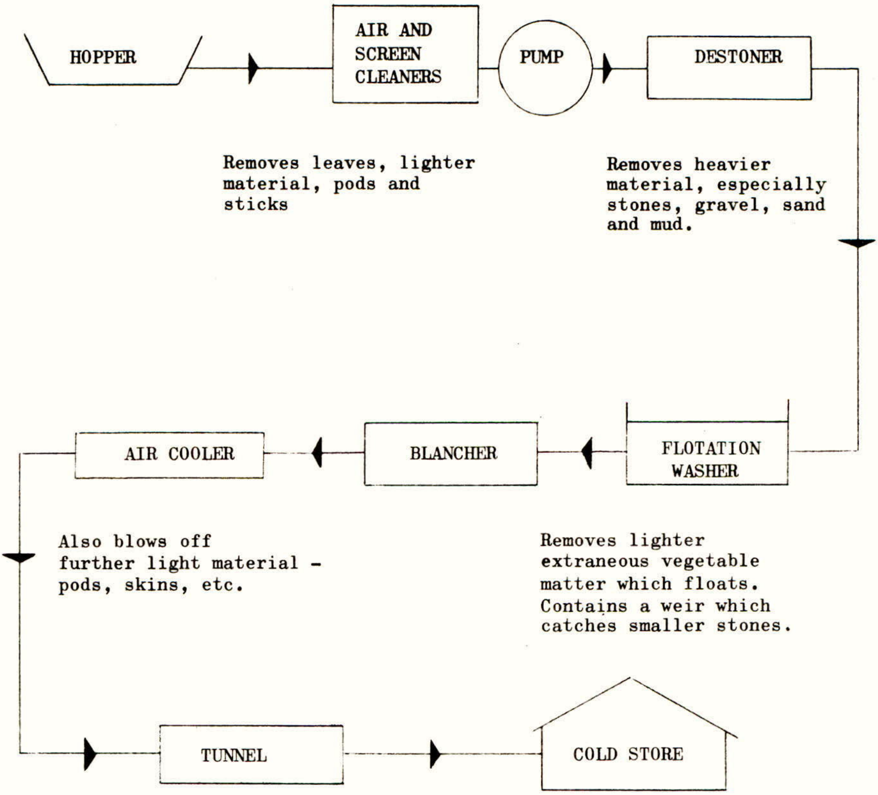
FIG. I FLOW CHART DIAGRAM OF PEA PROCESSING LINE FOR FREEZING



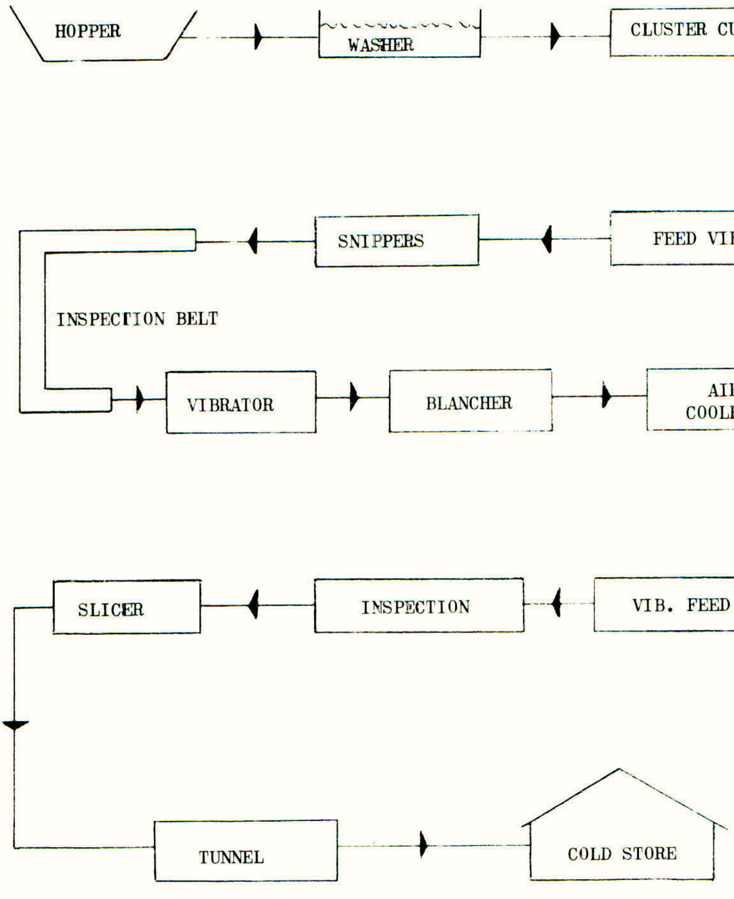
Removes leaves, lighter material, pods and sticks

Removes heavier material, especially stones, gravel, sand and mud.

Also blows off further light material - pods, skins, etc.

Removes lighter extraneous vegetable matter which floats. Contains a weir which catches smaller stones.

FIG. II CHART DIAGRAM OF DWARF BEAN PROCESSING LINE FOR FREEZING



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OBJECTIVES OF WEED CONTROL IN VEGETABLES

Effects of weed control practices on systems of production for vegetable crops

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Summary Past and current trends in systems of production for vegetable crops are described and are related to the need to control weeds. The importance of plant spacing in determining the size of vegetables and how the use of optimum row spacing is dependent on reliable herbicides is pointed out. The best theoretical methods of crop production are outlined and it is shown how these methods are modified by weed control practices, e.g. the decision to drill directly into the field or to transplant, row-spacings, seed-rates and seed-bed preparations. It is emphasized that weed control is the key to more efficient systems of vegetable production in the future with the need for improvements both in herbicides and herbicide management.

INTRODUCTION

The historical development of row-cropping for vegetable production from the 18th century to the early 1960's has been outlined by Bleasdale (1963a) who showed that the main reason for the change from broadcast sowing to row-cropping was the ease and cheapness of weed control by mechanical inter-row cultivation. There was, however, a price to be paid for the adoption of row-crop systems - reduced yields per unit area of ground. In recent years the development of reliable methods of chemical weed control for certain crops has removed constraints imposed by inter-row cultivations; plant population can now be varied to control the size of the vegetable to that required and with closer rows higher yields are generally obtained. Thus with some crops such as carrots, to produce roots of a relatively small size for canning and freezing, crops are now often grown on a bed-system (Bleasdale, 1963b) with rows only one inch apart and with plant densities often exceeding those used by the 'intensive' market gardeners of the earlier years. The wheel has turned full circle.

Many studies on a range of vegetable crops have shown that plant size is controlled by plant density and spatial arrangement. Therefore, with increasingly precise standards being placed on the size and quality of vegetables by the supermarkets and chain stores, and also by the processors, it is most important that the grower should not be restricted in choosing the optimum row spacing for his crops. This can only be achieved when adequate weed control can be guaranteed by methods other than inter-row cultivation. At present this ideal situation obtains with very few crops.

Production systems for vegetables

The object of any production system is to obtain high yields of vegetables of the desired size and quality in the required quantities at the right time as efficiently as possible. Obviously there is no universal ideal system for growing all crops because different factors will alter in relative importance with each crop. However, any system should aim at reducing variability in size, shape, weight or time of maturity of the individual plants to the limits that the genetic variability of the variety will dictate. To this end the aim as far as possible should be to obtain uniform emergence of seedlings as evenly spaced as possible at the correct density and thereafter to grow them to harvest time without their being affected by weeds, pests or diseases. Assuming that hand labour is expensive the system should make the maximum use of machinery for all operations provided that yield and quality of the crop are not seriously affected. This is a counsel of perfection and never achieved in practice!

In general, the replacement of hand labour by herbicides for killing weeds and increased mechanisation has resulted in a trend for larger units of vegetables to be grown on general farms. However, at the same time there is a need for increasingly precise methods of production in order to meet the more stringent standards of size and quality now being demanded. Achieving these standards with large-scale production units is a challenge that is being successfully met and, undoubtedly, one of the essential keys to success is reliable and adequate weed control.

Ways in which weed control can influence production methods

The necessity to control weeds in a crop may affect every facet of production. Indeed, it may assume such overriding importance with certain crops that the system of production is 'built' around the most successful method of controlling weeds. The following examples indicate how weed control practices can alter production methods.

To plant or drill? The weed flora and population present may with other factors, determine whether crops should be drilled in the field or raised elsewhere and transplanted at a later stage of growth. For example, many *Brassica* crops can be grown successfully by either method but the greater part of the acreage of these crops in this country is still transplanted. A major reason for this is that the number of herbicides available for drilled crops is restricted and all of them may damage the crop under unfavourable conditions. Transplanted crops are tolerant of a wider range of herbicides and can themselves contribute to effective weed control by the rapid formation of a canopy. In addition transplanted crops are usually planted at times of the year other than during the main spring germinating period of annual weeds.

Seed-bed preparations: Much more attention and care is needed to prepare seed-beds when herbicides are to be used. Especially with soil-acting herbicides the seed bed must be as uniform as possible to avoid patchiness in weed control or crop damage. Uniform seed-bed preparation is also required when post-emergence herbicides are applied because simultaneous emergence of all seedlings is required to get the correct timing of the application. This can be of great importance where large acreages require to be treated at a particular stage of growth of crop or weed. Uniform emergence is also a necessary prerequisite for a uniform crop.

Seed rate: In the past it has been customary to sow seed at a rate several times greater than that required to get the desired plant population and subsequently thinning of the unwanted seedlings has been carried out. In this situation some death and damage to seedlings due to herbicides could be tolerated. With the advent of precision drills and the increasingly high cost of vegetable seed, especially hybrid seed, much lower seed rates are used than in the past giving perhaps a stand twice that ultimately required. In these circumstances damage and death caused by herbicides will no longer be tolerated and much greater reliability will be required from them.

Row spacing: As has been mentioned earlier row spacing is very often determined by the efficiency and reliability of herbicides for controlling weeds. For example, where a range of herbicides is available to give reliable control of weeds as in carrots, then row spacing can be adjusted to give maximum yields and control of root size. However, in crops where few herbicides are available and their spectrum is restricted, for example in lettuce, then row spacings are adopted which enable inter-row cultivations to be carried out should they become necessary. It is believed that with lettuce such limitations on row spacing reduce potential yield and quality of the heads.

Requirements for weed control practices in the future

At present with most vegetable crops chemical methods of weed control are now the rule rather than the exception (Roberts, 1970) and in the future increasing reliance will be placed on herbicides for weed control. In order to make the practice as efficient as possible (1) improved herbicides are required together with (2) greater precision in their use.

Improved herbicides: It is most desirable that a range of herbicides is available for use with any particular crop in order to give flexibility to management in timing when control measures can be applied. If the weeds can be attacked at different stages during the growth of the crop then situations which arise when adverse weather conditions have prevented spraying at an early stage may be retrieved without recourse to inter-row cultivations. Also, alternative herbicides are required for use should previous control measures have failed to kill the weeds.

Improvements on existing herbicides are required in three respects (1) more selective herbicides are needed to kill, for example, cruciferous weeds in *Brassica* crops, (2) more persistent residual herbicides which would enable crops to become established and complete the major part of their growth free from weeds, without adversely affecting either that crop or any subsequent crop, and (3) the development of herbicides with control over a much broader spectrum of weed species. The trend, however, appears to be for the newer herbicides to control a narrower spectrum of species. Alternatively, it may be more flexible to kill a broad spectrum of species by a mixture of herbicides and/or successive applications of complementary herbicides in a planned programme (Roberts, 1970).

It is appreciated that with ever increasing development costs it is unlikely that new herbicides will be produced specifically for vegetable crops, nevertheless, these are the desirable characteristics and when screening agricultural herbicides for possible horticultural applications these three requirements should receive attention.

Use of herbicides: The increased reliance which will be placed on herbicides to control weeds will not be the easy way out for growers of vegetables. In fact much greater attention to detail and more precise methods of applying the chemicals will be needed. For example, soil preparations will require greater attention in order to get finer and more uniform seedbeds not only when soil-incorporated herbicides are to be used but also to ensure more even emergence of the crop seedlings and thus to allow subsequent weed control sprays to be applied at the correct growth stage for the majority of the plants. Timeliness of application will be most important in order to minimise any differential checking of plants as a result of spraying at the wrong time.

In the future there is likely to be a trend towards increased specialisation with monoculture as its extreme form. On such holdings far more attention will have to be paid to weed control practices so that the populations of weed species which are unaffected by the herbicide used do not build up and that the weeds do not enable pests and diseases to be carried-over from crop to crop.

As Lawson (1972) has pointed out, it is wrong to treat each crop in isolation rather than as part of a rotation and to consider that weed control operations apply to that crop only and must preferably be paid for by that crop. What is required is a planned rotational programme of weed control, so that desirable systems of vegetable production do not come up against weed problems which make them difficult, too expensive or impracticable to carry out.

Finally, it must be apparent that weed control is the key to more efficient vegetable production systems for with a reliable herbicide programme crops can be grown at optimum row-spacing and plant density to give the required plant size in an extensive, highly-mechanised production system.

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OBJECTIVES OF WEED CONTROL IN VEGETABLES
THE FUNCTION OF MANAGEMENT

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Producers of field scale vegetables are deeply concerned with the control of annual and perennial weeds. Their concern is based almost wholly on economic grounds as weeds may affect the success of crop plants in a number of ways. One major function of farm management is, therefore, to plan and organise in such a way that serious weed competition is not allowed to develop.

Growers acknowledge with respect the work of scientists and technologists who have developed, over the course of a few years, materials which have provided increasingly effective chemical weed control and which have enabled new systems of crop production to be developed. Considerable improvements in yield have also resulted in spite of a continual decline in the number of farm workers and hence in the resources available to management.

The skills associated with management remain partly scientific and partly intuitive. In many situations there is a precise scientific answer to a problem, in other circumstances farm management is, and will probably remain, an art. For example, the control of a particular range of weeds in a crop by means of an established herbicide in clearly defined circumstances will have a firm scientific basis; but circumstances in agriculture are not always clearly defined and the timing of applications of weedkillers to sensitive crops in unsettled weather conditions is but one example of the intuitive nature of management. This intuition is especially evident in the "day to day" decisions that have to be made on so many occasions and in such varying circumstances.

Given good management the following rewards may accrue to the vegetable grower through the control of weeds:-

(1) Lower overall costs of production

(2) Higher yields of more even size and improved quality

(3) Improved harvesting rates

(4) Machine harvested crops free of weed contaminants

(5) Improved storage conditions for certain crops

(6) More consistent and predictable financial results

THE RESPONSIBILITY OF MANAGEMENT IN WEED CONTROL

The first priority of management is to ensure an economically acceptable return on invested capital. Responsible managers are extremely conscious of the problems of weed control; they are equally conscious of the need to integrate this with all those factors which jointly constitute a successful farming business.

Management will adopt a number of approaches to weed control and paramount amongst these will be the following basic principles:

Availability of capital may place serious limitations upon the employment of labour and the purchase of machinery for weed control. A decline in capital resources usually develops over a period of years in association with a steady decline in net farm income. This in turn is associated with static or declining crop yields and a progressive increase in weed competition. It is important that management should recognise such trends and take appropriate action before the process becomes irreversible. Arable farms which are poorly managed pose a serious problem to neighbouring farmers whose endeavours may be diluted through the dispersal of weed seeds from fields adjacent to their own.

A further factor which may limit the institution of a sound rotation is the desirability of growing crops in certain fields on the farm. Thus on large holdings with central storage and packaging amenities there is a tendency to grow crops, for which these amenities have been provided, close to the store or pack-house. Similarly, certain fields lend themselves to aerial spraying and this may influence the choice of site for potatoes for example. Similarly, for obvious reasons, certain crops will not be grown on slopes, stony fields or where for one agronomic reason or another success is likely to be limited. Crops other than vegetables can be employed in rotations to great advantage. The significance of grasses, cereal crops and potatoes should not be overlooked. All of these are crops in which herbicides can be used that may not be employed with most vegetables. Materials based on 2, 4D or MCPA are used to control many annual and several perennial weeds. "Twitch" or "couch grass" can be controlled in potatoes by the soil incorporation of a herbicide prior to their planting. The control of wild oats in peas, an important vegetable crop, is considerably more satisfactory than in cereals. Similarly, knot-grasses and mayweeds can be more adequately controlled in brassicas than in cereals.

Not least amongst the problems facing management is the decision of whether and at what stage to control weeds. Time and effort may be wasted and crop damage caused where gangs are "set on" to hand hoe vegetables. On the other hand the success of crops may be prejudiced if a weed control operation is omitted and a late flush of weeds allowed to develop. The processed crops, peas and french beans, are one clear example of this.

THE SIGNIFICANCE OF WEEDS IN CROP PRODUCTION

It is difficult to quantify the effects of competition, as these may range from a minor interference in the process of production, to the extreme situation of complete crop loss if large numbers of competing weeds develop during the germination and emergence phases.

On farms where standards of husbandry have declined weeds may develop across the farm to such an extent that crop yields may fall substantially. The experience of capable farm managers suggests that 5 to 6 years are needed to repair such a situation and that the cost of this operation can be high. Thus while the average cost of weed control in vegetables is currently between £5 and £10 per acre for labour, spray chemicals and machinery, this may rise to £20 per acre where farms have been allowed to "run down".

The immediate effect of weeds growing in competition with crop plants may be considerable and crop losses may arise through a number of differing causes. By taking up space and utilising water and plant nutrients, weeds may substantially reduce the yield of many crops including vegetables. Even when water and nutrients do not become limiting, extensive weed development can result in a dense canopy which may smother crop plants and reduce yield and quality.

If weeds are allowed to seed and spread on a substantial scale, the entire organisation of day to day farm work can fall into disarray in the absence of a reserve of skilled labour to bring the problem under control.

PROBLEMS MET BY MANAGEMENT IN THE CONTROL OF WEEDS

The control of weeds in vegetable crops presents far more searching problems than merely the selection of the correct herbicide. Weed problems may arise through a number of widely differing reasons.

Amongst the more important and unpredictable of these are weather conditions met with during the spring, summer and autumn of the farming calendar Cold, dry weather during April and May can seriously reduce the effectiveness of many of the post-emergence residual herbicides commonly used in vegetables. Wet weather during June and July will interfere with inter-row cultivations aimed at controlling weeds growing amongst crop subjects to which post-emergence or post planting herbicides cannot with safety be applied. Prolonged wet spells in the late summer and autumn may interfere seriously with the cultivation of land fallowed for the control of perennial weeds and with the normal treatment of cereal stubbles for weed control. Vegetable crops are frequently grown after cereals in the eastern and south eastern counties and effective weed control in cereals, both during the growing season and post harvest, may serve as a contributory step in the successful production of vegetable crops. During the late autumn heavy falls of rain have perhaps the most serious and long term effects. Difficult weather can lead to appalling harvesting conditions for crops such as potatoes, beetroot, parsnips and sugar beet and the long term effect of this on soil structure is very serious. Poorly structured soils of low organic matter content break down badly if worked in wet conditions and this poor physical condition is typified by difficulties in seed bed preparation and a preponderance of compacted clods. Weed control either by chemicals or mechanical means becomes very difficult in such circumstances.

While great strides have been made in recent years with the development of new or improved herbicides, there are still strict limits in terms of the materials available for some important crops. Amongst the more important vegetables for which there is still a far from complete list of satisfactory herbicides are cauliflowers and lettuce. Many successful and widely used herbicides have limitations in their control spectrum. Propachlor for example gives a poor control of knotgrass while the soil incorporated herbicide Trifluralin provides a poor control of sherherd's purse and other cruciferous weeds.

The weather may have seasonal effects other than those to which reference has already been made. The emergence pattern of certain weeds is influenced by soil temperatures during the spring months. The non emergence of weeds during the control phase of a herbicide may mean that the treatment is ineffective.

A feature of recent years which has influenced the survival of large numbers of "groundkeepers", is the widespread introduction of machine harvesting for root crops such as potatoes and bulbs, such as daffodils and tulips. If difficult harvest seasons are followed by mild winters large numbers of tubers or bulbs may overwinter to cause serious embarrassment in following crops.

Economic consideration may, in a number of respects, bear considerably upon the effectiveness of weed control. For example farm policy may be directed towards the production of a very narrow range of crops (early potatoes and cauliflowers form the basis of the rotation on many small farms in Lincolnshire while intensive salad production, based largely upon lettuce, predominates on many market gardens in the south east). In such circumstances the range of materials available in a weed control programme will be very limited and weeds that are not controlled by the herbicides in use may achieve dominance. At the present time chickweed, knotgrasses, mayweeds and shepherd's purse constitute problems where vegetables are grown intensively. Nevertheless economic pressures and the development of competitively priced soil sterilants may point the way towards narrowing rotations and even perhaps mono-cropping. The need to develop wide spectrum herbicides or compatible mixtures to permit comprehensive weed control in such situations assumes increasing importance.

1. To plan, within the bounds of economic realities, crop rotations which allow for a succession of crops on which herbicides can be used having such a spectrum of weed control that none of the commonly met weeds are allowed to achieve dominance.

2. To catalogue closely from month to month and from year to year the pattern of weed occurrence on the farm in order that the appropriate control measures may be applied.

3. To decide upon the choice and timing of the basic tillage operations to ensure that a rapid germination and establishment of crops is obtained.

4. To allow, where appropriate, for the fallowing of fields in order to control troublesome perennial weeds.

5. To deploy labour and machinery to ensure that weeds are controlled in an early stage of development. This is especially important where pre-emergence residual herbicides have not been entirely successful.

6. To select the most appropriate herbicides for a weed control programme and to ensure that these are applied at the correct rate and at the time most appropriate to the stage of crop development and weed growth. In making this decision the prevailing weather must be borne in mind.

7. To arrange for drilling or planting systems that will permit the control of weeds throughout the duration of the crop either by chemical or mechanical means. The inter-row spacing allowed can be especially important in this respect for many vegetable crops. The temptation may be to reduce the distance between plant rows in order to ensure higher yields of a controlled size grade. In the absence of post-emergence contact herbicides that may be used in the crop, such a decision can lead to serious problems.

8. To ensure that headlands, hedgerows, banks, dykes and yards are kept free of seeding weeds. If weeds are allowed to develop and seed in such areas a great deal of effort elsewhere may be nullified.

From the examples given it can be seen that the role of management is especially important in weed control. It is also important that communication down through the chain of command is good. When good working relationships extend from manager to foreman and chargehands, it is much easier for day to day knowledge of changing situations to be passed on. This communication link is especially important when management has a considerable administrative function in addition to field involvement and where cropping is complex and the size of the farm or farms large.

The complex nature of arable farming with vegetables or large scale market gardening makes considerable demands upon management which is concerned not only with crop husbandry but frequently with complex marketing arrangements. In addition scientific developments occur so rapidly and in so many areas of production, harvesting, handling and marketing, that the allocation of resources of capital, labour and land attain a fresh significance.

A main responsibility of management is to take a balanced view of change as it occurs and to single out those features that present themselves as real opportunities. In terms of weed control, which is of such importance in relation to both costs and returns, this may involve alterations in long established policies. Thus it is only in recent years that the concept of minimal cultivations has gained acceptance and this largely as a result of developments that have occurred in the chemical control of weeds.

The spatial arrangement of vegetables grown both for processing and for the fresh market, constantly increases in importance. By adopting the correct plant density the producer is enabled to exert a considerable influence upon the size of the end product. Important instances of this development include the bed system of carrot production for canning and the spacing requirements for onions, for purposes as diverse as pickling and the ware market. In the absence of herbicides capable of achieving a comprehensive and lasting control of weeds, such systems of growing associated with beds or close rows could not have been successfully developed because of the expense that hand weeding would have involved. The control of weeds by mechanical means such as row crop steerage hoeing or even by hand labour, may result in crop losses through the physical damage caused to plants during such operations.

Research and experimental work has demonstrated that for a range of crops not only can the size of the end product be regulated by the correct spatial arrangement but that gross yield per acre can be substantially increased. Increases in crop yields, as long as they are not associated with loss of quality, can result in a reduction in the acreage given to the crop in question, especially if the subject is grown on contract. Such acreage reductions present opportunities for a wider farm rotation or for the inclusion of crops that may materially assist in the maintenance of soil fertility. Benefits may thus accrue to other crops grown on the farm leading to increased farm income.

Weeds may serve as host plants for serious pest and diseases of vegetables. Cruciferous weeds for example may encourage the survival in the soil of club root of brassicas. Stem and bulb eelworm, the oat-onion race of which can cause serious production and storage problems in onions, may carry over in weeds such as chickweed, mayweeds, knotgrasses and speedwells. Where such diseases and pests occur or are likely to be met, the importance of weed control assumes further significance.

Weed development may affect the evenness of crop plants especially if the distribution of the weeds is patchy. Uneven growth of crops can cause difficulties in harvesting. Unevenness also necessitates a greater degree of size and quality grading after harvest. Dwarf french beans may serve as an example of a crop the machine harvesting of which can be seriously impeded by the incidence of weeds. Many harvesters for use in vegetables, work less efficiently if weeds are present and the producer risks the rejection of peas and beans for processing, should the harvested sample prove to be seriously contaminated. The introduction of weeds into barns with crops such as onions, may result in crop losses in store because of reduced air circulation through the presence of weeds and adhering soil.

The agronomic and economic significance of weeds is therefore high in modern vegetable production and their control of very great importance.

In the face of almost constant change it is likely in the future that the keystones for successful weed control in extensive vegetable production will continue to be an adherance to the basic principles of crop husbandry. These are balanced crop rotations and the correct choice and timing of both basic cultivations and those associated with seedbed preparation.

This basis is essential to the best possible results being obtained from weed control materials that are available to the industry. Growers will continue to look to science and technology to develop new and improved materials and mixtures of herbicides that will provide control over a longer period of time, over a wider range of weeds and which are less influenced by weather fluctuations.

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SOME CONSIDERATIONS OF THE RELATIONSHIP BETWEEN BIOLOGY, CONTROL AND IMPORTANCE OF CERTAIN PERENNIAL WEEDS

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INTRODUCTION

The relationship between the biology of the perennial weeds, and the methods used to control them, has been discussed many times in research reports and in detailed reviews in previous conferences, the most recent occasion being in 1970. On this occasion I shall limit my discussion to certain aspects of the relationship between biology of specific weeds and their control by herbicides, which seem to me to be important in judging the success or failure of existing herbicides and the need or feasibility of finding new ones.

In this context I consider biology to include ecology and ecology to include economic and agronomic factors which affect the acceptance and utilisation of control measures by the user.

THE SPECIAL PROBLEMS OF PERENNIAL WEED CONTROL BY HERBICIDES

The property of perennial weeds generally regarded as presenting the biggest obstacle to their effective control, is the ability to regenerate from root, rhizome or stolon and even from fragments of these organs. One can take the view, however, that this method of regeneration and multiplication offers a better target for long-term control by herbicides than does the dormant seed, the method of regeneration and multiplication used by annual species. We already have herbicides that can be translocated into the perennating organs of many species with lethal or suppressive effects but a practical method of killing the reserve of annual seeds in the soil on an agricultural scale has so far eluded us. In a recent W.R.O. survey of cereal weed control in certain areas of England (Phillipson <u>et al</u> 1972), charlock could still be found in 33% of the fields examined in May 1970, but creeping thistle in only 10%. In July of that year frequency of both had dropped to 5%, presumably as the result of spraying. This survey makes no estimate of weed density but it clearly indicates that the eradication of an annual weed highly susceptible to herbicides can be a long process! The immediate practical problem, therefore, is the ability of perennials to regenerate vigorous shoot and root growth within days or weeks of their apparent distruction.

There is nowadays a wide range of suitable herbicides and techniques that can deal with the perennial weed growth and regrowth, but the choice in any particular situation is restricted by such factors as specific weed susceptibility, selectivity, economics, the feasibility of application techniques and the needs of cultural practice. These restrictions are generally greatest in agricultural crops where, for example, economic and cultural conditions often dictate that adequate control must be given by one treatment per year, a need that demands a very effective degree of destruction of the regenerating system. It is in these conditions, when we need to get maximum efficiency from a restricted choice of methods, that we hope biological studies will help us most. The problem is world-wide, but to keep the subject within bounds I shall concentrate mainly on a few species which are important in agricultural situations in Britain.

The judgment of this conference, on which species are most worthy of discussion, is quite clear. Of the research reports offered on the subject of biology and control of perennial weeds of agricultural importance in various conferences (including the present one) since 1953, about 80% relate to Agropyron repens, and at least half the remainder to bracken. While herbicides have given some degree of control of these species, the compounds available up till now have not been wholly acceptable or reliable. Species for which no adequate herbicide exists, like coltsfoot (Tussilago farfara), or species like thistles and docks, which used to be considered major problems in the days before the advent of selective weedkillers, have received only sporadic mention. I consider that the scarcity of field studies on the latter are particularly regrettable because our successes should be able to teach us as much or more about the importance of biological factors on perennial weed control by herbicides as our failures.

Cirsium arvense (Creeping thistle)

In arable land

Before the introduction of 2,4-D and MCPA creeping thistle was one of the major cereal weed problems in Britain (Brenchley 1920), in Canada and in many other countries.

In Britain, the susceptibility of both shoot and root to the fairly high levels of MCPA originally recommended (24-32 oz/ac) brought about a fairly rapid decline in the incidence of this species in the cereal crop, which has been more or less maintained ever since. Disappointment has often been expressed at our failure to eradicate this species with the existing methods (Chancellor 1970) but if we have succeeded in reducing the incidence from the 73% (Brenchley 1920) to the 10% or less recorded more recently, then a substantial degree of local eradication must have been achieved. This success is the more remarkable because the relationship of the crop and weed growth cycles has not permitted us to delay the use of the herbicides until the early bud stage of the thistle, the stage at which the maximum effect to MCPA on the root system will be obtained. In the early days spraying was late enough to allow complete shoot emergence to occur and thus to obtain a high degree of shoot kill. Subsequently, the main spraying season has become earlier and application rates have been reduced, changes which might have been expected to allow the re-establishment of this species.

In spite of this, the incidence of creeping thistle in cereals remains low. In the absence of any quantitative record of its decline one can only speculate on the factors involved, but I believe that early herbicide treatment controls the shoot growth present at the time, induces late regrowth which is suppressed by the crop and reduces the reserve of food and bud material in the rhizome. Continuous cereal growing and a steady increase in competitive power of the crop has produced a cumulative effect. It may seem strange to suggest that creeping thistle is not highly competitive but if we look back at the situations in which it was dominant in the past we see that these were mainly situations in which the capacity of the crop to compete was reduced by other circumstances. Spring barleys were later sown than now and being already severely checked by annual weed competition when the thistle shoots emerged, were quickly overtopped by them. In winter wheat, winter kill, caused by poor drainage, late seed-bed preparation, wireworm and wheat bulb fly, were commonplace. In these gaps creeping thistle flourished and established nuclei for expansion. Earlier harvests, vastly improved drainage, better varieties, higher fertility levels and the use of insecticides have made these patchy crops a rarity and have presumably reduced the supply of suitable habitats.

The rise in importance of grass weeds may introduce a new factor. To avoid the cost and inconvenience of separate treatments for grass and broad-leaved weeds more dual-purpose herbicides are being used. The time of use of these is usually dictated by the difficulty of controlling the grass weeds and the need to remove their competitive effect. This often requires very early application and whether this will increase the opportunities for creeping thistle or help the crop to be more competitive remains to be seen.

In break crops I believe that the reverse process is occurring. The in-crop cultivations which kept annuals and perennials alike in check have all but disappeared. Annual weeds are controlled chiefly by pre-emergence herbicides which do not in the main exert much effort on late emerging perennial weeds, and there are signs that creeping thistle is becoming more prevalent in these crops, especially in areas where the frequency of cereal cropping is still fairly low.

In grassland

Creeping thistle is still the most conspicuous weed of grassland and the economic importance has always been in dispute, especially as it tends to be reduced in intensely managed grassland and to be most persistent in the permanent grazing lands. In extensive pasture it can be sprayed at the optimum stage for root kill but the cost of a systematic programme spread over several years to keep it at a low level is difficult to justify. The low proportion of pasture sprayed, variously put at 1 to 4% of the whole per annum, has been remarked on many times before (Harpur 1966 and Allen 1970). If we look at these figures in terms of the better quality grassland and in terms of an application once every 3 or 4 years, the proportion of sprayed pasture looks less like the result of farmer indifference and more like a deliberate economic policy.

The establishment of creeping thistle in short or medium-term leys can build up problems for subsequent arable crops and it is perhaps significant that in the W.R.O. survey the incidence of this weed in cereals, both before and after spraying, was greater in the predominantly grassland areas than in the mainly arable areas. If there is a greater move towards meat production and a corresponding increase of leys and forage crops under modern systems of reduced cultivation, these changes may bring about an increasing prevalence of this species.

Basically, the situation now is that we lack fully effective herbicides for this species that can be used in crops other than cereals.

Rumex spp. (Docks)

The docks must be ranked with creeping thistle as being amongst the arable perennial weeds whose importance has largely declined as a result of the introduction of 2,4-D and MCPA. In arable conditions docks act as annuals, with seed being the main means of propagation, although the crowns and some root fragments can resist cultivation and can persist to produce new large plants each year (Chancellor 1970). The seedlings of both Rumex crispus and R. obtusifolius are susceptible to all phenoxy-alkanoic herbicides and although established plants of R. obtusifolius are somewhat resistant to MCPA and 2,4-D, they are more susceptible to the phenoxy-propionic acids. The mature plants are most susceptible in the rosette stage in April and May, and the standard weed control programme in the cereal crop will therefore attack both reproductive phases. The opportunity for regeneration offered by the grass rotation in former years has now largely disappeared in all the principal cereal growing areas, and this combination of circumstances seems to have virtually eliminated both species from the arable scene.

In grassland the situation is more obscure. Farmers have attempted to keep dock populations down by occasional spraying and have often succeeded. The difference between the susceptibility of the two species has been more marked, however, and where clovers are regarded as important the phenoxy-propionic acids can only be used as spot treatments. In the last few years *R. obtusifolius* does seem to have increased in intensity, particularly in higher rainfall areas, and the problem appears to be worse in high productivity grassland where high nitrogen levels are used to replace the clovers. Docks tend to benefit as much as the grass from these conditions and large multi-crowned plants are rapidly produced. The intensive level of grazing tends to separate these crowns mechanically into semi-independent sections, which then produce new tap roots. Very dense populations quickly develop.

There is no quantitative evidence on how much grassland is now seriously affected. It is probably small in terms of the total but appears to have been sufficiently high in terms of highly productive pasture to have revived interest in dock control in the past five years, and the phenoxy-propionic acids have been reinforced by asulam and dicamba. A similar problem occurs in the high rainfall areas of Switzerland, Austria and South Germany with *R. obtusifolius*, and at higher altitudes with *R. alpinus*. In these areas, however, clovers are considered to be vital and overall spraying with dicamba and mecoprop is impractical.

Research reports presented at the 1968 and 1970 conferences showed that recovery of *R. obtusifolius* within a year from a single application of all the available herbicides was fairly high. The regeneration of the dock occurs from readily proliferated basal buds and the herbicide may reach these through the leaves or roots, or by direct application to the crown. Soper *et al* (1968) showed that in the case of asulam only the mature leaves offered a satisfactory route to the regenerating zones. However, there appears to be little lateral movement in the crown and the herbicide may not give effective control of buds that are not close to the base leaves receiving treatment. In multiple crown plants, leaf shielding in dense stands and leaf loss by grazing may increase the likelihood of unaffected laterally isolated dormant buds giving rise to new shoot and root growth when the major part of the original plant has been killed by herbicides. Whether and how these factors operate with other herbicides is not certain but, as the relationship between time of treatment and optimum results seems to differ between them, it seems likely that penetration through the crown or even through the soil may play a part in some cases.

Farmers appear to expect eradication but Courtney (1970) showed, in effect, that routine annual treatment is probably necessary to keep the population to a low level. In intensive grass production the need to close the field or grazing strip to cattle for a required period before and after treatment can be a nuisance if it does not fit in with the grazing cycle. In the absence of clear evidence of the economic gain, farmers tend to attack only the most severe infestations.

In the circumstances, it is very difficult to decide whether there is a real economic need for better methods of dock control and, if so, whether we need better dock herbicides or a better understanding of how to use the ones we have.

Agropyron repens (Couch grass)

The biology and control of *Agropyron repens* in arable crops have been reviewed ably and exhaustively at the last two conferences and I shall confine my remarks to some specific aspects of herbicide efficiency. Unlike the previous species, there seems to be little doubt of the current economic importance of couch grass nor of the fact that we do not yet have a simple and reliable herbicide treatment. The basic motive for controlling this weed is to reduce or eliminate its competitive effects in the crop. A direct approach to this is possible by a pre- or post-emergence application of herbicides in several crops but up till now not in cereals, the crop in which it is probably most important and the crop which probably most favours the increase of the weed. At present we lack a herbicide which is selective between cereals and Agropyron either by post- or pre-emergence application in the crop year. The possibilities of post-emergence selectivity might seem remote, but bearing in mind that such a target has already been achieved with wild oats in wheat and Sorghum halepense in sugar cane, it is by no means impossible.

A more serious objection arises from the work of Cussans (1968) on the growth cycle of Agropyron in cereals, which shows that shoot emergence is fairly slow and that maximum growth of shoots and new rhizomes occurs from July onwards, long after applications to the crop would be feasible. Growth in May and June is from the previous year's rhizomes and a high level of control of these will be necessary to overcome the eight times multiplication rate described by Cussans for the later period of growth.

However, the work of Cussans and Wilson (1970), which compared the effect of a number of autumn treatments prior to sowing barley, produced data on shoot density in May in the crop and again in the stubble. These counts showed relatively small changes in either control or treatment densities, suggesting that if the rhizome growth had indeed increased by eight times during this interval, then the ratio of emerged leaf area to rhizome might be much more unfavourable in the autumn than in the spring. Until a selective couch herbicide is available, this proposition will have to remain untested.

Cussans suggests that the best time to attack is when the maximum growth is present, that is in September immediately after harvest. Several herbicides are available that ought to be effective by foliar application at this time but none have given consistent long-term results in practice. Part of the problem is, of course, the effect of rhizome bud dormancy and the difficult target presented by Agropyron. The importance of surface active agents in the penetration of herbicides into the plant are well known. Positioning of the deposit and droplet size can all be vital factors and, as Cussans pointed out (1970), the post-harvest populations will contain shoots of many ages and stages of development. Perhaps the basic problem is that we need herbicides that are more effective in their intrinsic action on rhizomes and rhizome buds. Evidence will be presented in this session that such herbicides may soon be available (Evans 1972).

The long-term effects of a more efficient shoot-applied herbicide will be still affected by post-harvest weather, straw burning and other factors influencing the incidence of surviving or regrowth shoots. Evans (1966) questioned the wisdom of continuing to seek long-term reduction with herbicides. He showed that it was relatively easy to get consistent yield increase following stubble treatment, whether or not any effect could be detected in the stubble of the following year. The difficulties and uncertainties of the more complex systems required to achieve long-term control deter many farmers and there has been a tendency to move to shorter-term but simpler methods, such as stubble treatment with dalapon or aminotriazole, or the "minimum cultivation" technique for TCA. The advent of herbicides (Evans 1972) with more efficient action on rhizomes and dormant buds will increase this tendency, especially if pre-sowing treatment becomes a practical possibility.

One is left with the impression that the problems of Agropyron control in cereals by herbicides are due as much to its being a grass as to its behaviour as a perennial, and that it should certainly be placed with other grass problems in any classification of targets for new herbicide research. Whether it deserves a special place is questionable. There are already signs that Agropyron has been overtaken in importance as a grass weed by wild oats and blackgrass, a situation helped by successive dry autumns.

Pteridium aquilinum (Bracken)

The competitive power of bracken as a grassland weed is not in doubt. Given the opportunity it can completely eliminate the herbage and all other competition. It can be controlled by ploughing and reseeding, but there are many hundreds of thousands of acres of bracken infested land on which control by cultivation is impracticable because of climate, topography, lack of money, manpower and economic incentive. Undoubtedly, the easiest means of reclaiming such land (where it is worth reclaiming) would be by a cheap and effective herbicide.

The complex nature of the bracken community, coupled no doubt with its stability and the attractions of its main habitats, encouraged much detailed work by botanists and ecologists, and the classic studies of Watt on the morphology of the rhizome system gave a clear idea of the severity of the task facing control by herbicides. Naturally, 2,4-D and MCPA, as the first effective systemic herbicides, were tried on bracken in the early 1950's but, although they produced some formative effects on the fronds, their effects on the rhizome system were negligible (Stevens 1953 and Conway and Forrest 1956).

4-CPA was shown afterwards to be much more effective, and the work of McIntyre (1962) suggested that this could be due to more efficient translocation into the rhizomes.

During the next few years this and other translocated herbicides - dalapon, aminotriazole and dicamba - were tested against bracken.

4-CPA, aminotriazole and, later, dicamba were all shown to give useful control but at high rates of application in relation to their cost and with considerable variability in long-term effect. Conway and Forrest (1961) showed that with 4-CPA, at least, the erratic control could be ascribed to failure of the herbicide to kill buds in rhizomes not directly connected with fronds. Timing of application for optimum control of regrowth was found to be critical and somewhat different for each herbicide, although all the optimum times fell within the predicted period of maximum downward movement of assimilates.

These problems led to pleas at the 1962 conference and later for more research on the factors affecting penetration and translocation in this species. The suggestion by Joice and Norris (1962) that a new herbicide was needed was not received favourably, yet the field evidence showed that the degree of improvement of herbicide penetration required to achieve an economic and reliable method of clearing land of low intrinsic value was beyond the limits one could reasonably expect from known methods of improving penetration.

For a time it seemed possible that picloram, which gave good long-term effects by pre-emergence, would fill this rôle, but cost and the problems of using a highly persistent herbicide on a large scale prevented its exploitation.

The practical outcome of this effort was summarised by Erskine (1968), who had compared the available materials under practical conditions for 10 years and concluded that aminotriazole most nearly approached an economic and practical control method in his conditions, where an undersward was present.

The 1970 conference saw the first mention of asulam for bracken control (Holroyd et al 1970) and further results will be presented at the present conference in this session and in the session on grassland. It would be tempting to assume that, as this herbicide is effective on bracken at dose levels similar to those effective on grasses and broad-leaved weeds, the problem of translocation efficiency had been overcome. In fact, Veerasekaran and Kirkwood (1972) have shown that translocation efficiency of asulam is low if measured as the proportion of herbicide applied to that reaching the rhizomes. Lack of penetration of the pinnae is a major factor. These were, of course, studies in pots. It may be that in the field the greater proportion of rhizome to frond would produce a greater 'sink' effect and induce more movement. The important fact is that the asulam that is translocated appears to be able to penetrate the rhizome and frond buds, and to prevent their further development.

Veerasekaran's results suggest that the decrease of efficiency of uptake with increasing frond maturity is a more important factor in end of season decrease in effectiveness than changes in translocation efficiency, which, on the whole, reaches a plateau level in these experiments. Differences in the balance between these factors with different herbicides may explain the differences experienced in the extent of the critical application period.

This cycle of efficiency has interesting implications in the control of bracken in climates such as that of New Zealand, where the fronds do not have an annual senescence cycle and individual fronds may persist several years. Frond emergence is mainly in the spring and summer, and a summer stand may contain fronds at all stages of growth.

Under these conditions one would expect variable translocation to the frond buds and that effective long-term control could only be obtained by cutting and burning to produce a frond population of even age. However, in warmer climates the immediate effects of asulam on the younger fronds can be quite severe and sometimes lethal, a condition which is rarely seen in Britain. In releasing young conifers from bracken competition (an important problem in New Zealand) this effect is valuable but the relationship between it and the efficiency of long-term control remains to be seen.

The cost and difficulties of application in most bracken sites means that a high degree of long-term control is desirable. The present economic climate in relation to meat production and land values gives us more hope of farmer acceptance than there was ten years ago, and more justification for considering aircraft application as a method of overcoming some of the practical problems.

Recent work in bracken suggests that greater increases of retention are possib possible by decreasing the water volume than by changing the formulation (Catchpole and Hibbitt 1972), and that the very low volumes as used in aircraft spraying tend to give the highest leaf loading, although accompanied by the greatest variability. It remains to be seen whether this can be correlated with a greater cost/efficiency ratio on an acreage basis. We do not know as yet the relation between frond-loading and the degree of translocation into non-frond bearing rhizomes, probably the most important factor in obtaining long-term control.

The important principle which I believe is illustrated by our attempts to control bracken is that where long-term control of an extensive rhizome system by a foliar-applied herbicide is required, it is largely a waste of time to try to improve the efficiency of application and uptake if the herbicide does not possess the intrinsic ability to reach, enter and destroy the dormant buds, however far they are from the point of application.

CONCLUSIONS

Although I have considered a very small range of species, I think that these have been sufficiently different to illustrate the value of biological studies to the herbicide scientist in revealing some shortcomings in the type of studies which are being conducted.

In all the species considered, our knowledge of the developmental biology of the plant has been most valuable in defining the nature of the target, in indicating the parts of the cycle most vulnerable to attack and in explaining the reasons for some failures.

There has been less help from the weed biologist in predicting what effects we will obtain in crop situations, where we may not be able to attack effectively at the most vulnerable time of the weed cycle. We are similarly lacking in quantitative information on the degree of long-term success we are obtaining in practice, and on the effect of changing circumstances on its continuance. Instead, we usually measure success by field experiments that deal with the immediate results from a random selection of sites of which little of the previous or subsequent weed history is known.

Ecological studies have tended to be ad hoc and short-term. We have suffered perhaps from too much experimentation and too little of the detailed observation which should have preceded and succeeded it. As a result I think we have sometimes pursued too long the unreal objective of eradication with herbicides that do not have the necessary intrinsic activity, instead of using the ecological situation to get a less perfect but economically or agronomically useful result by the simplest possible means.

I believe that we should devote more attention to long-term ecological studies in the field of crop/weed associations and their reaction to herbicide and other cultural practices. What a pity that no one had the foresight 25 years ago to start systematic quantitative observations on the effect of normal farm operations on the weed flora, for example, in 25 individual arable fields. We have lost the chance of knowing how we arrived at our present position but if we start now we might at least help the next generation of weed scientists. One of the difficulties is the relatively small number of biologists and ecologists directly involved in weed research. The pure ecologists tend, for obvious reasons, to study undisturbed or specialised plant communities. Could we suggest that the ecological situation in agricultural plant communities offers a greater challenge?

Another field of biological study which has perhaps been less useful than one might expect is that concerned with the uptake and translocation of herbicides in perennial weeds. Such work tends to result from the advent of particular herbicides and therefore to explain what has happened rather than to help us what to do next. Because of the wide discrepancy between the methods of application used in radio-tracer studies and those used in practice, it is usually impossible to establish a quantitative relationship between such studies and herbicidal efficiency in the field. Whether or not a more detailed knowledge of the factors affecting penetration and translocation will help us to design better herbicides is doubtful in our present state of knowledge of the relationship between chemical structure and herbicidal activity. In the short-term it will probably be quicker to find new chemicals by the traditional screening methods.

The time and money needed for development of new herbicides makes products with very specific uses less and less attractive to the manufacturer. Perhaps a better knowledge of the mechanisms involved will help us to design tests which can detect a more general potential activity against perennial weeds.

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