PRESIDENT'S INTRODUCTION

SIR JAMES A. SCOTT WATSON, C.B.E., LL.D.

As you know I am a mere onlooker of the complicated and, I feel bound to say, confusing activities with which most members of this conference are concerned.

We have a vast number of crop varieties, of many widely separated species, each with its characteristic levels of tolerance. We have a multitude of weed species, each with its characteristic susceptibilities to particular herbicides. We have a large and growing list of useful compounds, each of which may be used in various formulations, concentrations and may be applied in varying amounts in sprays of varying droplet size, at varying growth stages of crop and weed and under varying weather conditions.

Then there has been, and indeed still is a lack of real understanding of the mode of action of these materials, and of the fundamental basis of resistance or susceptibility. It is hence not surprising that a great deal of your research has been of the trial-and-error type. Inevitably much of our available time will have to be devoted to the findings of this kind of work.

But guiding principles are emerging, and I believe this Conference will be memorable as the occasion for the publication of at least one major discovery of a fundamental kind. I think we are looking forward, with intense interest and curiosity, to what Professor Wain will have to tell us.

Our first speaker is Dr. Templeman, who, although he is nearly as young as he looks, is truly one of the Founding Fathers of the Science of Herbicides.

WEED CONTROL IN PERSPECTIVE

Chairman: THE PRESIDENT

THE PRESENT POSITION OF HERBICIDES IN BRITISH AGRICULTURE

DR. W. G. TEMPLEMAN, (Imperial Chemical Industries Ltd., Jealott's Hill Research Station, Bracknell, Berks.)

The title of this general paper gives its author licence to rove at will over the adequacies and inadequacies of our chemical weed control knowledge. Furthermore I have considered it my duty to emphasise the important gaps in our knowledge rather than to dwell upon accepted fact.

It is now nine seasons since the so-called hormone weedkillers first came into use in this country and greatly increased the interest in chemical weed control. The initial phase of rapid development of this novel technique in cereal growing is over and a settled pattern of use of MCP, 2, 4-D and the dinitro compounds in British farming has emerged. A similar situation prevails in other parts of the world and it has been estimated from available data (by my colleague Mr. F. G. Ordish) that the world consumption of MCP and 2,4-D in 1952 was about 20,000 tons of acid equivalent. If an average application of ½ lb/acre is assumed then the total area to which these weedkillers were then applied was about 80 million acres; the present corresponding acreage may well be about 100 million. In comparison, in the United Kingdom in 1953 about 800 tons were consumed which at 1 lb/acre means around 1½ million acres treated; if ¾ lb is a better average then nearer 2 million acres were treated. To these acreages must be added those for other weedkillers and having in mind the increased food production which must have followed the use of herbicides it can be seen that they are of very considerable importance to both the agricultural and chemical industries as well as to the food economy of the country, indeed of the world, as a whole.

Although many of the conditions for successful weed eradication in cereal crops are now well defined some needs still require to be met. For example, an inspection of the agreed recommendations of the Recommendation Sub-committee of last year's Conference (1) shows that there are weeds against which no known herbicide is really effective. The mayweeds (Anthemis cotula and Matricaria maritima ssp. inodora), field pansy (Viola arvensis), knotgrass (Polygonum aviculare) and dove's foot cranesbill (Geranium molle) are of this type. Generally speaking such weeds are of little economic importance and there is little commercial reward for the successful seeker of some method of eradication. On the other hand wild oats (Avena fatua and Avena ludoviciana) and black grass (Alopecurus myosuroides) are serious weeds of cereal crops in some seasons and localities for which, at present, there is no adequate method of control.

The outstanding major problem of weed control in cereals is an economic one. The question is what rate of selective weedkiller application gives the greatest return to the farmer. It is possible to conceive that profit per unit of money spent may be greater from low doses where partial control is achieved than from higher doses which achieve eradication. This is a very different question from what rate is needed for weed eradication. It is particularly important for the hormone weedkillers where sub-lethal doses often greatly reduce the growth of the weed and presumably limit its competitive ability. Some information on this question may be forthcoming at this Conference but only the results of a very large number of field trials scattered over the country where the crop yields are very accurately measured following sub-lethal doses of MCP and 2,4-D to weedy crops can really provide the answer. On the other hand many farmers are not satisfied with anything less than complete kills of the weeds and are ready to pay for removing them. On a similar line of argument it may be thought that insufficient attention has been given to measuring accurately cereal yields following hormone weedkiller applications to resistant weeds. Weeds have usually been named resistant as a result of trials in which their numbers have been counted before and after treatment; in general we have ignored crop yield if weed control, as judged in this way, has been poor. There is no doubt that resistant weeds are often dwarfed and reduced in vigour after spraying (see report (2) in 1950 Eire Department Agric. Journal, p.143); what effect does this have on the cereal yield?

This leads me to a short consideration of the possibilities of compounds which are not very lethal at reasonable doses. It is, I think, quite evident that the effectiveness of a selective herbicide does not depend solely upon the chemical; amongst other things the result achieved is affected by the vigour of the crop. If the vigour balance of weed and crop can be altered to favour the crop, the latter usually takes advantage of the situation. It is a long time ago now that G. E. Blackman and I (3) were able to show that giving a dressing of nitrogen to a weedy crop often did as much good as killing the weeds, if only the yield of crop was considered. Similarly one of the great advantages of drilling fertiliser with crop seed as compared with broadcasting is that the crop is favourably placed to absorb the nutrients and the inter-row weeds are at a disadvantage. So anything which selectively places the weed at a disadvantage in respect to the crop should be investigated. Chemicals are known which markedly disorganise the growth of plants without being very lethal. I refer, as examples, to maleic hydrazide, a-naphthylphthalamic acid and amino-triazole. These compounds have received some attention in the U.S.A. and perhaps, demand more over here?

Another proposal worthy of some discussion is the possibility of autumn spraying of winter cereals. It has been thought that if autumn germinating weeds could be sprayed during the late autumn or during the winter, this would relieve the pressure on spring work on the farm and would, in keeping with good weed control practice, remove the weeds before any serious competition with the crop had taken place. Furthermore it has also been thought possible that when such spraying with either MCP, 2,4-D or DNC is carried out, it should be quite safe to undersow such crops with grass-clover seeds in the spring where it is desired to do this. There are, of course, several obvious possible drawbacks to this idea such as the difficulty of getting on the land at this time of the year (although this might be overcome by aerial application), the cereal may be at a susceptible stage of growth, the lower temperatures leading to slower and perhaps diminished activity of the chemicals and the fact that frost during the winter often kills most of the weeds present. I hope that we shall hear more of this aspect during the course of this conference.

It is probably well known to you that ever since DNC was used as a selective herbicide in cereals there have been intermittent reports that it stimulates crop growth over and above what would be expected from the removal of the weed competition. No useful discussion of this matter has been possible because of the absence of data from adequately replicated and carefully controlled field experiments. However, this situation has now changed and the work of Riepma in Holland over the last 6-7 years is particularly pertinent (4). These trials have been conducted on weed-free cereals. The yield stimulating effect of ammonium DNC (5 kg in 1000 litre water/ha) on winter cereals amounts to 250 kg/ha for winter rye and to 400 kg/ha for winter wheat. These effects were only obtained when the chemical was sprayed at the beginning of the tillering stage, that is, when winter rye and winter wheat had about 3½-5 leaves. Results with oats and spring cereals generally were not so marked. DNC-treated plots were generally darker green in colour 5-6 weeks after spraying. Riepma has published earlier this year the results of a series of trials as follows:-

Material and quality		Yield kg/ha.	
		Grain	Straw
Ammonium DNC	5 kg/ha	30·9	52·1
o-nitrotoluene	9·6 "	25·4	47·1
2,4-dichlorophenol	4 "	23·8	44·5
Urea	2·1 "	25·5	47·6
Ammonium nitrate	2·8 "	24·7	45·9
Untreated	-	25·2	45·1

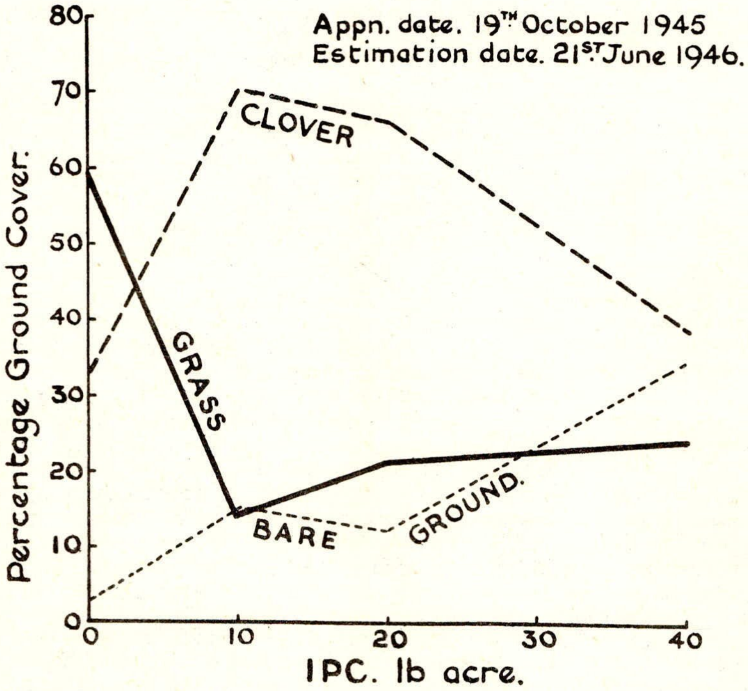
Yield of winter rye treated in the 4th leaf stage with about 1 kg/ha N or with DNC or related compounds.

(From Riepma, P. 1954, Landbouwvoorlichting, 11, (4), 180-2).

Riepma has also demonstrated the yield increasing effect of DNC on winter rye at a range of levels of nitrogen fertilisation; the DNC effect was still obtained at high nitrogen levels. From these results it seems that the beneficial effect obtained is unconnected with the nutrient action of nitrogen in the DNC and is either some physiological action, some protective action against an unidentified pest or some indirect action via the soil in which the plants grew.

Turning away from cereals to grassland, it is only since the discovery of the hormone weedkillers that any chemical method has been feasible on this most important crop. However, it is still not possible to find more than the meagrest information on the quantitative benefit derived from weed control or eradication. It is quite clear that creeping buttercup (Ranunculus repens) and rushes (Juncus sp.) are well controlled and appreciable results achieved against creeping thistle (Carduus arvensis) and ragwort (Senecio jacobaea) by MCP and 2,4-D. For grassland, however, it can frequently be argued that the most profitable method of dealing with a weedy pasture is to plough it up and reseed or to manage it in some way (e.g. by taking successive hay cuts or grazing at the required intensity at the appropriate times) which gradually eliminates the weeds. When the infestation of a susceptible weed is heavy or where it occurs in unploughable land or in pasture which cannot be properly managed, then there is a clear case for the use of chemical weedkillers. There is nevertheless a wide hinterland where at present it is impossible to decide whether it is more profitable to use a herbicide or whether the farmer should spend his money on such things as cultivations, extra stock and/or fertilisers. The research required to elucidate this matter would be difficult, tedious, lengthy and costly and presumably for these reasons little has been done so far. Much study is now being given to methods of measuring pasture productivity [see for example, the recent Bulletin of the Commonwealth Bureau of Pastures and Field Crops (5)] and it is to be hoped that some of this may be extended to suitable means of the measurement of increased herbage and beef or milk production which follow chemical weed control.

It has been pointed out many times before that the chief weeds of British grasslands are other grasses. Many swards contain bents, fescues, Yorkshire fog and the like which might well be replaced by more productive grasses and clovers. The changes in botanical composition which can be accomplished by different methods of management are well-known. These methods usually bring about gradual changes and one is tempted to enquire whether some quick-acting ch chemical method could not be devised. In the present state of our knowledge this is a very difficult matter but there are indications that it may not be insuperable. For example in 1945-1946 we were able to increase very markedly the clover content of a permanent pasture by the use of isopropylphenylcarbamate (IPC) as shown in the following graph:-



The Effect of IPC. on the Botanical Composition of Permanent Pasture.

Freed (6) has taken this matter further and shown that fall applications of the phenylcarbamates to grass seed crops weedy with annual grasses bring about remarkably beneficial increases in yield and purity of seed harvested. The timing of the application was critical and for Western Oregon and South-Western Washington, October was the best month. The following table shows this:-

Seed Crop	Yield of seed as % of Control			
	IPC		Chloro IPC	
	3 lb/acre	4½ lb/acre	3 lb/acre	4½ lb/acre
Alta fescue	186	178	255	238
Chewings fescue	208	148	154	139
Red fescue	90	97	121	116

Effect of fall applications of IPC and Chloro IPC, used to eliminate annual grasses, on yield of perennial grass seed crops.

(After Virgil H. Freed, 1953. Proc. 5th Ann, Calif. Weed Conf. p.83).

Blouch, Fults and Thornton (7) have also shown that the annual grass downy cheat (Bromus tectorum) could be eradicated from the valuable perennial range grass blue grama (Bouteloua gracilis) in the Colorado foothills by fall applications of 6-12 lb/acre chloro-IPC.

The problem of changing the composition of our British pastures by chemical methods warrants further study.

As far as I am aware there has been no recent important development of new application equipment. The number of low-volume sprayers in use in this country continues to increase and a useful bulletin entitled "The Economics of Crop Spraying was published earlier this year by the Farm Economics Branch of the School of Agriculture at Cambridge (8). No doubt this publication will be mentioned at the appropriate time in this Conference but it seems worthwhile to indicate its main conclusions. The investigation reported was largely concerned with the determination of the costs of spraying by contract and by the farmer using his own machine. It was concluded on a purely cost basis that about 30 acres spraying per year would justify the purchase of a low volume sprayer; for areas below this it was cheaper to employ the contractor. High-low volume sprayers were more difficult to assess but for a 200 gallon machine spraying DNOC about 66 acres just about justified its purchase. Acreages above this, in contrast to low volume spraying, showed little difference and farmers might readily prefer to use the contractor's services when dealing with toxic materials and when the job called for specialised experience or skill. There are, of course, many other considerations such as timeliness, convenience and local facilities which affect the issue.

The part which aerial application can play in weed control in this country is still in its infancy but I read a statement the other day that, of the total cultivated acreage of the United States, aerial application for seeding, fertilisation or crop protection was employed for about one-sixth - a very high proportion.

Perhaps the most dismal aspect of the chemical weed control position in farming (as distinct from market gardening) in this country is that concerning root crops like kale, sugarbeet and mangolds. I know that sulphuric acid is being used on kale and sodium nitrate plus a wetting agent on sugar and fodder beet but these methods cannot be regarded as consistently satisfactory, although dilute sulphuric acid is still a very good killer of annual weeds. A wide variety of chemicals have been examined as both post-emergence and pre-emergence applications without success. In this country pre-emergence weed control using a good contact weedkiller (like sulphuric acid) to spray weed seedlings before the crop seedlings have appeared through the soil surface, has proved successful for onions and other slow germinating crops but unfortunately is not useful for those of major importance. Pre-emergence application of weedkillers is nowadays usually taken to mean application before both weed and crop have emerged. There are three important reasons why it is difficult to foresee that this method of weed control can be successful in this country with herbicides so far known. They are:- (i) the weed populations infesting root crops are usually very mixed and it is not a simple matter of killing one species and leaving the crop unharmed, (ii) the results achieved are very much influenced by the amount and time of rain falling in relation to the amount and time of herbicide application - as everyone knows an absolutely unpredictable situation and (iii) most farmers are not prepared to take wood control measures until the weed has appeared and, in any case, it is very seldom possible to know which weed species are present until the seedlings have emerged from the soil. It is not difficult to understand that pre-emergence weedkillers can be very effective where weather conditions are predictable or where uniform growing conditions (such as for many crops grown in various parts of the world under irrigation) are experienced from season to season. In some places, too, fields or areas are known where specific weeds are almost certain to appear in certain crops - annual grasses in cotton in some of the cotton growing areas of the U.S.A. is an example. In my experience in this country, however, none of the chemicals examined (and this includes many of those tested in other parts of the world) has proved consistently satisfactory.

The inadequacy of our weedkilling methods in root crops leads me to describe two new approaches we have made. Neither has yielded a successful weedkiller but they suggest new lines of thought which one day may prove fruitful.

Shortly after the announcement of the unusual growth regulating properties of a-naphthylphthalamic acid by Hoffman & Smith (9), Mentzer & Nétien (10) and we found at about the same time that this compound was able to upset to a remarkable extent, the normal geotropic and phototropic responses of plants. It was not long before some of my colleagues (11) were able to show that two other groups of compounds, of which 2,4,6-tribromophenylnitramine and 2-chloro 9-fluorenol 9-carboxylic acid are examples respectively, also possessed this property to a remarkable degree. If a seed is put to germinate on an agar plate containing as little as 0·1 to 1 ppm of either of these two compounds the young root continues to grow in the direction at which it comes out of the seed instead of bending downwards under the influence of gravity. Similarly if seeds are sown in soil in the normal way and followed immediately by an application of a few lb/acre of one of these substances followed by normal watering, the subsequent behaviour of the germinating seedlings is very interesting. Some come up normally, some fail to appear at all but the majority show all sorts of contortions, some even pushing their roots up into the air with no sign at all of the young shoot. It was quite evident that many of these seedlings could not establish themselves and many died. Here, then, perhaps, was a new method of pre-emergence weedkilling. The following table shows how these compounds behaved when applied to ground infested with chickweed and groundsel.

Treatment	Rate lb/acre	Chickweed (Stellaria media) Plants/sq.ft.	Groundsel (Senecio vulgaris) Plants/sq.ft.
Control	–	4·4	2·8
2:4:6-tribromophenyl nitramine	10	0·1	0·7
	15	0·0	0·3
2-chloro-9-fluorenol-9-carboxylic acid	5	0·1	0·3
	10	0·0	0·0

Pre-emergence Weed Control Trial. Jealott's Hill.

Application date: 16 April 1952. Weed count date: 18 June 1952.

Similar control is achieved for a number of other weeds but, unfortunately these compounds possess very little selectivity and most crops which have been examined have also proved susceptible. These facts coupled with the intrinsic difficulties of pre-emergence applications have prevented these substances from reaching practical use. The link between upsetting the tropic response and behaviour of seedlings and possible herbicidal properties has been established and is worthy of much more research.

In December 1948 my colleagues at Hawthorndale drew my attention to the peculiar effect of trichothecin on the early seedling growth of cereals. Trichothecin is an antibiotic produced by Trichothecium roseum Link and was isolated in the I.C.I. Nobel Division Research Department at Ardeer (see Freeman & Morrison (12). The effects produced suggested to me an interference with the normal auxin relationships of the plant and so we examined the effect of trichothecin on the well known auxin of plants - β-indolylacetic acid, using one of the standard biological tests. The results are shown in the following table:-

Trichothecin ppm	β-indolylacetic acid. Ppm.			
	0	1	2·5	5
0	0	17	27	29
2·5	0	5	5	6
5	0	0	4	3
10	0	0	1	1

Effect of Trichothecin on β-indolylacetic acid response in Went pea test.

It is quite clear that trichothecin has markedly interfered with the action of β-indolylacetic acid. Now MCPA is also very active in this test so that a similar experiment with it was undertaken.

It is quite clear that trichothecin has markedly interfered with the action of β-indolylacetic acid. Now MCPA is also very active in this test so that a similar experiment with it was undertaken. Results are shown below:-

Trichothecin ppm	2-methyl-4-chlorophenoxyacetic acid (MCPA). Ppm.			
	0	1	2·5	5
0	0	15	17	14
2·5	0	5	6	5
5	0	0	2	2
10	0	0	0	0

Effect of Trichothecin on MCPA response in Went pea test.

Again it is evident that the action of MCPA has been inhibited and these effects were confirmed in other biological tests. These findings led to a new idea that it might be possible to protect a crop seedling by the use of trichothecin against the hormone weedkillers such as MCPA and 2,4-D. This idea was tested by soaking cress seed overnight in trichothecin solutions and then planting the seedlings out on agar media containing MCPA. Growth was assessed by measurement of root length.

Trichothecin ppm	Na MCPA. Ppm.			
	0	0·025	0·05	0·075
0	25·5	19·6	18·2	14·1
20	21·6	27·6	23·8	22·6
40	23·2	21·4	19·3	19·9

Effect of Trichothecin on MCPA effect on root length of cress seedlings

Unfortunately similar results have not been obtained in soil tests but these findings point to an entirely new approach to selective weedkilling. As well as looking for single compounds which kill weeds and leave the crop, we might now turn our attention to systemic substances which could be applied as seed dressings, by combine drilling or other means to protect the crop against a good non-selective weedkiller broadcast over the land. It is, of course, a far cry to the practical realisation of this suggestion but the way seems to be opening. Plant physiological knowledge of auxins, auxin inhibitors, auxin antagonists and auxin precursors in plants is advancing steadily and it is becoming more and more possible to devise experiments along these lines.

Finally I am often asked what are the chances of a new herbicide being found and one is bound to admit that over the last twelve years or so since the discovery of the so-called hormone weedkillers, the number of new herbicides unrelated to the phenoxyacetic acids, the phenyl carbamates or previously known herbicides, has been few and they are of limited use. Intensive search for new products is, however, proceeding in industry in this country and to an even greater extent in the U.S.A. Very large amounts of money are being spent by commercial concerns on both fundamental work and on screening tests for plant protection chemicals including herbicides; this latter is a job which they are in an unrivalled position to undertake. In 1952 Wellman (13) estimated that on average, of every 2000 chemicals examined one succeeded as an agricultural chemical and that costs chargeable for research and development against one successful agricultural chemical by a commercial firm might be more than 1½ million dollars. There are many criticisms which can be levelled at such broad generalisations as these and obviously they cannot be used to prophesy when the next outstanding weedkiller will be found. The point to be made is that alongside the excellent work being done in our academic laboratories, industry is also contributing its share.

References

1. BRITISH WEED CONTROL CONFERENCE, RECOMMENDATIONS SUB-COMMITTEE. (1953). Proc. Brit. Weed Control Conf., 427.

2. REPUBLIC OF IRELAND DEPARTMENT OF AGRICULTURE, (1950). J. Dep. Agric. Repub. Ire., 47, 143-6.

3. BLACKMAN, G. E. & TEMPLEMAN, W. G. (1938). J. agric. Sci., 28, 247-71.

4. RIEPMA, P. (1954). Landbouwvoorlichting, 11, 180-2.

5. BROWN, D. (1954). Bull. Bur. Past., Hurley, No. 42.

6. FREED, V. H. (1953). Proc. 5th Calif. Weed Conf., 83-7.

7. BLOUCH, R. FULTS, J. L. & THORNTON, B. J. (1952). Res. progr. Rep. W. Weed Control Conf., 22.

8. CAMBRIDGE SCHOOL OF AGRICULTURE, FARM ECONOMICS BRANCH. (1954). Fmrs' Bull., Camb., No. 16.

9. HOFFMAN, O. L. & SMITH, A. E. (1949). Science, 109, 588.

10. MENTZER, C. & NÉTIEN, G. (1950). Bull. mens. Soc. linn. Lyon, 19, 102-4.

11. JONES, R. L., METCALFE, T. P. & SEXTON, W. A. (1954). J. Sci. Food Agric., 5, 32-8; 38-43; 44-7.

12. FREEMAN, G. G. & MORRISON, R. I. (1949). Biochem. J., 44, 1-5.

13. WELLMAN, R. H. (1952). Agric. Chemic., 7, (9), 32-4, 137, 139.

DISCUSSION

Professor G. E. Blackman: One of Dr. Templeman's paragraphs started, "Perhaps the most dismal aspect of chemical weed control ...." Surely we should feel a little more optimistic about the progress that has been made in the last 12 years. If we assume that 100 million acres are sprayed annually and that there is a 10 per cent increase in yield due to spraying, then it would mean 10 million more acres of land each producing, let us suppose, ½ ton of food. Now if each ½ ton was worth only £5 we would have £50,000,000 worth of extra productivity by the result of one year's spraying. Further multiplication for the number of years of application will increase the figure even further.

It is quite true that there are a considerable number of less important weeds, which are not very easy to control with existing herbicides. However, the present general trend in cereal spraying suggests for example that oats can be sprayed in the 2 - 3 leaf stage, and this brings Polygonum aviculare and Mayweed under certain circumstances into the class of fairly readily controllable weeds, because MCPA and 2,4-D applied at the cotyledon stage kill or very largely suppress the growth of these species. I do agree with Dr. Templeman that we ought to think again about whether we want complete eradication or a very large degree of suppression, because with a large degree of suppression there will seldom be any seed production by the weed species, and what is more, if we insist on weed suppression rather than weed kill there is evidence that it is possible to use rather more toxic and less selective materials if total weed destruction is desired. Some of you may remember a diagram in a paper by Dr. Woodford (N.A.A.S. Quart. Rev. 9,1, 1950) on the relative merits of DNBP and its ammonium salt. DNBP is undoubtedly less toxic but more selective consequently in terms of economics it is better to use the less selective ammonium DNBP and decrease the concentration.

I am also greatly intrigued by Dr. Riepma's experiments but I think on the whole it would be only fair to leave comment until we have heard Dr. Riepma's paper.

Now this problem of what can be done to obtain some economic assessment of the value of the use of the growth regulator herbicides in grassland management. It is a theme I think I have heard before, if not from Dr. Templeman, then certainly from Dr. Holmes. My reaction is that if you are looking to us at Oxford to do that sort of work, we are not going to touch it at the moment, for the very simple reason that I, in my rather academic and may be over-precise attitude, don't believe that there are as yet any proper tools for measuring the productivity of grassland.

I agree that the use of herbicides to shift the balance of species is practicable and that the use of CIPC and IPC as illustrated by Dr. Templeman looks promising. May I remind him that about 1935, somewhere I think in Berkshire, when we were experimenting with sodium chlorate for the control of creeping thistle we did precisely the same thing; we shifted the balance in favour of white clover on some old worn out and ill-managed swards largely because the chlorate in small doses stopped the growth of the grasses to a much greater degree than it stopped the growth of the legumes.

In relation to 2,4,6-tribromophenyl nitramine, it is interesting to recall Professor Bennet-Clark's work where he showed that the horizontal movement of the rhizomes of Aegopodium were to a certain extent controlled by the balance between at least two hormone-like substances and that the carbon dioxide concentration could alter the response. It is true that our knowledge is advancing, but how far is our general knowledge on a broad physiological front advancing in explaining the action of auxin or auxin-like substances? Taking things by and large I think that there is a great deal more fundamental work to be done before we can pick out instances where we can point a physiological finger and say that that is where a new herbicide is coming from.

I have pleasure in thanking Dr. Templeman for opening this first session and giving us such a stimulating paper.

Mr. S. J. Willis: Shouldn't we look again at sulphuric acid and see whether we might not use it more than we're doing?

Dr. W. G. Templeman: The spectrum of weeds which sulphuric acid controls is very very wide. If the antipathy and antagonism of people to the use of such a corrosive chemical can be overcome, I am of the opinion that this acid might return to a wider use in our farming than it has at the present time.

The President: There seems to be a difference of opinion between Professor Blackman and Dr. Templeman regarding measuring the productivity of pastures. You seem to suggest, sir, that this last bulletin from the Commonwealth Bureau of Pastures and Field Crops had brought the thing a stage further, whereas I gather that Professor Blackman is extremely sceptical as to whether we are yet in a position to measure pasture productivity.

Dr. W. G. Templeman: I think the answer to the President's question is that Professor Blackman had his feet on the ground while I was coat-trailing hoping that in our private as well as our public discussions at this Conference something might be suggested which would help us on our way. It is true that it is difficult to devise a technique for experiments of this kind which does not require a whole research station. What is, I think, perhaps more important and I hoped it would be raised by someone, is whether this elegant experimentation is really necessary. Perhaps there is, in fact, sufficient information already available to permit the recommendation of weedkillers on grassland?

Dr. H. P. Allen: Is it not better to divide this question of pasture productivity and the use of weedkillers into two parts, the first dealing with the control of weeds in permanent pasture, which is the subject of recommendation, and the second concerning the newer subject of the control of weeds in temporary pasture, about which much less is known. I feel that the farmer who is satisfied that he must remove the weeds from his permanent pasture does not need to be further convinced of the benefits in augmented milk yield or live weight increase which will arise from the removal of those weeds - the fact that the weeds are there is, to him, enough reason for their removal. But the benefits of weed control in temporary pastures, where a young and rather susceptible ley is concerned, is not so well established. Surely it is here that research is required in order to determine the effect that even a temporary check of clovers might have on the productivity of such leys.

Professor R. L. Wain: In the experiments involving the Went pea test was the tricothecin inhibiting the indolylacetic acid and MCPA by an antagonistic effect or was the compound producing a toxic effect on the pea tissue?

Dr. W. G. Templeman: So far as I know and from the limited experimentation we have done, tricothecin does not seem to be a very toxic compound. In oat coleoptile tests and seedling root growth tests, the concentrations necessary to show any toxic effects at all seem to be rather high. I believe that the effect observed in the experiments I reported is a true inhibition.

CULTIVATIONS AND WEED CONTROL

PROFESSOR H. G. SANDERS, (University of Reading)

Anyone who has glanced at the programme for this Conference will have realised that I am the stooge of the party. It is now well established practice that at all conferences on herbicides there should be one such person and I have to admit to filling this role previously. As time goes on, however, it becomes a more and more difficult part to play. Ten years ago, few people realised the potentialities of herbicides and it was easy to carry a meeting along with one when urging that the control of weeds has always been an important part of good farming and was likely ever to remain so; a gracious acknowledgment that herbicides might be distinctly useful from time to time when a farmer got a bad infestation of a particular weed was usually made but that did not detract much from the general argument. But progress with herbicides has been so rapid in recent years that the old arguments are wearing a little thin and no-one would now take the lofty line that herbicides are merely the refuge of the inefficient farmer and that need for them betokens a low standard of farming. In venturing to draw your attention to - or, rather, to remind you of - other methods of controlling weeds, I am not to be taken as an opponent of herbicides; on the contrary, my chief grumble against these other people is that I can't keep up with them - it is a subject in which one always seems out of date.

There is really no need for me to apologise for talking of these other, less exciting, methods of weed control because as far as I know no-one has ever claimed that herbicides provide the complete answer, or indeed that they are ever likely to do so. Their cost militates against them, whilst the search for the perfect one that will kill every weed with no harm to any crop may prove lengthy. We should not, therefore, forget the tradition of clean farming, almost synonymous with good farming, built up by our forefathers.

First of all, I would put rotations. The mere fact of growing varying crops in successive years means that cultivations of different types are given at different times of the year. To cultivate similarly year after year is to invite trouble because there is bound to be some weed species that will revel in that particular programme; the simplest example of this is the appalling infestation of Black Grass (Slender Foxtail) which some heavy land farmers have built up in the past by concentration on autumn sown corn. As everyone knows, a simple method of controlling this weed is to go through the motions of preparing an autumn seedbed but not to sow, in order that the land may be ploughed after Christmas; this means a spring sown crop to follow, that is, a move in the right rotational way.

A decent rotation will bring a cleaning crop in turn to each field and I do not think we ought to under-value the long ley as a cleaning crop. Best of all I consider a mixture of cocksfoot and lucerne. It is real joy to grow this crop on a field which is infested with annual weeds. If it is sown on bare ground in early April the weeds come up with it in glorious profusion. The thing to do then is to bear the reproaches of one's neighbours for as long as possible - till at least the end of May before putting the mower over. With the possible exception of an infestation of chickweed, I cannot understand why anyone should want to spray a new lucerne ley - the mower is cheaper and more efficient. Having disposed of this crop of weeds, lucerne, with cocksfoot as a companion, (and that, I think, is an important proviso) will keep itself absolutely weed-free for 4 or 5 years. It is true of course that not all the weed seeds in the ground will die in that time, but some will and anyway a method of control which gives complete freedom from weeds for 4 years is not to be despised

Should the rotation include a fallow? A whole year with no crop to show for it certainly needs some justification but many heavy land farmers still resort to it and I am not at all sure they are wrong. The advantages of getting a good crumb structure, of releasing tied up plant nutrients and of having a field ready to sow at the end of the summer are very considerable and if only the weather is kind the weed-kill may be very good. A fallow does not necessitate many cultivations but it does require a certain degree of discrimination over the timing of operations and choice of implement. If the main weeds are couch and watergrass a cultivator may do most of the work after the initial ploughing and 3 or 4 strokes with this implement in June and July so timed as to ensure the thorough drying out of the clods will suffice; that is, until annuals start to come as the mould develops, when a plough again becomes necessary. But if creeping thistle is the main enemy cultivating is a mere waste of time. It makes me wild to walk behind a cultivator when thistles are about; it is almost uncanny how they worm their way around the tines and how happily established they remain after the implement has passed. For them the plough is the one and only answer. Not that this need be very frequent, because the thistle should be given some time to get going again and exhaust itself between the ploughings. I would say that three ploughings in the period June to September should suffice and the real cost to the farmer in these days of tractors is slight.

Much of the benefit of a full fallow can be got in a bastard fallow and on light land it should be unnecessary to sacrifice a whole year. The bastard fallow is usually taken after a silage or hay crop but now that we have the turnip fly under control it is possible to use the spring and early summer to kill annual weeds and still get nearly a full crop of kale or a full one of rape and Italian ryegrass. In this case, of course, the land should be ploughed for the winter so that there is plenty of mould for the seeds to germinate in during the spring. If the furrows are harrowed or cultivated in early April and perhaps twice more at intervals and the field is ploughed shortly before sowing the crop, very good control is obtained. Too much cultivation should I think be avoided lest valuable moisture be lost. If perennials, especially couch, are the main trouble monthly ploughings from February to July may be necessary.

Nowadays we rarely see a farmer dragging rubbish out of the ground and burning it. On the whole I think this is a good thing because it was generally directed at couch and watergrass and in many cases the couch rhizomes were broken, to multiply that scourge. This meant that after considerable labour the last state was worse than the first. A deep ploughing, possible on more soils than we used to admit, is a much better solution. It is of course important to get all the rubbish covered at least 10 inches deep but once that is done it can be forgotton. Deep ploughing has been known to bring up many weed seeds but the most common one exhumed is charlock, which is child's play to our herbicidal friends.

We sow crops earlier than we did 20 years ago. This applies I think to all crops and it is undoubtedly responsible for part of the increase in crop yields of recent years. Earlier sowing, however, makes weed control more difficult. It often precludes that pause to allow a crop of weeds to come, to be killed by the final seedbed preparation. Spring corn should certainly be sown as soon as the land can be worked in March and very few weeds can be expected to grow before then. But something can be done before sowing a root crop if the season is at all favourable. It is very good practice to complete the preparation of the seedbed for a root crop - to apply the fertilisers and do the final harrowing and rolling - and then to withhold the drill for a week or 10 days. In that time the field will not green over with weeds but scraping away half an inch of the surface soil will often reveal many white threads of sprouting weeds; these of course are in an extremely vulnerable stage and once over with broad shares running half an inch deep will effectively dispose of them. A light harrow may do the trick but the whole point is to avoid disturbing the soil to any depth; the object is to grow out and kill those that would come away with the sown seeds and so to give the latter a clean start.

The hoe is the cultivating implement most obviously designed to deal with weeds. But it does more than that. It produces a surface tilth and modern views on soil science seem to be getting ever more favourably disposed to this; a panned surface hinders the aeration of the soil which is necessary for the proper functioning of plant roots and more obviously, holds water for loss by evaporation. Up to the outbreak of the last war a fair proportion of corn crops - principally the winter wheat - was hoed and it was possible to make a good case for the use of the old-fashioned horse drawn hoe, the one that took a drill width at a time. Experiments at Cambridge showed a slight but significant increase in yield to follow this operation done in early spring; the increase was only 1 to 2 bushels per acre but that was ample to make it worth while. There are few of these implements in existence now and horses are becoming rare so that there is little point in urging an extension of the practice which might still prove economic. The effect of this hoeing was very similar to that of a small dressing of nitrogenous manure, which might be due to any of three things: the reduction of competition from weeds, the tearing off of superfluous tillers or the better aeration of the soil.

Hoeing is still an important operation in growing roots and likely to remain so. The standard of work is very dependent on the soil. On stoneless soils such as are to be found around the Wash, the tool-bar can be set up so that the blades run really close to the rows of young plants, leaving little more than an inch for the crop row, and if singling is to be done rapid and accurate hand work is possible. By contrast, the best that can be achieved on stony soil is deplorable; to set blades to run close to young plants is to murder a high proportion of them whilst the hand hoer is continually having his blades deflected by the stones he hits. But even in those conditions a surface tilth is obtained and I have never seen a good crop where the top of the ground has been panned for any considerable part of the early growing period. Quite apart from weed control, then, I hold that the early hoeings of root crops are necessary and once the surface tilth has been formed it is rarely lost by subsequent beating rain. Later hoeings have therefore only one advantage, weed destruction, and it is significant that experimental evidence of their benefit is lacking; indeed, it has been claimed that they are harmful since they cut roots of the crop plants which have by then spread across the rows. I think, however, that good farming requires that the late growing weeds shall be prevented from seeding.

Kale is a crop which can be cleaned very satisfactorily by spraying with sulphuric acid but that alone will not suffice as the only after-cultivation. Inter-row work is essential in the early stages as otherwise the little kale plants will never get to the stage where they can stand the spray nor will they grow in a soil with a hard, unbroken top.

Potatoes provide a magnificent opportunity for cleaning the land. For really first class work you must have the rows perfectly straight and equidistant along their length; otherwise you can't work close to the setts in the early stages, neither can you earth up properly without moving some of the established plants. Much can be done before the plants are through. The loose ridge thrown up at planting gives good germinating conditions over its surface and no very secure foothold for perennial weeds. The ridges should be harrowed down (and I prefer saddleback harrows for this) and earthed up again at least twice before the potatoes poke through. Unless late frosts are feared it is better to harrow just before they appear so that the plants may not be too leggy. Hand hoeing can be avoided altogether if a final harrowing is given when the potatoes are about 6 inches high. This is one of those jobs where you send a chap to do it and carefully avoid going near him all day - if you see him at it you are bound to stop him but, in fact, the potatoes suffer very little harm. On the other hand, there are usually plenty of weed seedlings coming on the summits of the ridges and these will perish.

On land in good condition these horrowings and earthings up together with stirrings between the ridges will produce a really clean crop with no hand work at all. On foul land a full crop of potatoes may be got together with much cleaning effect. There is, however, another result of these cleaning cultivations, a result of which the importance can scarcely be exaggerated. All this work leads up to a final ridge which is fat and full of mould. Sharp, triangular ridges are all very well in the early stages but when the crop bulks there must be a ridge 6 or 7 inches broad at its shoulders to hold a full crop of tubers decently covered and so protected from the light and from any blight spores that may be about. And of mould there must be plenty as otherwise the ridges will be liable to dry out; where the work has been properly done and good tilthy ridges produced it is very satisfying to scrape the surface of a ridge in a drought - there is ample moisture just beneath.

All this illustrates a point on which I would like to close. Cultivations are powerful as controllers of weeds but they have other objects as well; most of them would be necessary if there were no weeds there at all. At this Conference it is perhaps tactless to suggest that weed control is not the sole object of farming. Good cultivation, the skilful use of the right implement at the right time, is a part of good farming, and, like the other components, such as sound rotations and generous manuring so that crops may be heavy and smothering, it gives as a by-product very valuable control of weeds.

DISCUSSION

Professor J. Morrison: Having listened to Professor Sanders' very practical paper which he delivered in his usual racy style, I quite agree that he is an admirable stooge for this Conference and I venture to say that he will be in great demand at future Conferences such as this, provided, of course, that he doesn't show undue deterioration in the new spheres of higher administration which he is about to undertake. However, I don't think there's much danger of that.

In the light of Professor Sanders' paper I would like to make a few observations on this question of herbicides as opposed to good cultivations. We, in the north and in the west, always maintain, of course, that farming in the South of England is comparatively easy. Some of you might not agree with that, but I think you will agree that our weed problems are different from those that face the farmer in the drier districts. There's a very close correlation between rainfall and weed infestation; the higher the rainfall the greater the weed infestation and the more difficult it is to deal with the weeds by ordinary cultivations.

I agree entirely with Professor Sanders that field cultivations should always take first priority on our farms, but nevertheless, I do think that the farmer now has in addition a very potent means and a relatively easy means of weed control by the use of herbicides.

It has always struck me as one who is closely associated with farming that as the standard of farming improves, and there is no question that it is improving, we get a higher level of fertility and the weeds become a more acute problem. This applies especially to those weeds that are grass feeders. In districts of high rainfall, not only do the weeds get the upper hand despite what can be done in cultivations but at the same time we often find that we can't possibly get on to the land to carry out those desirable field cultivations that, Professor Sanders has mentioned.

Herbicides and field cultivation are complimentary and not in the least bit antagonistic to one another. Professor Sanders mentioned couch for which I believe herbicides will be the ultimate answer, especially in the northern areas where it is impossible to have a bare fallow or even a short term fallow. The same applies to other weeds, such as the dock which is becoming widespread. Perhaps I'm not up-to-date in recent developments in the destruction of dock, but I don't know a good method of getting rid of them especially the broad leafed type, other than by hand pulling. This is extremely costly and very laborious. Professor Sanders also mentioned rotations. They are undoubtedly very important but again we find that in many of the Northern areas there is a tendency to go back to grass. Whilst rotations are necessary for keeping land clean, the use of herbicides, even on grassland or in rotation farming does not limit the scope of the farmer. On the contrary it rather widens his scope and gives him further opportunity to keep his land clean and productive.

I would like to thank Professor Sanders for his very able paper so well delivered.

Mr. F. W. Morris: I think it is about time we introduced into this discussion a note of controversy. The people connected with herbicides have been accused from time to time of living in their own little Utopia. I just wonder if the boot is not perhaps on the other foot. For the last year or two I have always thought that this was probably the case; after hearing the first part of Professor Sanders' paper I was convinced that it was. There is only one yard-stick of measurement that I can see by which to choose as to which is right and which is wrong, and that is the cost of the operation and the return to the farmer. I was very pleased to hear about two thirds of the way through Professor Sanders' paper, when he jumped on the other side of the fence and advocated the use of the chemical for weed control, that he became very economically conscious. On the other hand, when he was belabouring the use of bare fallows - two or three ploughings, three or four cultivations - no costs or economics were mentioned at all.

I would like to ask him what it would cost the farmer today to carry out a bare fallow, using the ploughing and cultivations recommended, and taking into consideration the rent the farmer is paying and the loss in return from that field for the year. I would also like his views on what extra the farmer gets back the following year over and above what he would get back by controlling the same weeds by other methods.

Professor Sanders also mentioned that the combine harvester scatters the weed seeds over the fields; I would like to ask him if he has scientific proof of the importance of the combine harvester as a distributor of weed seeds. I have seen many fields where the weed seeds have already shed before the combine enters the field and I think we are apt to put a slur on the combine harvester when in actual fact that is not the case. Farmers are leaving their crops to get dead ripe, and quite rightly so as it improves the quality and the weight of the corn, but as a consequence the shedding of weed seeds takes place before the combine ever enters the field.

Professor H. G. Sanders: The combine harvester, of course, requires that you shall leave the corn longer in the field, about 10 days in the case of wheat, and in consequence a lot more weeds shed their seeds than when the same crop is cut with a binder. The fact that in the old fashioned method of farming you got a tremendous amount of weed seed in the chaff underneath the thrasher surely indicates that with the modern combine much more weed seed is now scattered in the field. I would think a proposition that a combine leaves weed seed on the field, which otherwise would not have been left there, was almost self-evident. I admit I rather threw that one in and I am not attaching too much importance to it. If, however, we do get rather more weed seeds on the top of the ground, it is an argument for the idea that we ought to do more stubble cleaning.

The question of fallow can be argued all night. I suppose the cost of the fallow is about the cost of spraying twice by contract-sprayer. If you have let the land get in rather a foul condition you cannot be so awfully sure of this spraying. I know there is just the right time and so on, but suppose you have a lot of cottage gardens all round the field and suppose you have a fortnight's high winds when you know you ought to be spraying. I admit that it is possible to argue whether a fallow is the right method for weed control or not. I am not prepared to say that every farmer ought to have a bare fallow in his rotation. But such a fallow may be necessary for the control of couch which as yet you cannot kill by herbicides. When you can kill this weed then perhaps we will talk again.

Mr. F. W. Morris: Professor Sanders is still not very precise about the cost of fallowing.

Professor Sanders: I said twice the cost of spraying by contract. I have paid as much as £3.10.0. an acre and £7 is just about right for the cost of a fallow.

Professor G. E. Blackman: I wonder whether there are really many experiments which show that the tilth produced by hoeing in a clean crop does in fact increase the yield. It is easy enough to put forward theories but there is probably just as much evidence to prove that the value of the hoe lies solely in weed destruction and has nothing to do with tilth. In the Honour School of Agriculture at Oxford one of our hardy perennial questions is concerned with the effect of rolling on crop production, and among the answers there is frequently the statement that on light land the value of rolling is to increase the carbon dioxide content of the soil such that it decreased the pH, increases the solubility of phosphates and therefore produces better growth of the crop. It is a theory which is against the hoe on chalk soils.

Professor H. G. Sanders: The worst of these academic people is that they will demand chapter and verse for anything and, of course, it is very difficult to give chapter and verse in this case. The obvious instance is to mention Korsmo's work in Norway. He produced very good evidence that there was something in the surface mulch quite over and above the weed effect, and admirable evidence to show that a surface mulch had a very considerable effect on crops like carrots and turnips. The experiments, although unreplicated, were repeated at many different places.

Mr. S. J. Willis: There is recent work by Swanson and Jacobson of the Connecticut Experimental Station (World Crops (1951), 3 ; 9 ; 345-8) which shows that under certain soil conditions it is possible, with surface cultivations in the absence of weeds to obtain an increase in yield.

Mr. H. Laurance: Professor Sanders still advises the use of cocksfoot as a companion grass to lucerne because of its ability to control weeds. I have used S 143 cocksfoot mixed with lucerne and I have found it to be a non-selective weed killer. The cocksfoot is so aggressive it kills lucerne even when sown at a seed rate of 3 lbs. per acre. Does Professor Sanders recommend that I go below 3 lbs. per acre on my heavy land?

Professor H. G. Sanders: First, Mr. Laurance is wrong to use S 143. He should use S 37 or S 26. Second, the balance between cocksfoot and lucerne is, of course, controlled by autumn grazing. Unless the mixture is grazed the cocksfoot may indeed control the lucerne, but if you graze about now (November 2nd) - our cows are busy grazing at the present moment - you can kill the cocksfoot right out if you like. We have had several leys which have gone into their fourth and fifth year as practically pure lucerne. It is the autumn grazing which controls the cocksfoot. If the ley is grazed properly it is possible to sow 6 lbs. per acre.

RECENT ADVANCES IN WEED CONTROL IN THE UNITED STATES

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I am greatly honoured to have been invited to participate in the second British Weed Control Conference. I am also grateful for the opportunity to see and learn more about the excellent and rapid weed control developments that have occurred recently in England.

The officers of the Association of Regional Weed Control Conferences and the officers of the four regional weed control conferences in the United States have asked me to extend to you their best wishes for a successful second British Weed Control Conference.

Losses Caused by Weeds

Weeds are among the greatest contributors to production costs on American farms. The losses caused by weeds on farms in the United States have now reached an estimated four billion dollars annually. These losses are estimated to equal the combined losses from insects and diseases and are second only to farm losses caused by soil erosion.[2]

Weeds compete with crops for water, light, and mineral nutrients. They increase the cost of labor and equipment, reduce the quality and quantity of farm and livestock products, harbor insects and diseases and impair the health of livestock and humans. One plant of common mustard (Brassica kaber) requires twice as much nitrogen, twice as much phosphorus, four times as much potassium and four times as much water as a well developed oat plant. The average cost of tillage on cultivated land is estimated at 16 percent of the value of the crop produced. If we assume that at least one half of the tillage required is due to the presence of weeds, it means that our farmers are losing 8 percent of the value of the products they produce annually.

The objectives of the national weed control program in the United States include, the reduction of losses caused by weeds, and the development of weed control technology which will result in increasing the efficiency of crop and livestock production.

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1. The author wishes to thank Drs. L. L. Danielson, R. D. Sweet, L. G. Holm, G. F. Warren and E. K. Alban for the use of their color slides on weed control in vegetable crops; Dr. Richard Behrens for slides on mesquite control and Mr. V. F. Bruns for slides on the control of aquatic weeds.

2. Losses in Agriculture - A Preliminary Appraisal for Review. Agricultural Research Service, United States Department of Agriculture. Washington, D.C. ARS-20-1 June, 1954.

Obviously it will not be possible to discuss all the aspects of the weed program in the United States, but an attempt will be made to review briefly the organization of weed control work in the United States and to discuss some of the advances that have been made in the research and extension phases.

The Organization of Weed Control

One of the most unique aspects of the science of weed control is the requirement for cooperative effort. The organization of weed work in the United States strongly reflects this basic need. Essentially, weed work involves a combination of federal, state, industrial and independent agencies participating in the research, regulatory, development, extension, and teaching phases of weed control.

In the United States Department of Agriculture, the responsibility for weed research and regulatory aspects is centered in the Agricultural Research Service while the extension phase is the responsibility of the Federal Agricultural Extension Service. The weed research in the Department is conducted in or coordinated by the Weed Investigations Section, Field Crops Research Branch, Crops Research, Agricultural Research Service (Fig.1 and 2).

The research program of the Weed Investigations Section includes studies on cultural, ecological, chemical, mechanical, and biological methods of controlling weeds. These methods of weed control are incorporated in four broad general projects including: (1) research on the evaluation of chemicals for their herbicidal properties, including studies on the factors affecting the efficiency of chemicals as herbicides, (2) research on the physiology and ecology of weeds, (3) research on weed control in cultivated crops, including field and horticultural crops on non-irrigated and irrigated lands and (4) research on weed control in pasture and rangelands and non-cultivated areas (Fig.2). The head of the Section and project leaders are responaible for developing the research program to be conducted in these four general projects. The research program is coordinated in the field by four regional research coordinators with regional headquarters as follows: (1) Northeastern region: New Jersey (regional headquarters), Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, Delaware, Maryland, and West Virginia, (2) Southern region: Mississippi (regional headquarters), Virginia, North Carolina, Kentucky, Tennessee, South Carolina, Georgia, Florida, Alabama, Louisiana, Texas, Oklahoma, Arkansas, and Puerto Rico, (3) North Central region: Missouri (regional headquarters), Ohio, Indiana, Illinois, Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Iowa, Wisconsin, and Michigan, and (4) Western region: Wyoming (regional headquarters), Washington, Oregon, California, Idaho, Nevada, Montana, Utah, Arizona, Colorado, New Mexico, and Hawaii (Fig.2). At present the research programme of the Weed Investigations Section involves cooperative investigations with 23 States and studies at eight locations that are federally controlled.

In addition to the investigations conducted in cooperation with State Weed Research programmes, the Section research programme involves cooperative herbicide evaluation studies with 39 chemical companies engaged in screening and herbicide evaluation studies.

The federal weed research programme is only one segment of a three way attack which includes well organized and effective weed research programmes being supported by some of the State Experiment Stations and by the chemical and equipment industries.

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AGRICULTURAL RESEARCH SERVICE

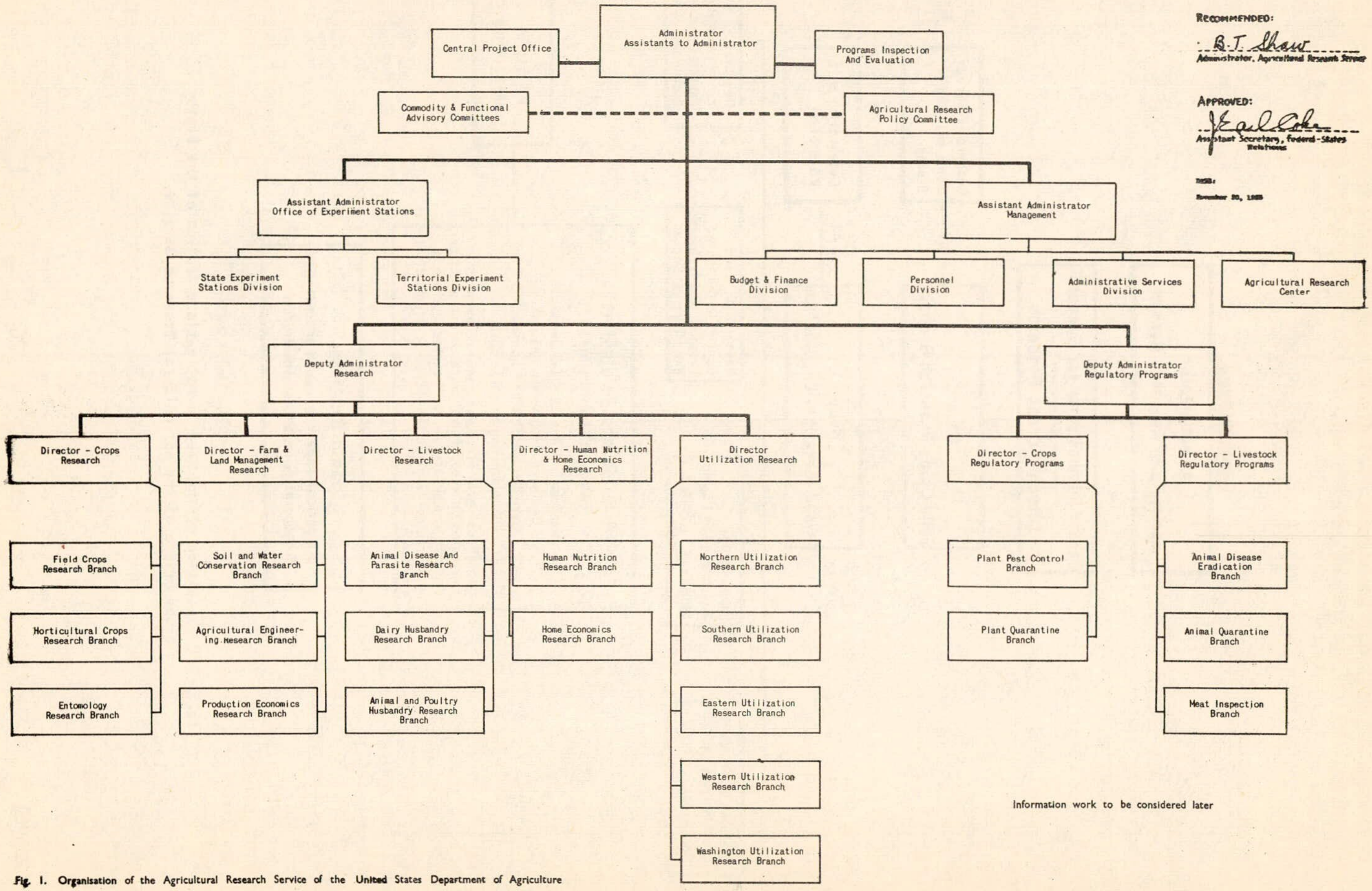


Fig. 1. Organisation of the Agricultural Research Service of the United States Department of Agriculture

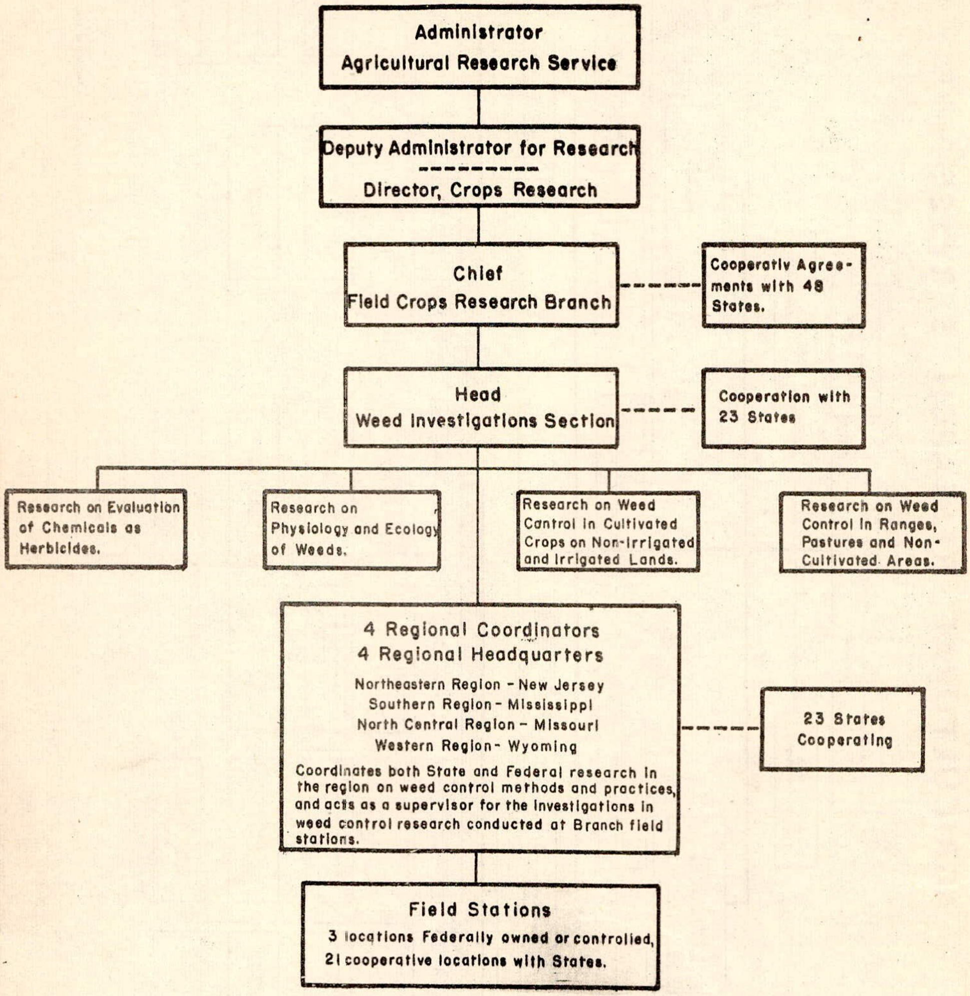


Fig.2. Organisation of the Weed Investigations Section of the Field Crops branch of the Agricultural Research Service.

The research, extension, and regulatory phases of the field of weed control are coordinated through the four regional weed conferences which meet annually. These include: The Southern Weed Conference, The Northeastern Weed Control Conference, The North Central Weed Control Conference and The Western Weed Control Conference. Personnel attending the conferences present the most recent advances in the field of weed control and formulate weed control recommendations on a regional basis. The four regional conferences have formed The Association of Regional Weed Control Conferences (ARWCC) which represents the interests of the regional conferences on matters of national interest. For example, the "Weeds" Journal and the First National Weed Control Conference were sponsored by ARWCC. Recently weed personnel have indicated considerable interest in forming a National Weed Society and some progress has been made in this endeavor.

Recent Advances In Chemical Weed Control Research

Many important advances have been made recently in cultural, mechanical, and biological methods of controlling weeds. Cultural practices are and always will remain important weed control techniques. Numerous weed research investigations and farm practice have shown that good clean seed is a sound starting point for any weed control programme. Thorough seedbed preparation, followed by clean, efficient, shallow, timely cultivation, has an extremely important place in weed control. There are no substitutes for proper fertilization and management of adapted species, varieties or hybrids of crop plants. Nevertheless the progress in the field of chemical weed control during the past ten years has been almost fantastic. Within this brief period, many new chemicals and new weed control techniques have been developed. Three of the most important developments in weed control in the past decade were the discovery of the herbicidal properties of the phenoxy compounds, the introduction of pre-emergence weed control and the development of the technique of low gallonage application.

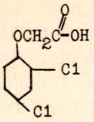
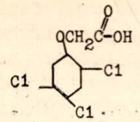
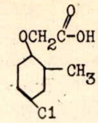
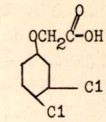
These discoveries have had a profound effect on the entire scope of and accomplishments in the field of weed control. For this reason I would like to discuss briefly the scope of chemical weed control research in the United States and some of the accomplishments that have resulted from these investigations.

Screening and Evaluation Studies With New Herbicides

The screening, evaluation, and development of new agricultural chemicals as herbicides in the past ten years in the United States has occurred at a rate which has exceeded the imagination. Most of the credit for these developments is due to an efficient forward thinking Chemical Industry working in close cooperation with Federal and State research agencies. Not all the discoveries have been made by industrial scientists, but regardless of where the activity of such products is discovered it eventually becomes the responsibility of industry to manufacture them.

Quite aside from empirical screening are herbicide evaluation studies which involve fundamental, systematic studies of families of compounds or closely related compounds to determine the relation between molecular structure and herbicidal activity, including studies of the properties of chemicals and other factors affecting herbicidal efficiency. In the United States, scientists have looked largely to the chemical industry as a source of these compounds. The good relations, mutual respect, and confidence that have developed has provided the primary impetus in the rapid development of herbicides.

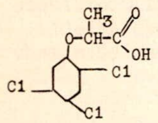
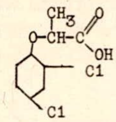
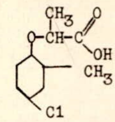
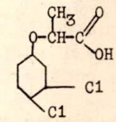
A - The Phenoxyacetic Acids

2,4-D (1944) | 2,4,5-T (1948) | MOP (1949) | 3,4-D (1953)

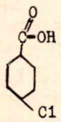
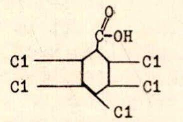
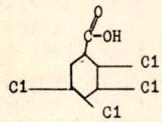
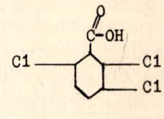
Changes in Molecular wt. = 221 300 600 900

B - The Phenoxypropionic Acids

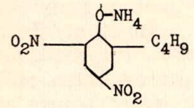
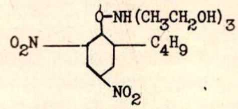
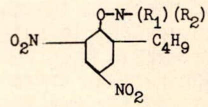
2,4,5-Trichlorophenoxy-propionic acid (1952) | 2,4-Dichlorophenoxy-propionic acid (1954) | 2-Methyl-4-chlorophenoxy-propionic acid (1954) | 3,4-Dichlorophenoxy-propionic acid (1954)

C - The Benzoic Acids

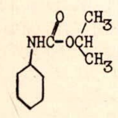
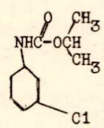
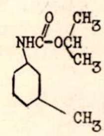
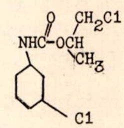
p-Chlorobenzoic acid (1942) | Pentachlorobenzoic acid (1951) | Tetrachlorobenzoic acid (1952) | 2,3,6-Trichlorobenzoic acid (1954)

D - The Dinitro Compounds

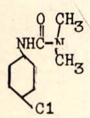
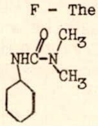
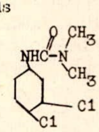
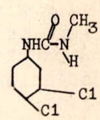
Ammonium DNOSBP (1944) | Triethanolamine DNOSBP (1948) | Alkanolamine DNOSBP (1950)

E - The Carbamates

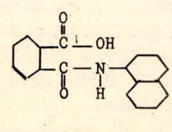
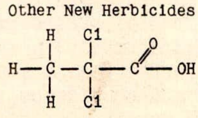
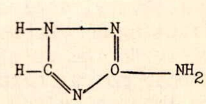
Isopropyl N-phenyl carbamate (1944) | Isopropyl N-(3-chlorophenyl) carbamate (1950) | Isopropyl N-(3-methylphenyl) carbamate (1952) | 2-(1-Chloropropyl)N-(3-chlorophenyl)-carbamate (1953)

F - The Urea Compounds

3-(p-Chlorophenyl)-1,1-dimethylurea | 3-(Phenyl)-1,1-dimethylurea (1952) | 3-(3,4-Dichlorophenyl)-1,1-dimethylurea (1953) | 1-(3,4-Dichlorophenyl)-3-methylurea (1953)

G - Other New Herbicides

N-1 Naphthyl phthalamic acid (1952) | 2,2-Dichloropropionic acid (1953) | 3-Amino-1,2,4-triazole (1953)

Fig. 3. Trends in the Development of Herbicides.

Another stimulus to herbicide evaluation and development research has resulted from studies designed to develop equipment and techniques for the application and evaluation of chemicals as herbicides. Much progress has been made in this field and much additional work is needed.

We are tending to use more herbicides and to use specific herbicides for the control of specific weeds in specific crops. The present demands of a new herbicide necessitate that careful consideration be given to all factors affecting the specificity and selectivity of a particular chemical. The rate of development and some of the trends in the development of herbicides are presented in Fig.3.

The phenoxyacetic and phenoxypropionic acids. The use of these chemicals for the control of broadleaved weeds in tolerant grasses and other plant species as post-emergence sprays and for the control of annual grasses and weeds in tolerant crops as pre-emergence sprays has increased at a rapid rate. Recent studies have shown that the propionic acids may add a great deal of selectivity and specificity to that already possible with the phenoxyacetic acids. In addition to 2,4-D, 2,4,5-T, MCP and 3,4-D, the 4-chlorophenoxy and 2,5-dichlorophenoxy acetic and propionic acid derivatives also show promise as herbicides. (Fig.3A and 3B)

The benzoic acids. These compounds have been studied intensively for their growth regulating properties since 1942. The herbicidal properties and persistence of these compounds in soils have been of considerable interest to weed research workers interested in pre-emergence weed control. In recent preliminary studies, 2,3,6-trichlorobenzoic acid has shown promise as a residual pre-emergence herbicide for weed control in corn (*Zea mays*), and sorghum (*Sorghum vulgare*). These compounds appear to be more persistent and less likely to leach in soils than are the phenoxy type compounds. For these and other reasons, this family of compounds is expected to contribute greatly to the versatility of the pre-emergence chemical attack on weeds. (Fig.3C)

The substituted phenols. The dinitro alkyl phenols and chloro substituted phenols have been used widely as contact selective and non-selective post-emergence herbicides. More recently they have been developed as pre-emergence herbicides for use in a number of large seeded crops including cotton, peanuts and soybeans. Many studies have shown that these compounds are essentially contact, non-translocated herbicides, but very little additional information was available on the basic effects of these chemicals on plant growth until recently. As illustrated in figure 3D emphasis has been placed on selectivity, specificity, lower phytotoxicity, and lower vapour activity in the successive development of the ammonium, triethanolamine, and alkanolamine salts of dinitro ortho secondary butyl phenol. More fundamental research is needed to understand more fully the effects of this group of chemicals on plant growth.

The carbamates. The substituted N-phenyl carbamates have exhibited a high degree of selectivity and specificity as herbicides. This high degree of specificity and selectivity has led to their wide scale use as post-emergence sprays for the control of annual grasses in legume crops, and more recently as pre-emergence treatments for weed control in cotton, vegetables, and other crops. Recent studies indicate that isopropyl N-(3-methylphenyl) carbamate, 2-(1-chloropropyl) N-(3-chlorophenyl) carbamate (Fig.3E) and other derivatives in addition to isopropyl N-phenylcarbamate (IPC) and isopropyl N-(3-chlorophenyl) carbamate (CIPC) possess important herbicidal properties. As indicated in Figure 3E the trend in the development of the carbamates has been to develop low volatile derivatives with a high degree of selectivity and specificity.

The substituted ureas These compounds, represented at present by 3-(p-chlorophenyl)-1, 1-dimethylurea, 3-(phenyl)-1, 1-dimethylurea, 3-(3,4-dichlorophenyl)-1, 1-dimethylurea, and 1-(3,4-dichlorophenyl)-3-methylurea are among the most promising new pre-emergence herbicides and soil sterilants that have been introduced in the field of weed control. The urea herbicides are the first group of organic chemicals having sufficient stability and residual effect in the soil to be used as soil sterilants. As a group these compounds are valuable new tools for the attack on weeds on non-agricultural lands. However, much more must be learned about their fate in the soil before they can be recommended widely, especially as pre-emergence herbicides on crop land. (Fig.3F).

Other new herbicides. Some of these include N-1, naphthyl phthalamic acid, 2,2-dichloropropionic acid, 3-amino-1,2,4-triazole and there are others. The phthalamic acids have shown promise as pre-emergence herbicides for weed control in cucurbits and other crops. The new herbicide 2,2-dichloropropionic acid is a methylated derivative closely related to trichloroacetic acid. However, unlike trichloroacetic acid it appears to be readily translocated downward when applied to the leaves of certain grasses. It also has shown promise as a pre-emergence herbicide in a number of crops. Another new herbicide, 3-amino, 1,2,4-triazole is translocated in certain monocots and grasses, and inhibits chlorophyll production in a number of species. This compound shows promise as a post-emergence spray for the control of grasses, as a pre-emergence spray for the control of weeds in several crops, and as a fortifying agent in general weed killing sprays on industrial areas. A versatile compound, it is also being used for cotton defoliation.

Herbicide Development Trends

For the first time we now have chemicals that may be applied successfully at low dosages, in low carrier volumes, and at low pressures as preplanting, pre-emergence, post-emergence and soil sterilant treatments. A review of the development trends presented in figure 3 indicates clearly that we are tending to use an increasing number of herbicides. More and more we are using specific compounds for the control of specific weeds in specific crops.

In attempting to provide the specificity and selectivity demanded, the most active derivative in a family of compounds is usually the starting point. In progressive developmental steps, the structure of the compound is continuously changed in the process of balancing herbicidal activity, herbicide volatility, residual activity, and selectivity. The final objective being a compromise resulting in a compound with a molecular configuration which permits the desired degree of activity, selectivity, and residual properties. For instance in the development of the phenoxyacetic acids, the molecular weight of these compounds has varied from 221 to over 900. The new low volatile esters with molecular weights of the range 400 to 600 represent a compromise. The butyl ester of 2,4-D, due largely to its molecular size (mol. wt. = 277.0) penetrates readily, is readily translocated, is highly active, but is also volatile under high temperatures. The property of volatilization does not materially reduce the initial effectiveness (it may increase it) of this compound for controlling annual weeds under moderate temperatures. However, as a pre-emergence herbicide and for the control of perennials where long sustained activity is needed under high temperature conditions a less volatile 2,4-D derivative may be needed. The heavier molecular esters such as the propylene glycol butyl ether ester and others, even though they possess lower initial in vitro activity due to their increased molecular size and thus reduced absorption rates, appear to be more effective under conditions favoring volatility because of their lower vapor activity and thus greater persistence on plant and soil surfaces.

The pattern followed in the development of the carbamates has closely followed the phenoxyacetic acids. Isopropyl N-phenylcarbamate has been used to only a limited extent in the United States because of its high volatility. Isopropyl N-(3-chlorophenyl) carbamate is approximately 25 percent less volatile and possesses a much greater residual activity. A new carbamate, 2-(1-chloropropyl) N-(3-chlorophenyl) carbamate is 80 percent as active as isopropyl N-(3-chlorophenyl) carbamate and 80 percent less volatile. These slight changes in structure have greatly changed the performance of these compounds as herbicides. Similar trends are occurring in the development of other groups of compounds in Figure 3.

The Relationships Between Molecular Structure and Herbicide Activity

Intensive studies on the relationship of chemical structure to absorption and translocation, mechanism of action, plant metabolism, plant composition, volatility, and total herbicidal activity have revealed many important correlations which are being used to guide the future synthesis and development of new herbicidal compounds. These investigations have not provided the many answers needed to enable the chemist to practice the systematic synthesis of new herbicides or to predict with confidence the structures that will produce the desired degree and type of activity. This is not to imply that we have not made progress. To the contrary, considerable progress has been made in establishing guides to a more systematic synthesis of active compounds within families of chemicals or closely related derivatives.

Methylation appears to be important in the translocation of several compounds. Sodium trichloroacetate is toxic to most grasses when applied to the soil and absorbed through the roots, but its downward translocation when applied to the leaves of grasses occurs very slowly if at all. A closely related compound, 2,2-dichloropropionic acid, which contains a methyl group substituted for a chlorine atom appears to be translocated downward when applied to the leaves of perennial grasses. Isopropyl N-phenylcarbamate is not readily translocated downward when applied to the leaves of barley seedlings. A closely related analogue, a-carboxyethyl N-phenylcarbamate containing a methyl substitution on the alpha carbon of the side chain appears to be translocated downward when applied to leaves of barley.

Methyl substitutions in the 2 position in the ring of the phenoxyacetic acids and in the 3 position of the ring of N-phenylcarbamates decreases the toxicity of these two groups of compounds to certain broadleaved species. Isopropyl N-(3-methylphenyl) carbamate is less toxic to ragweed (Ambrosia artemisiifolia), lambsquarter (Chenopodium album), sugar beets (Beta vulgaris) and other dicots than isopropyl N-(3-chlorophenyl) carbamate, while 2-methyl-4-chlorophenoxyacetic acid is less toxic to flax (Linum usitatissimum) and red clover (Trifolium repens) than 2,4-dichlorophenoxyacetic acid. Many other examples could be cited. Nevertheless, inadequate fundamental information in this field is a serious handicap to the synthetic chemist who must rely largely on empirical screening of chemicals to accomplish the desired activity. It is a time consuming, inefficient, frustrating, costly approach to an old problem that requires much additional research.

Absorption and translocation, mechanism of action, effect on plant metabolism, effect on the chemical composition of plants and herbicide volatility are all inextricably associated and related to one or more aspects to chemical molecular configuration. It is a failure to understand the basic concepts of chemical structure and activity that has made the progress tedious and slow in our understanding of the related factors affecting herbicidal activity.

We now know that we cannot speak intelligently of absorption and translocation or mechanism of action as collective entities. We must study the absorption, translocation, and mechanism of action of specific chemical molecules in or on specific plants.

Effect of Some Soil Properties on the Activity of Herbicides

Many investigations have been conducted to determine the fate of herbicides in various soils in the United States. In general these studies have clearly demonstrated that chemicals may (1) be absorbed by soil particles, (2) be leached through and past the root zone, (3) be decomposed by soil micro-organisms, (4) volatilize from soil surfaces and be dissipated in the vapour state and (5) be inactivated as a result of chemical reactions in the soil.

In a medium so complex as soil it is extremely difficult to summarize the effects of the many soil properties on the activity of herbicides on various soil types. An attempt has been made to indicate the effect of several soil properties on the activity of herbicides in Figure 4. In general in the United States, the highest activity per unit of herbicide applied pre-emergence is obtained on a sandy soil low in organic matter, with a low pH and a high moisture content. The lowest activity per unit of herbicide applied pre-emergence on a sandy soil occurs on a sand high in organic matter with a high pH and low moisture content. The lowest activity per unit of herbicide applied pre-emergence is obtained on a clay soil high in organic matter, with a high pH and a low moisture content. The highest activity per unit of herbicide applied pre-emergence on a clay soil occurs on a clay low in organic matter, with a low pH and high moisture content (Fig.4).

This scheme of classifying herbicidal activity on the basis of soil type, as influenced by other soil properties, must be interpreted as a general method of summarization. Exceptions to these generalizations are known to exist. For instance pH is known to have little or no influence per se on the activity of some herbicides. Herbicidal activity as influenced by soil properties is greatly altered when volatile herbicides are considered. The volatilization of herbicides as influenced by temperature is one of the few single factors that has sufficient effect to outweigh the influence of organic matter, pH and moisture effects (Fig.4).

Advances in Chemical Weed Control Practices

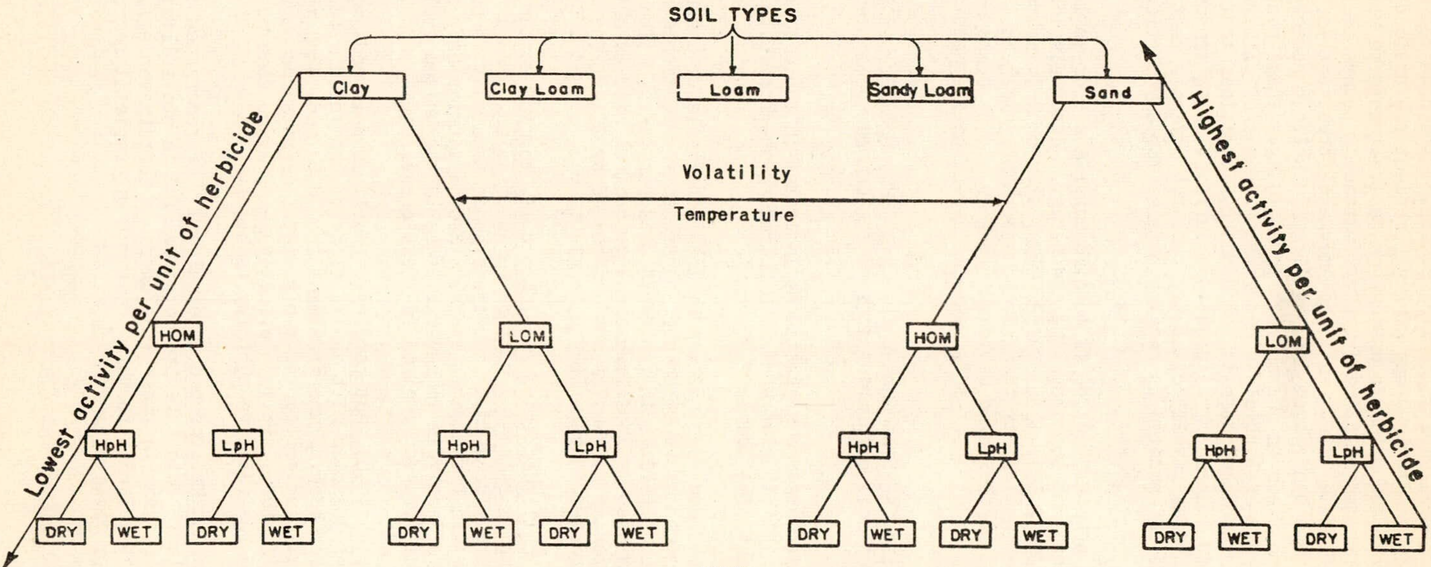
The weed control practices described in Table 1 are an indication of the emphasis being placed on chemical weed control in field crops in the United States. Every weed control practice listed has been developed within the past 10 years as efficient, economical methods, in competition with and supplementary to the best cultural weed control practices that have been developed.

These practices have been listed to indicate some of the advances being made in weed control practices in field crops in the United States. They should not be interpreted as recommendations for any particular region in the United States since it must be recognized that many factors which vary from region to region have pronounced effects upon the results obtained from the application of herbicides.

Weed Control in Horticultural Crops

The advances in weed control practices in horticultural crops have in many respects been more outstanding than the weed control developments in field crops. Vegetable crops in particular are usually grown in specialized areas

Fig. 4 - The Effect of Some Soil Properties on the Activity of Herbicides



INDEX

L = Low	HpH = High pH
H = High	DRY = Low moisture content
OM = Organic matter	WET = High moisture content
LpH = Low pH	

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to take advantage of the extremes in growing season. The chemical weed control recommendations in vegetable crops strongly reflect the basic differences in the response of crops and weeds to pre-emergence treatments on various soil types and under the extremes of climate. For instance 2 pounds of isopropyl N-(3-chlorophenyl) carbamate (CIPC) as a pre-emergence treatment is used to control weeds in onions on a sandy loam soil in Virginia while 8 pounds are required to kill the same weeds on a muck soil in Indiana. These real differences in the performance of herbicides under the extremes of climate and soil make it impossible to recommend chemical weed control practices that would apply generally in the United States. The practices outlined below are only an indication of the practices developed and the research advances that have been made and should not be interpreted as recommendations for any particular region or section in the United States.

Asparagus. The most common practice is to disc asparagus beds to loosen the soil, destroy the weeds, and to remove the old ferns. After discing and prior to spear emergence, 2,4-D, SES, TCA, DNOSBP, CIPC, CMU, or N-1 naphthylphthalamic acid or combinations of these compounds as pre-emergence treatments may be used to control broad-leaved weeds and grasses. The compound or combinations of compounds and the rates to use will depend on the weed problem, soil type and other factors.

After harvest, disc the beds and apply 2,4-D, SES, DNOSBP, CIPC, CMU, or N-1 naphthyl phthalamic acid or combinations of the compounds as pre-emergence treatments.

Beans. The same treatments are suggested as indicated in table 1 for soybeans. In some areas PCP is also used as a pre-emergence herbicide for weed control in snapbeans and lima beans.

Beets. TCA, PCP or IPC and combinations of these chemicals or these compounds in combination with endothal are being used as pre-emergence treatments. TCA is the most widely used herbicide in red beets or sugar beets. The combination treatments are usually used in localized areas to control wild oats (Avena fatua) and several broadleaved species not controlled by TCA. The same chemical combinations are being used in sugar beets. table 1.

Cabbage, cauliflower, collards, kale, rape, broccoli, turnip, mustard, lettuce, and in general, vegetables belonging to the genus Brassica. When these crops are direct seeded, TCA may be used as a pre-emergence treatment to control annual grasses and certain broadleaved weeds. Recent studies have also shown that CIPC may be used effectively in several areas in the United States as a pre-emergence treatment for weed control in these crops.

Carrots, celery, dill, parsnips, and parsley. Small annual weeds may be controlled on muck and upland soils with applications of undiluted stoddard solvent at 80 to 100 gallons per acre. The treatment should be made when the weeds are two to three inches tall and before the tap roots of carrots and parsnips are more than ¼ inch in diameter. Maximum effectiveness may be obtained when air movements are down and the relative humidity is high.

Cantaloupes, cucumbers, muskmelons and watermelons. Pre-emergence treatments of N-1 naphthyl phthalamic acid have proven successful in controlling annual broadleaved weeds and grasses in these vine crops. Certain varieties of pumpkins and squash are not tolerant to this treatment and varietal responses should be known prior to large scale use.

Onions. For pre-emergence weed control, stoddard solvent at 40 to 80 gallons per acre, a 3 to 5 per cent solution of sulphuric acid at 100 gallons of water per acre, or CIPC at 2 to 8 pounds per acre may be used. The chemical and rate of application will be determined by the soil type and the weeds present.

For post-emergence weed control after the first true leaf of onions is at least two to three inches long (loop stage), a post-emergence spray of two to three per cent sulphuric acid at 100 gallons per acre or potassium cyanate at 12 to 16 pounds in 50 to 100 gallons of water is suggested.

For weed control in onions in the five leaf stage and after the last cultivation when the onions are being or have been "laid by" and are bulbing, basal directed post-emergence treatments applied so as to avoid hitting the tops of the onion plants are suggested. A three to four percent sulphuric acid solution in water at 100 gallons per acre, potassium cyanate at 16 to 20 pounds, CIPC at 2 to 8 pounds, DNOSBP at 1 to 2 pounds or CMU at 2 pounds in 50 to 100 gallons of water per acre is suggested. The chemical and rate of application to use will be determined by the weeds present, the soil type and the stage of growth of the onions and the weeds.

Potatoes. For pre-emergence weed control following blind cultivation prior to the emergence of the potatoes, DNOSBP at 3 to 6 pounds, PCP at 10 to 20 pounds, TCA at 8 to 10 pounds, 2,4-D at 1 to 2 pounds and CMU at 1 to 2 pounds in 20 to 50 gallons of water per acre may be used for the control of annual weeds. For the control of weeds following the last cultivation, SES at 3 pounds in 40 gallons of water per acre should be applied immediately following the last cultivation.

Brambles. Weeds that grow in brambles grown in the hedge or linear system are difficult to control with mechanical implements. Suitable mulches will aid in reducing the weed problems but mulching costs are usually high. The bramble crops are tolerant to a number of herbicides. For the control of weeds in early spring, SES at 3 pounds, 2,4-D at ½ to 1 pound, or DNOSBP at 2 to 4 pounds in 20 to 40 gallons of water per acre should be applied prior to emergence of the weeds or new canes. The second application should be delayed until the new canes are tall enough to permit a directed basal application so as to avoid getting the spray on the cane tips. SES must always be applied to the soil before weeds emerge or if weeds have emerged the seedbed must be clean cultivated before treatment. All other basal directed sprays should be applied when the weeds are small.

Grapes. For the control of weeds beneath the trellis, treatments with oil-water emulsions of DNOSBP, PCP, CIPC and mixtures of CIPC and DNOSBP have proven effective. A mixture consisting of 6 pounds of CIPC plus 2 pounds of oil soluble DNOSBP in an oil (20 gals)-water (80 gals) emulsion at 100 gallon per acre has given excellent control of emerged grasses and broadleaved weeds. The contact action of DNOSBP kills the emerged annuals and the CIPC provides residual pre-emergence weed control. The spray treatment should be directed so as to avoid the grape trunks as much as possible.

Strawberries. For weed control on a full year basis, pre-planting treatments of DNOSBP at 8 to 10 pounds or CIPC at 4 to 8 pounds per acre followed by post-planting treatments of SES as needed (30 day intervals) will give good control of weeds in strawberries from planting until fall dormancy. Cultivation should precede each SES treatment until runner production limits cultivation. For fall and winter weed control when strawberries are dormant, DNOSBP at 1 to 2 pounds and CIPC at 2 to 4 pounds in 40 gallons of water will give excellent control of winter annual broadleaved weeds and grasses. For the control of

TABLE 1

Recent Advances in Chemical Weed Control Practices in Field Crops

Crop and Time of Treatment	Chemical, Rate Per Acre, and Volume of Application	Weeds that are Controlled	General Comment
Corn and Sorghum Pre-emergence	2,4-D ester: 1½ to 2 pounds in 20 gallons of water	Annual grasses and annual broadleaved weeds such as crabgrass, foxtail, ragweed, pigweed, lambsquarter, etc.	Use lower rates on loam soils. Treatment not advised on light sandy soils. Dry weather following treatment may reduce effectiveness. Excessive rain creates hazard to corn.
Post-emergence: Corn 4 to 24 inches tall	2,4-D: ¼ to ½ pound in 5 to 20 gallons of water. Use esters at lower rates than amine salts.	Ragweed, pigweed, lambsquarters, field bindweed, morning glory, cocklebur, etc.	Plants may be injured if sprayed within a week after leaves unfold. Brittleness and breaking increases as plants get taller. Cultivation or wind immediately after treatment may increase injury. Some hybrids more susceptible than others.
Post-emergence: Corn more than 24 inches tall. Directed lay by sprays immediately after last cultivation.	2,4-D amine: Use directed spray from drop nozzles. ½ pound on bases of corn stalks and weeds in the row. 1½ pounds on area between rows.	Broadleaved weeds growing in association with the corn in the row and pre-emergence control of annual grasses and broadleaved weeds between the rows.	Treatment especially valuable in river bottom fields where weeds become serious between lay by and harvest. Nozzles may be arranged so that both rates of 2,4-D are applied at the same time.
Sweet Corn Pre-emergence	2,4-D amine: Same as for field corn.	Same as for field corn.	Same as for field corn.
	DNOSBP amine: 6 to 8 pounds in 10 to 20 gallons of water PCP or its sodium salt: 8 to 16 pounds in 10 to 20 gallons of water.	Annual broadleaved weeds and grasses	Heavy rains following application create a hazard to corn.
Post-emergence	Same as for field corn.	Same as for field corn.	Same as for field corn.

TABLE 1

(Continued - 2)

Crop and Time of Treatment	Chemical, Rate Per Acre, and Volume of Application	Weeds that are Controlled	General Comment
Cotton Pre-emergence	CIPC: 1½ to 3 pounds sprayed on soil behind packer wheel at planting time to completely cover 12 to 14 inch band packed by wheel. Complete coverage applications desirable but cost more. Use lower rate on sandy soils.	Will control most annual grasses and most broadleaved annual weeds for 3 to 6 weeks. Less effective on certain broadleaved weeds than DNOSBP. Does not control perennial weeds.	Some injury may be expected from CIPC if heavy rains follow application. Enlarged hypocotyls as result of CIPC injury more susceptible to infection by disease organisms. Weed control reduced by temp. of 90°F immediately after planting.
	DNOSBP, amine salts: 1½ to 3 pounds on a 14 inch band. Same method as for CIPC. Use lower rate on sandy soils.	Will control most annual grasses and broadleaved weeds for 3 to 6 weeks. Less effective on certain grasses than CIPC. Does not control perennial weeds.	Vapors from DNOSBP will injure or kill cotton seedlings if temperature exceeds 85°F for 3 straight days after plants come up. Do not use when such temperatures are likely to occur. Excessive rains after treatment increase the chance of injury.
Post-emergence directed sprays. Apply 3 treatments at least 5 days apart beginning when weeds are in the seedling stage.	Non-fortified herbicidal oils; apply with directional spray so 2 fan-shaped patterns, horizontal to ground are directed across row so cotton foliage is not contacted. Apply no more than 3 treatments 5 days apart. Fortified herbicidal oils. Follow recommendations of manufacturer.	Control both annual grasses and broadleaved weeds but not perennials.	Most herbicidal oils should not be applied after bark cracks begin to form. Oils are less efficient when foliage is wet. Nozzles must be set properly to avoid injury to cotton or failure to control weeds.
Soybeans, peanuts, snap beans and lima beans Pre-emergence	DNOSBP, amine salts: 6 to 10 pounds in 10 to 40 gallons water. Use lower rates on soy-beans and snap beans on sandy soils.	Annual grasses and broadleaved weeds such as crabgrass, foxtail, pigweed, lambsquarter, morning glory, cocklebur and others. Perennial weeds not controlled.	Injury to soybeans and snapbeans may occur if heavy rains follow application prior to crop emergence.

TABLE 1

(Continued - 3)

Crop and Time of Treatment	Chemical, Rate Per Acre, and Volume of Application	Weeds that are Controlled	General Comment
Wheat, Oats and Barley Fall seeded: Post-emergence - When cereals are fully-tillered 4 to 8 inches tall. Do not treat in seedling or boot stage.	2, 4-D or MCP: 1/4 to 1/2 pound in 5 to 20 gallons of water. Use esters at lower rates and amines at higher rates.	Ragweed, vetch, mustard, wild radish, yellow rocket and other broadleaved weeds.	If cereals seeded to legumes a canopy of growth should be allowed to develop prior to treatment. Use only amines of 2,4-D or MCP. A reduction in stand and vigor of legumes may result. All legumes are sensitive to 2,4-D and most may be injured by MCP.
	DNOSBP, amine salts: 3/4 to 1 pound DNOSBP in 30 to 50 gallons of water if cereals seeded to legumes.	Yellow rocket, ragweed, mustard, lambsquarters.	
Wheat, Oats and Barley Spring seeded: Post-emergence - when cereals are fully tillered and 4 to 8 inches tall. Do not treat in seedling or boot stage.	2,4-D or MCP: same as fall	Same as fall seeded cereals	Same as fall seeded cereals
	DNOSBP: same as fall seeded cereals	Same as fall seeded cereals	Same as fall seeded cereals

TABLE 1

(Continued - 4)

Crop and Time of Treatment	Chemical, Rate Per Acre, and Volume of Application	Weeds that are Controlled	General Comment
Ladino clover or white clover - grass mixtures Post-emergence in late spring or summer, depending on the stage of weed growth and tolerance of clover. Young weeds are more easily killed.	2,4-D, ester or amine: ½ to 1 pound in 5 to 20 gallons of water per acre.	Curled dock, bitterweed, pigweed, chicory, burdock, dandelion, Canada thistle, wild onion and wild garlic (3 years with at least one treatment each year necessary for control).	Chemical weed control is not a substitute for fertilization and management of adapted pasture species. Don't spray more than 1/3 of pasture area at one time. Carrying capacity will be temporarily reduced. Don't spray seedling Ladino or white clover.
Alfalfa - grass mixtures Post-emergence - fall or winter. Seedling alfalfa - 3 to 6 inches tall.	DNOSBP, amines: 1 to 1½ pounds in 20 to 40 gallons of water.	Chickweed, henbit, vetch, ragged robbin, mustard, wild radish, ragweed, pigweed, lambsquarters.	Apply DNOSBP when temperatures are above 60°F and there is little danger of rain for 6 to 12 hours after treatment.
Established dormant alfalfa fall or winter.	DNOSBP, amine or ammonium salts: 1½ to 2 pounds in 20 to 40 gallons of water.	Same as above.	

TABLE 1 (Continued)

Crop and Time of Treatment	Chemical, Rate Per Acre, and Volume of Application	Weeds that are Controlled	General Comment
Alfalfa - pure stands Post-emergence - fall or winter. Established dormant alfalfa	DNOSBP, amine or ammonium salts: 1½ to 2 pounds in 20 to 40 gallons of water.	Same as for seedling alfalfa.	Same as for DNOSBP applied on alfalfa-grass mixtures.
	CIPC: 1 to 4 pounds in 20 to 40 gallons of water.	Chickweed, other broadleaved weeds, and is especially effective on annual and some perennial grasses.	CIPC will injure cultivated annual and perennial forage grasses and should not be used on mixed stands unless it is desirable to remove the grass from the mixture.
Perennial grasses: tall fescue, orchard grass, bluegrass grown for seed. Post-emergence.	2,4-D, amine or ester: 1/2 to 1 pound in 5 to 20 gallons of water.	Curled dock, wild garlic, wild onion, most legumes, mustard, pigweed, smartweed, wild radish and others.	Do not spray in the seedling or boot stages.
Flax Post-emergence - when flax is 3 to 6 inches tall.	2,4-D or MCP, amines and esters: 1/8 to 1/4 pound in 5 to 20 gallons of water. Use esters at lower rates and amines at higher rates.	Most annual broadleaved weeds.	Do not spray after early bud through bloom stages.
	TCA, sodium salt: 5 to 8 pounds in 10 to 20 gallons of water.	Foxtail and other annual grasses but not wild oats.	Apply TCA for best control of foxtail when flax is not over 3 inches high.
Peas Post-emergence when peas are 3 to 8 inches and weeds are small.	DNOSBP, ammonium and amine salts: ¾ to 1 pound ammonium salt or 1 to 1½ pound amine salt.	Pigweed, lambsquarters, wild mustard, wild radish and other broadleaved weeds.	Applications at earlier or later stages of growth may injure peas and fail to control weeds.
	MCP, esters and amines at 1/8 to 1/4 pounds when peas are 4 to 8 inches tall.	Mustard and other broadleaved weeds.	Peas may show temporary injury and maturity may be slightly delayed.
Sugar beets Pre-emergence	TCA, sodium salt: 6 pounds per acre in 10 to 20 gallons of water endothal 2 pounds per acre.	Foxtail grasses (Setaria sp.) and other annual grasses. Does not control wild oat or perennial grasses.	TCA does not control broadleaved weeds.

broadleaved weeds, 2,4-D may be used as a selective foliage treatment at the rate of ½ to 1 pound per acre during the period from 2 to 4 weeks after setting until fruit bud differentiation begins.

Nursery stock. Methyl bromide and other soil fumigants may be used to control weeds in transplant beds and seedling beds. Stoddard solvent or equivalent non-fortified aromatic oils and aromatic oils fortified with PCP or DNOSBP may be used for the control of seedling weeds in coniferous seedling and transplant beds and for weed control in coniferous transplants and deciduous stock in rows respectively. The sprays should be basal directed so that application to the stem of nursery stock is avoided as much as possible. CIPC and SES are also being used in a variety of ways for weed control in nurseries.

The Use of Herbicides For Weed Control in the United States.

In 1954, it is estimated that over 85 million pounds of herbicides were used for weed control on agricultural and non-agricultural lands in the United States. Chemicals are being applied on one out of every 10 acres of cultivated land annually for weed control. A recent survey by personnel of the Agricultural Research Service and Agricultural Marketing Service, U.S. Department of Agriculture indicates that in 1952 a total of about 60 million acres of farm crops or land in the United States were treated one or more times for the control of insects, diseases, and weeds and brush. The acreage treated amounted to more than one-sixth of the principal crop acreage harvested that year. Of the total acreage sprayed and dusted for all purposes in 1952, more than half was sprayed for weed and brush control.

In 1952, 33.5 million acres were sprayed for weed and brush control. In the same year the combined acreage sprayed and dusted for disease and insect control was about 29 million acres. It is almost unbelievable that the use of chemicals for weed control could have advanced so rapidly.

About 70 per cent of the acreage sprayed and dusted for weed control in 1952 was treated by the farmer using his own equipment. The cost of materials on this acreage amounted to about 26 million dollars. On the remaining 30 per cent of the total acreage, custom operators furnished and applied the herbicides for a total charge of about 22 million dollars. These costs do not include materials and application costs for the control of weeds on non-agricultural lands.

The data in Table 2 indicate the principal uses being made of herbicides for weed control on agricultural lands in the United States. While the greatest increases in the use of herbicides have involved the newer chemicals, the use of the older herbicides such as sodium chlorate, borax, and the arsenicals have also increased rapidly.

Future Problems and Progress in Weed Control.

In attempting to outline some of the accomplishments in weed control we are always reminded of the backlog of unfinished business and unsolved problems in this promising and challenging new field.

The field of weed control is rapidly becoming highly specialized. The chemical method of controlling weeds is much more complicated than the methods used in the past. Weed control is rapidly developing as a separate scientific discipline and not as a branch of any single science. It is a combination of agronomy, horticulture, agricultural engineering, and public health. Like all separate biological disciplines with practical agricultural applications it draws heavily on the supporting sciences including chemistry, physics, ecology, botany,

TABLE 2

Some of the Crops Treated and the Cost of Chemical Weed and Brush Control[1]

Crop	Acres treated	Times treated	Percentage sprayed by		Cost per treatment per acre	
			Farmers	Custom operators	Chemical cost	custom operators rate
	1000 acres	No.	Percent	Percent	Dollars	Dollars
Small grains[2]	17,012	1.04	63	37	.66	1.84
Corn (Zea mays)	9,065	1.05	75	25	.69	1.86
Pasture and rangeland	2,192	1.14	64	36	1.09	2.60
Other crops[3]	2,629	1,37	77	23	4.22	--

(1) Does not include the average of non-agricultural land such as highway, utility lines, and railroad rights-of-way; and industrial and military sites treated for weed control.

(2) Includes wheat, oats, rye, barley, flax and rice.

(3) Includes all crops and land other than small grains, corn and pasture.

plant physiology, mathematics, engineering and others.

Twenty years ago there were less than five full time weed research workers in the United States. Today there are more than 150 Federal and State employed persons engaged at least part-time in weed research. Nevertheless there are still many states that do not employ a weed specialist. One of the most serious problems in weed control in the United States is the lack of personnel adequately trained to conduct effective and productive research in this ever increasing field of specialization.

Even more serious is the shortage of state and federal extension weed specialists. In 1953, there were less than six full time state extension weed specialists in the United States to aid farmers in adopting the technological advances that have been developed. There were no federal extension weed specialists. The farmer producing field crops is by far the greatest consumer of herbicides (Table 2). At the same time he has had much less experience in spraying techniques than farmers growing horticultural crops. The lack of extension specialists is greatly handicapping the acceptance of chemical weed control practices in the United States at the present time.

Developments in chemical weed control in the past 10 years have been overwhelming and research has not kept pace with application. We are gradually catching up, but we must be careful to keep the balance between fundamental and applied research more sharply in focus. We have not had sufficient time to build up the reservoir of fundamental research that will be needed if practical applications are to continue at the rate they have occurred during the past decade.

A number of serious problems face the weed scientist in the future. The problem of plants becoming more resistant to herbicides is not as serious as the build-up of resistance of insects to chemicals but a problem nevertheless to be dealt with eventually.

Of much greater significance and practical importance are the changes in ecological relationships as a result of the use of herbicides. This is not mere speculation as to what may happen. We already have ample proof as measured by what has happened. In the North Central United States, 2,4-D is used for the control of weeds in over 8 million acres of corn annually. The weedy grasses and many serious broadleaved weeds are not controlled by the treatments. As a result the broadleaved annual weeds are decreasing and the grasses are increasing, presenting a different and in many cases a more difficult weed problem than the original. Over one million acres of mesquite, a weedy perennial, and other brush is being treated annually with 2,4,5-T in the Southwestern United States. Many pernicious perennial weedy plants are not killed by 2,4,5-T and these species are on the increase. These are but two examples of shifts in ecological relationships which we must deal with in the future. There will be others. We must design our research programs to be versatile enough to meet the challenges of these ecological changes.

We are devoting far too little attention to the long term effects of herbicides on soils.

The rapid developments in weed control have not permitted sufficient time to study the life histories of the important weeds in the United States. Often investigators have conducted studies on the control of species of which little or nothing is known regarding their life histories. This situation is general in the field of weed control. There are less than a dozen weeds in the United States of which the life histories have been adequately studied. The situation is comparable to trying to control a fungus disease without knowing the life history of the causal fungus. No pathologist would attempt control studies without knowing something about the life history of the fungus. Yet in weed control we are still trying to kill weeds by mass effect.

There remains a vast and intriguing amount of unfinished business in weed control. What then will determine our rate of future progress? It would appear that our rate of progress will be determined by how carefully we analyze our problems and how accurately we outline the objectives of this new and fascinating science.

Our problem in weed control involves fundamental physiological differences between the plants to be controlled. The protoplasm of animals and plants is sufficiently different so that scientists have found a wealth of chemical compounds that may be used to kill insects without killing the plants they infest. Plant diseases are caused by lower, simpler, more primitive plants. And here too an abundance of chemicals have been available to the pathologist for the control of plant diseases. The differences between the protoplasm of these higher and lower forms of plants is likely to be rather great and it is possible to control selectively the lower forms without injury to the higher forms. The control of weeds on the other hand involves the control of plants that are quite similar to the crop plants which they infest. Compare wild oats (Avena fatua) with cultivated oats (Avena sativa). It is quite likely that the differences between the protoplasm of these two species are quite small. At the same time the number of chemicals that are selective enough to kill wild oats without injuring cultivated oats must be quite small in comparison to the number of chemicals that will kill leafhoppers without injuring sugar beets.

It seems obvious then that our future rate of progress will be largely determined by: (1) The discovery of more selective, more specific, better translocated, more efficient, better formulated, and more economical herbicides; (2) a basic fundamental understanding of the effects of chemicals on plant growth and soils; (3) our ingenuity in supplementing and combining chemical and cultural practices and (4) the development of new and more efficient weed control techniques.

For years plant breeders have been developing varieties of cereal crops that are resistant to rust diseases. Various physiological strains of rust appear to be highly specific with respect to the varieties they will infect. Is it too fantastic to suggest that we should use the reverse breeding technique and develop rust diseases that are specific for specific weeds? Think what it would mean if a strain of rust could be developed which was specific in its control of quackgrass (Agropyron repens). This is a relatively unexplored field that may yet prove practical and fruitful.

As the public becomes aware of present weed losses and the potential available for reducing these losses, great pressure is brought to bear for research to find immediate solutions. This situation is intensified by the fact that herbicides are being developed at a rapid rate and new ones are continually coming into the picture.

One of the most important tasks ahead is to find the time to build up a reservoir of fundamental research out of which may come the practical applications. The time element must be stressed. Fundamental studies cannot be hurried.

A List of Plants and Chemicals Referred to in this Paper

Horticultural Crops

1.	Asparagus	*Asparagus officinalis*	15.	Lima beans	*Phaseolus lunatus*
2.	Brambles	*Rubus sp.*	16.	Muskmelons	*Cucumis melo*
3.	Broccoli	*Brassica oleracea*	17.	Mustard	*Brassica juncea*
4.	Cabbage	*Brassica oleracea*	18.	Onions	*Allium cepa*
5.	Cantaloupes	*Cucumis melo*	19.	Parsley	*Petroselium hortense*
6.	Carrots	*Daucus carota*	20.	Parsnips	*Pastinaca sativa*
7.	Cauliflower	*Brassica oleracea*	21.	Potatoes	*Solanum tuberosum*
8.	Celery	*Apium graveolens*	22.	Rape	*Brassica napus*
9.	Collards	*Brassica oleracea*	23.	Red beets	*Beta vulgaris*
10.	Cucumbers	*Cucumis sativus*	24.	Snap beans	*Phaseolus vulgaris*
11.	Dill	*Anethum graveolens*	25.	Strawberries	*Fragaria sp.*
12.	Grapes	*Vitis sp.*	26.	Turnip	*Brassica rapa*
13.	Kale	*Brassica oleracea*	27.	Watermelons	*Citrullus vulgaris*
14.	Lettuce	*Lactuca sativa*			

Field Crops

1.	Alfalfa	*Medicago sativa*	9.	Orchard grass	*Dactylis glomeratus*
2.	Barley	*Hordeum vulgare*	10.	Peanuts	*Arachis hypogaea*
3.	Corn	*Zea mays*	11.	Peas	*Pisum sativa*
4.	Cotton	*Gossypium hirsutum*	12.	Sorghum	*Sorghum vulgare*
5.	Flax	*Linum usitatissimum*	13.	Soybeans	*Soja max*
6.	Ky. bluegrass	*Poa pratensis*	14.	Sugar beets	*Beta vulgaris*
7.	Ladino clover	*Trifolium repens*	15.	Tall fescue	*Festuca sp.*
8.	Oats	*Avena sativa*	16.	Wheat	*Triticum vulgare*

Weeds

1.	Bitterweed	*Helenium tenuifolium*	13.	Lambsquarter	*Chenopodium album*
2.	Burdock	*Arctium minus*	14.	Morning glory	*Ipomoea purpurea*
3.	Canada thistle	*Cirsium arvense*	15.	Mustard	*Brassica kaber*
4.	Chickweed	*Stellaria media*	16.	Pigweed	*Amaranthus retroflexus*
5.	Chicory	*Cichorium intybus*	17.	Ragged robin	*Centaurea cyanus*
6.	Cocklebur	*Xanthium sp.*	18.	Ragweed	*Ambrosia artemisilfolia*
7.	Crabgrass	*Digitaria sanguinalis*	19.	Smartweed	*Polygonum pennsylvanicum*
8.	Curled dock	*Rumex crispus*	20.	Vetch	*Vicia sp.*
9.	Dandelion	*Taraxacum officinale*	21.	Wild garlic	*Allium vineale*
10.	Field bindweed	*Convolvulus arvensis*	22.	Wild onion	*Allium canadense*
11.	Foxtail	*Setaria sp.*	23.	Wild radish	*Raphanus raphanistrum*
12.	Kenbit	*Lamium amplexicaule*	24.	Yellow rocket	*Barbarea vulgaris*

Chemicals*

1.	2,4-D	2,4-dichlorophenoxyacetic acid
2.	2,4,5-T	2,4, 5-trichlorophenoxyacetic acid
3.	MCP	2-methyl,4-chlorophenoxyacetic acid
4.	3,4-D	3,4-dichlorophenoxyacetic acid
5.	IPC	isopropyl N-phenylcarbamate
6.	CIPC	isopropyl N-(3-chlorophenyl)carbamate
7.	DNOSBP, (DNBP)	4,6-dinitro ortho secondary butylphenol
8.	PCP	pentachlorophenol
9.	TCA	trichloroacetic acid
10.	SES	sodium 2,4-dichlorophenoxyethyl sulfate
11.	endothal	3,6-endoxohexahydrophthalic acid
12.	CMU	3-(p-chlorophenyl)-1,1-dimethylurea

* All other herbicides are referred to by the chemical name of the active ingredient.