THE RESPONSE OF VEGETABLE CROPS TO APPLICATIONS OF SOME PHENOXYBUTYRIC ACIDS

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Summary

The results of one year's field trials are reported in which four substituted phenoxybutyric acids were applied to a range of vegetable crops. Crop responses are described and discussed in relation to information on weed susceptibility obtained in the same year. It is concluded that MCPB holds some promise for the control of certain susceptible weed species in crops of peas and celery.

Introduction

Following the accounts given by Wain (2,3) of the herbicidal activity of a series of phenoxybutyric acids, it seemed desirable that the effects of these compounds on vegetable crops should be further investigated in the field. After discussion with the A.R.C. Unit of Experimental Agronomy, the four compounds MCPB, 2,4-DB, 2,4,5-TB and 4-CPB were selected for a trial at Wellesbourne in 1955 involving ten vegetable crops. The A.R.C. Unit also undertook two similar trials. The results from all three were in general agreement and only those from Wellesbourne are presented in this report.

Experimental Results

Single rows of ten crops, replicated three times, were drilled two feet apart and the four materials were sprayed across them at rates of 1 and 4 lb/ac a.e. The first application was made when most of the crops had from 1 to 4 true leaves and a second series of plots was treated nine days later. After this, all plots were hand weeded and thereafter kept as free from weeds as possible. In order that effects on annual weeds could be determined, a weed strip was left in each replicate. The chemicals were in the form of sodium salts and were applied in a volume of 12 gal/ac by means of an Oxford Precision Sprayer. Various assessments were made on the crops, including visual ratings of injury, measurements of height and counts of leaf number. The values for stand and fresh weight of whole or parts of plants relative to the control values are shown in Table 1. As the reaction of any one crop to the same spray was similar at the two stages of growth, the data for these have been considered together. The results obtained for the different crops may be summarised as follows:-

Onion: Only 4-CPB at the high rate seriously affected the stand, but all treatments induced distortion of the leaves shortly after spraying and at harvest, abnormalities of the bulbs were found in plants sprayed with MCPB, 2,4-DB and 4-CPB. The bulbs tended to be elongated at the base and had many short, thick roots which were sometimes fasciated.

Table 1

The relative effects of four phenoxybutyric acids on vegetable crops

		Stand and plant weight at harvest as percent. of control							
Compound		MCPB		2,4-DB		2,4,5-TB		4-CPB	
Rate, lb/ac		1	4	1	4	1	4	1	4
Onion*	stand	95	87	99	84	96	113	93	63
	weight of whole plants	159	91	149	111	117	182	101	42
Lettuce	stand	16	3	1	0	119	115	71	10
	weight of whole plants	4	0	0	0	81	52	6	1
Spinach	stand	55	60	70	49	106	105	70	6
	weight of whole plants	42	30	44	21	112	114	40	2
Radish	stand	77	83	91	56	89	107	39	4
	weight of whole plants	90	84	98	61	98	104	18	0
Red beet	stand	31	18	17	0	71	75	82	13
	weight of roots	31	6	18	0	62	53	27	3
Broad bean	stand	108	101	108	100	126	113	121	90
	weight pods over 3 in.	97	40	61	34	119	100	13	2
French bean	stand	108	100	108	47	100	70	58	62
	weight pods over 3 in.	26	0	0	0	6	0	0	0
Pea	stand	103	96	100	93	93	100	98	93
	weight marketable pods	106	100	106	69	92	99	96	33
Carrot	stand	113	106	97	61	105	105	79	29
	weight of roots	101	115	88	59	95	96	33	8
Parsnip*	stand	85	103	97	53	112	88	109	76
	weight of roots	135	150	130	125	96	133	111	93

* Growth on the control plots was affected by late-developing weeds.

Lettuce: 2,4,5-TB caused a reduction in growth without affecting the stand whilst all other treatments killed the majority of the plants. Surviving plants from the edges of the plots had narrow, rigid, crisped leaves with rough surfaces.

Spinach: All treatments except 2,4,5-TB caused reduction both in stand and growth. Slight contact injury was noted on plants sprayed with MCPB, 2,4-DB and 2,4,5-TB and plants on all treated plots had swollen, split stems with proliferation of tissue at the base to a greater or less degree. Many of the plants, especially those sprayed with 4-CPB, were stunted and bushy in appearance, with abnormal basal branching.

Radish: At the time of treatment the radish plants were well grown and 2,4,5-TB and the lower rates of MCPB and 2,4-DB had little effect on subsequent development, although that of 4-CPB was severe and resulted in the death of many of the plants. Examination of the roots, however, showed that all treatments had induced some proliferation of tissue, slight with 2,4,5-TB but severe with the other three compounds. Many of the tap roots were split, rotten and blackened, with secondary fungal infection. Further trials in which the sprays were applied at the cotyledon and first true leaf stages gave similar results regarding the relative activity of the four compounds and confirmed that the effects on the roots were much more severe than those on the shoots.

Red beet (globe): All sprays reduced both stand and yield of roots, but with this crop 4-CPB appeared to be less injurious than 2,4-DB. Surviving plants showed a number of abnormalities. The leaves were narrow, twisted, often cupped and sometimes had frilled edges to the lamina or bifurcated midribs, whilst the petioles were reflexed and many of the tap roots were pear-shaped.

Broad Bean: The stand of this crop was not affected but crop weight was reduced by all treatments except 2,4,5-TB and the low rate of MCPB. As with spinach, some contact injury was noted and all compounds induced typical growth-substance injury of the leaves, whilst 4-CPB caused marked stunting and basal branching.

French Bean: All treatments severely affected growth and most of them arrested the development of the plants at the stage at which they were sprayed.

Pea: In this trial the variety Onward showed considerable tolerance to the phenoxybutyric acids. None of the treatments reduced the stand and only the 4 lb rates of 4-CPB and 2,4-DB reduced the yield of marketable pods. After the initial distortion, from which the plants soon recovered, abnormalities in growth were slight. Some treatments, however, notably 4-CPB and 2,4-DB, induced formation of narrow leaves, twisting of the stems and a tendency to form a rosette at the apex of the plants. In a yield trial with a weedy crop of the same variety, both MCPB and 2,4-DB increased yields above that of the unweeded control, but owing to competition from remaining weeds not killed by the sprays, no treatment equalled the hand weeded control plots in terms of yield.

Carrot: This crop also proved to be relatively tolerant to MCPB and 2,4,5-TB but 2,4-DB and 4-CPB reduced both stand and yield of roots. With all compounds, the tap roots were misshapen with proliferation of tissue at the crown, this injury being most severe as a result of treatment with 4-CPB. In a further trial, MCPB at rates of 1, 2 & 3 lb/ac was applied to carrots at the 2 and 4 true leaf stages, after which the whole experiment was weeded. None of the treatments caused significant reductions in total yield, but the roots showed abnormalities which were more frequent and severe as a result of spraying at the later stage. In addition to proliferation at the crown, there were many lateral rootlets produced from the main tap root in plants from the treated plots. Effects on the leaves were very slight.

Parsnip: In the main trial both stand and yield of this crop were variable but it was clear from visual estimates of injury that it was relatively tolerant to 2,4,5-TB and MCPB whilst 2,4-DB and 4-CPB caused greater injury. In a further trial, MCPB was applied at the 1 and at the 3-4 true leaf stages. No weeds were present at the first date and MCPB at 2 and 3 lb/ac slightly reduced the stand and vigour of the parsnips. By the second date, total ground cover was 60% and none of the sprays affected the growth of the crop. It was then weeded and thinned according to normal practice and when final yields were taken, there were no differences. Abnormalities of the roots were present however, similar in form to those described for carrots but less marked both in frequency and degree.

Celery: This crop was not included in the main trial, but two small yield trials were carried out with MCPB on self-blanching celery transplanted into Dutch lights. Good control of *Urtica urens* was obtained and no adverse effects on yield or quality could be detected with rates of up to 4 lb/ac. In a trial on seedling celery in 1956 it was found that MCPB had produced very marked root abnormalities, but it is not yet certain what effect these are likely to have on yield.

Discussion and conclusions

Of the four compounds investigated, 2,4,5-TB caused least injury to all crops except French beans where the effect on growth and yield was greater than that of MCPB. All the evidence from this and other trials, however, indicated that correspondingly little damage was caused to weed species, so that this compound appears unlikely to have any practical application as a selective herbicide for the control of annual weeds. A similar conclusion was reached by Carpenter and Soundy (1). On the whole, greatest injury to the crops was caused by 4-CPB, and this compound would seem to be insufficiently selective for use in vegetables. The other two materials were more or less intermediate in effect, with 2,4-DB tending to be rather more injurious than MCPB.

In trials with mixed stands of annual weeds, 4-CPB, 2,4-DB and MCPB proved to be similar in activity but there were some interesting variations in the relative order of toxicity to different species. Comparison of the dosage-response curves for the three materials and *Thlaspi arvense* showed that 4-CPB was consistently the most active, whilst in the case of *Fumaria officinalis*, it was the least active of the three. 4-CPB was also less active against *Polygonum aviculare* and *P. convolvulus* than either MCPB or 2,4-DB, a result noted also by Carpenter and Soundy (1). In general, it appeared that the range of species adequately controlled by rates of 2 lb/ac was rather narrow. Two of the most common weeds of vegetable crops, *Urtica urens* and *Chenopodium album* were effectively controlled, but others, notably *Stellaria media*, were virtually resistant. The fact that good control of *Cirsium arvense* with MCPB has been reported (1,2) is of importance however, since this is an advantage not possessed by other herbicides currently used in vegetable crops.

Several of the crops investigated, such as lettuce and French bean, were very susceptible to the three more active compounds. Others, such as carrot and parsnip were relatively tolerant, confirming the original observations reported by Wain (2). In the present trials, however, abnormalities of the roots were present in these crops and it would seem that any use of MCPB in them would be attended by a definite risk of affecting marketability of the produce. Throughout the trials there appeared to be a general tendency for the growth of roots to be affected even when visible injury to the aerial parts of the plant was negligible.

From the limited tests carried out, it would appear that there are practical possibilities for the use of MCPB in celery and pea crops, when susceptible weed species are predominant. Further work is obviously required with celery, but trials in 1956 with peas indicate that this material can be safely applied to a number of widely grown varieties in addition to Onward.

References

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THE TOLERANCE OF FRUIT CROPS TO CERTAIN SELECTIVE AND PRE-EMERGENCE HERBICIDES

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SUMMARY

In exploratory trials with a range of selective and pre-emergence herbicides in nursery crops and bush fruits the following were found to show promise:-

(i) 2,4,5-TB for the control of certain perennial weeds (particularly Greater Bindweed) in black currants.

(ii) 2,4-D for weed control in red currants.

(iii) 2,4-DES as a pre-emergence herbicide on a wide range of fruit nursery crops.

It is emphasised that these recommendations are tentative and that the possibility of varietal differences in susceptibility to damage by herbicides must be borne in mind. Another possibility, which remains to be assessed, is that of undesirable growth effects in the year following application of the herbicide.

INTRODUCTION

Chemical weed control is of great potential value in fruit tree nurseries, stoolbeds and cutting beds, and in field plantations of bush fruits, but has not yet found wide application owing to scarcity of information on the tolerance of different species and varieties of fruit plants to the numerous herbicidal compounds now available. The present report describes three series of preliminary trials designed to investigate the effect of various selective and pre-emergence herbicides on a wide range of fruit plants, with a view to selecting those compounds which might warrant further investigation as chemical weed control agents in fruit crops.

EXPERIMENTAL

(1) Trials with phenoxyacetic and phenoxybutyric acids.

The compounds listed in Table I were sprayed at a concentration of 1000 ppm. (acid equivalent) on to 2-year old nursery trees of apple, pear and plum, and on to fruiting bushes of black and red currant and gooseberry. All compounds were applied as their sodium salts, with the exception of 2,4-D, where a commercial formulation of the amine salt was used. The plants were sprayed to run-off, and therefore received a considerably heavier dose of each compound than they would from application of the herbicide at the normal rate of 100 gallons/acre. Treatments were carried out on June 11th, 1956 and final assessment of the damage was made in September. Results are summarised in Table I.

TABLE I Sensitivity of various fruit plants to a range of phenoxyacetic and phenoxybutyric acids at 1000 ppm.

O = negligible damage
D = slight damage
DD = considerable damage
DDD = very severe damage
K = killed.

	2,4-D	2,4-DB	MCPA	MCPB	2,4,5-T	2,4,5-TB	4-CPB*
Pear Laxton's Superb	K	K	K	K	DDD	DD	DD
Pear D. du Comice	K	K	K	K	DDD	DDD	DDD
Apple Cox's O.P.	D	DD	DDD	DDD	DDD	DDD	O
Apple Cheddar Cross	DD	DD	K	DDD	DDD	DDD	DD
Plum Giant Prune	DDD	DD	K	K	DDD	K	DD
Blackcurrant Wellington XXX	K	DDD	DDD	DD	DDD	O	DDD
Red Currant Red Lake	O	O	DD	D	DDD	DD	-
Gooseberry Whinham's Industry	DDD	DD	DDD	DD	DDD	DD	DD

*4-(4-Chlorophenoxy) butyric acid

Tree fruits: All the compounds tested either killed or caused considerable damage to pears, plums and to the apple Cheddar Cross. Cox's Orange Pippin on the other hand, showed remarkable resistance to 2,4-D and to 4-CPB and, by the end of the season it was difficult to detect any damage on trees sprayed with these compounds. Such results indicate that, in apples and perhaps also in other tree fruits, rather wide differences in varietal susceptibility may exist. It is also possible that trees showing no damage in the year of spraying, may exhibit undesirable growth characters the following season resulting from the effect of the herbicide on the developing leaf primordia within the buds.

Bush fruits: Of the compounds tested 2,4,5-TB was outstanding in causing only negligible damage to black currant. Since this compound appears to be highly effective against bindweed (Calystegia sepium) it would certainly warrant trial as a selective herbicide in black currant plantations infested with this weed. All the other compounds tested caused severe distortion and death of the tips of the maiden shoots of black currant. Red currant exhibited a high degree of resistance to several compounds, in particular to 2,4-D and 2,4-DB, but none of the compounds tested showed promise as selective herbicides on gooseberries.

(2) Trials with soil-acting herbicides on black currant.

The following treatments were applied to nursery beds of black currant (var. Mendip Cross) in their third year of growth on May 28th. The beds had previously been kept clean by routine hoeing and were weed free at the time of application of the herbicides.

Na-2,4-dichlorophenoxy ethyl sulphate	(2,4-DES)	1 lb/acre.
" " " "	"	4 lb/acre.
3-(p-chlorophenyl)-1,1-dimethyl urea	(CMU)	1 lb/acre.
" " " "	"	4 lb/acre.
Isopropyl-N-(3-chlorophenyl) carbamate	(CIPC)	6 lb/acre.

All applications were made at the rate of 100 gallons per acre on plots measuring 2 x 4 yards the spray being applied uniformly over the bushes and the surrounding soil surface. The dominant weeds in the area were Groundsel (Senécio vulgaris) and Annual Meadow Grass (Poa annua). Also abundant were Capsella bursa-pastoris, Matricaria suaveolens, Stellaria media and Epilobium angustifolium. Perennial weeds were absent. The results of this trial are summarised in Table II.

TABLE II. Pre-emergence application of herbicides to 3-year old nursery beds of black currant (var. Mendip Cross)

Compound	Rate lb/acre	Damage to crop	Weed Control
2,4-DES	1	None	Complete control for 8 to 10 weeks. Some growth of Poa annua in Sept.
2,4-DES	4	? Very slight	Complete control for 10 to 12 weeks. Some growth of Poa later.
CMU	1	Slight stunting	Very good - some growth of Groundsel in Sept.
CMU	4	Severe stunting	Complete control.
CIPC	6	Very severe stunting and defoliation	Good control of Poa annua - no control of Groundsel.

It appears from this trial that 2,4-DES at rates not exceeding 4 lb/acre would prove very suitable for the pre-emergence control of annual weeds in black currants in the nursery.

(3) Trials with 2,4-DES for pre-emergence control of annual weeds in nurseries.

In this trial 2,4-DES at rates of 2 or 4 lb/acre was applied in mid-July as a pre-emergence herbicide to the nursery crops listed in Table III. All applications were made at approximately 100 gallons per acre. The general weed population in the area was much the same as in the previous trial, Groundsel and Annual Meadow Grass being dominant.

TABLE III. Effect of 2,4-DES applied as a pre-emergence herbicide in mid-July on various nursery crops.

Crop	Rate lb/acre	Damage to crop
Apple seedlings - maiden	2	None
Pear seedlings - maiden	2	Slight stunting?
Peach seedlings - maiden	2	Slight distortion
Apple rootstocks - stoolbeds M.I, M.II, M.IV, M.VIII, MIX, M.XII, M.XVI.	2 & 4	None
Quince C stocks - stoolbed	2 & 4	None
Plum stock - Brompton - layer bed	2	Slight scorch
Plum stock - Mariana - cutting bed	4	None
Plum - Early Laxton - maiden	2	None
Cherry stock - F12/1 - layer bed	2	None
Cherry seedlings - 3 year old	2	None
Loganberry - layer beds	4	None

In spite of very wet weather following these applications of herbicides almost complete suppression of weed germination over a period of 4 to 6 weeks was obtained, and even by mid-September there was still very little weed growth visible on the sprayed areas. Adjacent unsprayed areas by this time carried a very dense cover of Groundsel and Annual Meadow Grass. The herbicide was least effective in the Loganberry layer beds, where the prostrate habit and large leaf area of the crop prevented an even distribution of the spray over the soil surface. As noted in Table III few of the crops suffered in any way and what damage was noted was negligible. The possibility of delayed effects in the year following spraying must however be borne in mind, so that final assessment of the results of these trials cannot be made until 1957.

DISCUSSION ON THE PREVIOUS TWO PAPERS

Mr. H. A. Roberts (Introduction to discussion)

The two reports now before us are mainly concerned with the effects of some synthetic growth-regulating substances on vegetable and fruit crops. In the first, field trials with four phenoxybutyric acids and eleven vegetable crops are described. The majority of the crops were found to be susceptible to those compounds capable of controlling annual weeds. Peas and celery, however, were found to be tolerant to MCPB. The pea crop has already been dealt with in some detail, but I should like to mention celery briefly. Our initial trials showed that transplanted self-blanching celery was not affected by MCPB at rates of up to 4 lb/ac. When we treated celery at an earlier stage of growth, we found that MCPB induced the formation of abnormal roots, and also had some effect on final yield. It would seem that further work is required before MCPB can be confidently recommended for use in this crop. The experiments as a whole indicated a tendency for the phenoxybutyric acids to produce root abnormalities even when effects on aerial growth were slight. This occurred with carrots and parsnips for example. At present, therefore, MCPB shows promise for use in only two vegetable crops, peas and celery, and then only in those instances where the dominant weeds are susceptible.

It is very interesting that 2,4,5-TB, which is relatively inactive against annual weeds should be found to be effective on some deep rooted perennials. The paper by Dr. Luckwill and Mr. Campbell suggests that this material may have some value for use in blackcurrant crops infested with bindweeds, which are often a serious problem. The relative immunity of red currants to 2,4-D and 2,4-DB is also striking, since related crops were severely damaged or killed by these materials. In top fruit, there were indications of wide varietal differences in susceptibility to some of the growth-regulating compounds. For the control of annual weeds in the germination phase, 2,4-DES showed most promise. It seems probable that this material will find a useful place in nursery practice, but we shall be hearing more about it tomorrow. Dr. Luckwill and Mr. Campbell emphasise in their paper that very little is known as yet about the effects of herbicides on fruit crops generally, and their preliminary experiments are thus valuable. Weed problems undoubtedly exist, particularly in bush fruit and in nursery beds and we shall look forward to further contributions on this subject from Long Ashton.

Mr. F. A. Roach

It is interesting to learn that Dr. Luckwill has found MCPB more damaging than 2,4-DB. We have used both on strawberries and found the former lethal at 2 lb/ac rates. MCPB was more damaging than 2,4-DB. We have also found that if MCPB is applied on bare ground at 2 lb/ac it will give nearly 100% control of germinating seedlings. 0.5 and 1 lb rates also give a good control.

At Long Ashton the plots treated with 4 lb/ac monuron in May are still weed free. With 2,4-DES we often get a good control of *Poa annua* but results vary widely apparently, perhaps depending on the type of soil.

Mr. D. W. Robinson

Mention has been made by Dr. Luckwill of the possibility of very wide differences in varietal susceptibility to herbicides among fruit crops. In experiments with dalapon for grass control around young apple trees, some varieties appeared to show considerable susceptibility to 10 lb/ac while others have shown little effect.

Incidentally, dalapon also seems to be promising on blackcurrants and raspberries. In our experiments, although the grass was killed, the problem of creeping buttercup became serious, about six weeks after spraying. Mr. Roberts made a point earlier this morning that *Poa annua* was one of the four worst weeds in vegetable crops in the country. I would go further and say that in Northern Ireland among soft fruit it is the worst weed. Very good weed control of annual meadow grass has been obtained in strawberries with both CIPC and propham without serious reduction of the crop. It is to be hoped that they will become available commercially before long, in Great Britain.

Mr. A. D. Harrison

I have been concerned with an experiment with MCPB on celery grown on clean ground. The trial is still proceeding so that results are not yet to hand; however, I am quite satisfied that in the early stages there was a definite check to growth.

Chairman: Prof. R. L. Wain

FACTORS INFLUENCING THE RELATIVE TOXICITY OF PHENOXY-BUTYRIC ACIDS AND THEIR CORRESPONDING PHENOXYACETIC ACIDS

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The well-established hypothesis of Wain states that the substituted straight-chain 4-phenoxybutyric acids are active as plant growth regulators only after β-oxidation to the corresponding phenoxyacetic acids within the plant. Any advantage that the 4-phenoxybutyric acids have over the phenoxyacetics as selective herbicides is due to the relative phytotoxicity of the two homologues varying with different species. If it was the same in all instances they would only do what the phenoxyacetics do but with greater expenditure of chemical. If on the other hand, as an example, the acetic is three times as active as the corresponding butyric on the crop but only twice as active on the weed then the butyric has greater selectivity. Such variation exists and can be ascribed to different plant species varying in their efficiency in performing this - β-oxidation (Wain 1955), though it must not be assumed that both homologues inevitably penetrate into and are translocated within the plant to the same extent.

This paper is largely concerned with the butyric : acetic ratio, which is the ratio of the amounts of the two compounds required to produce the same effect. That large differences in the butyric : acetic toxicity ratio occur between species has been shown with laboratory tissue tests (Wain and Wightman 1954) and by the spraying of intact plants (Wain 1955, Fryer and Chancellor 1956). It is also well established that the butyric : acetic ratio can vary widely according to the nature and position of the nuclear substituents (Wain 1955). Selectivity found with one configuration of alkyl and halogen substitution may not occur with another, which may have quite a different selectivity.

We have been investigating in experiments involving spraying of whole plants grown in pots, whether certain other factors can bring about changes in the butyric : acetic ratio. These experiments have been primarily of an empirical nature to evaluate the possible effect of such factors on the efficiency and selectivity of the straight-chain 4-phenoxybutyric acids, as one stage in the evaluation of their herbicide potentialities. Any change in butyric : acetic ratio, unless occurring equally with all species in all circumstances, will affect the selectivity of the phenoxy-butyric compound.

Some difficulty arises in the determination of the butyric : acetic ratio. Chlorinated 4-phenoxybutyric acids have a variety of effects on plants including growth inhibitory effects of various sorts, at concentrations below those at which mortality occurs. If the phenoxybutyric acids are active only after conversion to their phenoxyacetic acids it might be expected that they would show a similar relationship between inhibitory effects and mortality. In fact this direct correlation does not occur in all the instances for which data have been obtained. In a striking case with seedlings of Sinapis alba it took 70 times as much 4-2- methyl-4-chlorophenoxy)butyric acid (MCPB) as 2-methyl-4-chloro-phenoxyacetic acid (MCPA) to kill 50% of the plants, which is not an exceptional ratio for this species. However MCPB had a marked effect on the growth of the plants at much lower doses and if the two compounds are compared on the basis of the doses required to reduce the fresh weight of the plants by 40%, then only 17 times as much MCPB as MCPA was required. In other experiments on the same species reductions in the butyric : acetic ratio have been evident when suppression of flowering rather than mortality has been used as the criterion of response. This has occurred when 2-methyl-4-chloro-, 2,4-dichloro- and 2,4,5-trichloro- substituted compounds have been applied. Similar information is available from experiments on red clover. In one experiment 8 lb/ac of MCPB applied at the one trifoliate leaf stage caused only slight mortality, as against nearly 75% by 4 lb of MCPA, but over a range of doses both compounds were very similar in their effect in reducing the dry weight, measured 5½ weeks after spraying. One possible hypothesis to cover these instances of deviation from the simpler result which might have been expected, is that the phenoxybutyric acid is only slowly converted to the phenoxyacetic acid within the plant so that the plant in effect receives a lower dose spread over a longer time than when the phenoxyacetic is applied direct. This might be sufficient to produce inhibitory effects but not mortality.

This leads to enquiry as to whether the phenoxybutyrics are slower in acting on the plant than are the phenoxyacetics. If the β-oxidation process within the plant takes a considerable amount of time, then the phenoxybutyric will be slow in exerting its effect and the butyric : acetic ratio would decrease as the time interval between application and observation increases. This is of some practical importance as the quicker a plant is killed the less the competition with the crop.

Within a period of hours of application the phenoxybutyric acids show a contact phytotoxicity effect on many species, noticeable primarily as leaf scorch. This demonstrates that there is no undue delay in entry into the plant. In many pot experiments counts of survivors were made on more than one occasion after spraying to determine whether there was any greater delay in action with the phenoxybutyric acids. In some cases, with S. alba and Papaver rhoeas, the MCPB : MCPA ratio was not greater at about 2 weeks after spraying than later - the phenoxybutyric had not been slower in developing its effect. In a detailed experiment on peas the growth inhibition was measured at weekly intervals. The effect was greatest 2 to 3 weeks after treatment and thereafter there was a tendency to recover from both MCPA and MCPB applications. In another experiment equi-effective doses of MCPA and MCPB at two levels were applied to one leaf of young sunflower plants and the development of effects over the ensuing 20 days studied. The treatments caused a considerable inhibition of the growth in dry weight of the shoot by the end of this period and this effect developed at the same speed with both compounds, marked depression occurring by the sixth day. Measurements of the rate of internode elongation also failed to differentiate between the compounds in their rapidity of action.

These examples indicate that the interposition of an additional step in the shape of a β-oxidation process between the application of the chemical and exertion of its effect, has not caused any serious delay in the 4-phenoxybutyric acid becoming effective on the plant. However, against this must be set a few instances where the butyric : acetic ratio has decreased with time. A clear-cut case was on S. alba sprayed at the cotyledon stage in which the butyric : acetic ratio shown by counts of survivors 14 days after spraying was 67 but had decreased to 23 by 30 days after spraying. In other words the 4-phenoxybutyric had been slower in affecting the plants. In another experiment on S. alba the relative toxicity of 3,4-dichlorophenoxyacetic acid to 4-(3,4-dichlorophenoxy) butyric acid decreased from 3.8 to 1.3 between 20 and 54 days after spraying.

It is clear therefore that under some circumstances, which may well be connected with the environment at and after spraying, the butyric : acetic ratio can decrease with time due to the 4-phenoxybutyric acid being slower to become effective. The problem requires further study under controlled conditions.

In some circumstances we have found that seedlings after emergence can suffer considerable damage from application of 4-phenoxybutyric and phenoxy-acetic acids only to the soil between the plants, taking great care to avoid contact with the foliage. In these circumstances uptake must be wholely by the roots. The butyric : acetic ratios obtained from such soil applications are of some interest. In experiments on peas and red clover this ratio was as high with soil as with spray application. This would appear to indicate that the 4-phenoxybutyric acid was not rapidly β-oxidised in quantity by the micro-organisms in the soil, for that should lead to a reduction of the ratio. Rather it would seem that entry into the roots was as the 4-phenoxybutyric acid and it was then subjected to the same processes as when entering by the foliage.

Little is known concerning the enzyme system postulated for the conversion of the 4-phenoxybutyric acid to the phenoxyacetic acid within the plant. In view of the variation in its occurence or efficiency between different plant species it is justifiable to speculate whether with any one species the enzyme functions to the same extent at all stages of its life history. If it does, then the butyric : acetic ratio should be the same when they are applied at all stages of growth, provided factors of penetration and translocation do not differentiate between the two compounds at some times more than others. A number of pot experiments have been conducted in which seedlings of various ages have all been sprayed with a range of doses of MCPA and MCPB (and also 2,4-D and 2,4-DB in some instances) on the same occasion. The primary object was to obtain practical information on the development of resistance to both 4-phenoxybutyric and phenoxyacetic acids with increasing age of plant. Although the absolute level of resistance changed, no appreciable alteration in the butyric : acetic ratio has been found with red and white clovers between the cotyledon and 2-trifoliate leaf stage, with peas between 2-and 4-leaf stages and P. rhoeas between 4 and 8-11 leaves. The only instance in which a change in ratio has so far been found is with S. alba. In this case an approximately fourfold increase in ratio occurred between the 2-leaf and the 4-5 leaf stages; in other words the resistance to MCPB increased with age more rapidly than did the resistance to MCPA. There is no evidence to indicate the reason for this but it emphasises the point that with the 4-phenoxybutyric acids even more stress must be laid on the need for early spraying of the weeds than is already necessary with the phenoxyacetic acids.

A number of pot experiments were conducted on the formulation of 4-phenoxybutyric acids when applied as sprays, primarily with a view to determining whether their selectivity can be improved in that way. The problems involved in the subject of the formulation of herbicides are well-known to be complex and the present experiments have only touched on the fringe of them. However they clearly indicate that changes in formulation can alter the butyric : acetic ratio. To some extent this might be expected where this involves the addition of a wetting agent to water soluble salts. The 4-phenoxybutyric acids differ from the corresponding phenoxyacetic acids in their physical properties. In particular the properties of the water soluble salts are such that there is an increased retention of sprays and perhaps easier penetration. As an example, the retention of MCPB and 2,4-DB solutions by P. rhoeas seedlings was approximately one-third greater than that of MCPA and 2,4-D solutions. It is therefore not surprising that with this species the addition of a wetting agent increases the butyric : acetic ratio through bringing the spray retention to an approximate parity. The effect of the phenoxyacetic is thereby increased more than that of the 4-phenoxybutyric acid. In a typical experiment on P. rhoeas the butyric : acetic ratio was increased from 1.0 with solutions of amine salts without added surface-active agents, to 1.7 and 2.2 with the addition of two different wetting agents. However, elimination of the surface-tension differential is not the whole explanation because using the butoxyethanol esters raised the ratio still further to 2.5. Also the effect is not necessarily repeated on other species. In some instances the ratio has not been changed appreciably by the addition of a surface active agent and with S. alba the reverse effect has been obtained. With the latter species addition of a wetting agent had little effect on the toxicity of MCPA but increased that of MCPB. The butyric : acetic ratio was thus brought down from 65 with the amine salts alone, to 13-15 with the addition of wetting agents. The butoxyethanol esters gave a ratio of 21. There is thus obviously much scope for changing the selectivity of 4-phenoxybutyric acids by changes in their formulation and the subject would repay further, more detailed study.

To sum up, it has been found that the relative toxicity of the 4-phenoxybutyric acids to their corresponding phenoxyacetic acids can be affected by other factors besides those of the nature of the nuclear substitution and the species on which they are tested. The results indicate a pressing need for a physiological study of the action of substituted 4-phenoxybutyric acids, particularly on their penetration and translocation, and on the nature and functioning of the β-oxidation process.

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DISCUSSION ON THE PREVIOUS PAPER

Dr. E. K. Woodford

I think the point that Dr. Holly has made about the phenoxybutyric acids having a contact phytotoxic action as well as a growth regulation action is one that needs further consideration. He mentioned only the contact effect on the leaves. I have also observed that when sunflowers are grown in water culture solution and MCPB is added to the solution, it has a higher immediate toxicity as measured by the initial effect on wilting than MCPA or 2,4-D. Perhaps the reason for some of the variable responses from the phenoxy butyrics is due to this direct contact action.

Does Dr. Holly think that formulation affects the selectivity of the phenoxybutyrics any more than the phenoxyacetic acids?

Dr. K. Holly

We cannot assess precisely whether the selectivity will be affected more or not. It always seems to me that insufficient attention, as indicated by published reports of research, has been given to the effects of formulation on the selectivity of the phenoxyacetics. In fact, I suspect a lot of work has been done but not published.

Prof. G. E. Blackman

Dr. Holly stated that we want to know a lot more about the penetration and translocation of the phenoxybutyrics. Surely the answer is we still want to know a lot more about penetration and translocation of 2,4-D or indeed any compound which is physiologically active.

Dr. K. Holly

I feel that the surface tension properties of these phenoxybutyrics and their other physical properties are of the greatest significance. I think, perhaps, penetration is of greater interest with these particular compounds than with some other herbicides.

Prof. R. L. Wain

Perhaps Dr. Pfeiffer may have a contribution to make on the surface tensions of these acetic and butyric derivatives.

Dr. R. K. Pfeiffer

I regret to say that I am not in a position to tell you very much on this subject.

Our physicists did not find a difference in surface tension between MCPB and MCPA. Has Dr. Holly found a significant difference between the two compounds? The formulations of the materials used will have to be checked if our results disagree.

Dr. K. Holly

We have measured the surface tension of the materials used by us, which were reputedly pure materials, and we did in fact find quite a substantial difference. The surface tension of MCPA and 2,4-D solutions is very little lower than that of distilled water, whereas the surface tension of the MCPB and 2,4-DB solutions at approximately 0.5% w/v was reduced to 49-54 dynes/cm.

Mr. G. E. Barnsley

We have isolated from a technical grade sample of MCPB an impurity not yet identified which does appear to reduce surface tension.

We have also observed a considerable difference in the degree of scorch induced by the pure and technical MCPB respectively, and are at present trying to determine the significance of impurities in technical MCPB in the scorch problem, particularly in relation to their effects on surface tension.

Dr. R. E. Slade

This is, of course, an exceedingly interesting problem, not only from the point of view of weed control but also of getting to know something about what is happening in the plant. I do not want in any way to discourage investigations on the surface tension. They would certainly assist in giving us more knowledge of the penetration into the plant, but cannot we get to know something about the movement of the material in the plant, for instance by means of radioactive carbon. Is there much difference between the effects of acetic and butyric acids on the plant?

Dr. K. Holly

There are qualitative differences which are difficult to put on a quantitative basis, and we are not quite sure how they relate to this general principal and whether the whole of the action of the phenoxybutyrics is due to their conversion to phenoxyacetics. For instance, there are all sorts of instances, such as reports mentioned this morning, in which phenoxybutyrics seem much more liable to cause root proliferation than the phenoxyacetics. Tracer techniques to study the movement of these compounds are actually under active consideration by some of the physiologists in our Unit.

Butyric acids and acetic acids as such have no growth regulation activity whatsoever. They only have activity purely as acids in the same way as a mineral acid.

Dr. A. Zeller

Acetic acid - mainly in the form of the so-called "active acetate" (a coenzyme A complex) - is an important intermediate in fat metabolism and in other biochemical processes. No similar function is known for butyric acid.

Mr. J. G. Elliott

When working with the butyrics we have noticed a marked lack of dose response by clover; we have seen as much effect on clover by 0.5 lb/ac as we have seen by 4 lb/ac. Similarly on oats, we have observed as much deformity at 1.5 lb as we have seen at 4 lb.

Dr. K. Holly

With regard to this lack of increasing response with increasing dose in the field, I would mention that in pot experiments I never failed to get something approaching a normal dose-response relationship. One explanation could be that in pot experiments one is always dealing with a more uniform population of plants all at the same stage, and thus one does get an increase in response with increase in dose. In the field it may well be that in many instances you have got a mixed population, possibly at different stages of growth and only a proportion of your population is at a very susceptible stage. In the circumstances, you would not then expect a normal dose-response relationship.

Dr. H. J. Barber

We are, of course, very conscious of the need for finding out the fate of MCPB in the plant, but though it is I think partly academic work we have given a good deal of thought to it. This is in reply to Dr. Slade on the role that carbon^{14} labelled 2,4-DB or possible MCPB might play in elucidating what happens. It is really very important that such studies should be very carefully designed beforehand otherwise you may get results which are very difficult to interpret, and may even be meaningless. We are proposing to discuss this with the Radio-chemical Centre at Amersham, because we think that if a number of workers are going to study this problem it may be as well if we all worked with a material which is essentially the same. If necessary we will make the material, but we would prefer it if a body such as Amersham prepared the material; we would help where our special experience with these products might be useful.

Mr. A. L. Abel

The phenoxyacetics have been shown to depend to some extent on light intensity for their action as weedkillers, and under conditions of light and shade similar results against weeds are not obtained. Has anything similar been found with phenoxybutyric compounds?

Dr. K. Holly

I am afraid that so far as the Department of Agriculture at Oxford is concerned no comparable experiments have been done.

Prof. R. L. Wain

The speaker is quite right that the movement of the phenoxyacetic acids in the plant is dependent on light conditions and on sugar reserves. A plant kept for a few days in the dark and then treated say on a leaf with 2,4-D, does not show growth responses in other parts of the plant. On the other hand if you cut off the tip of the treated leaf and dip it into sugar solution you will get your responses in the dark.

I think we are over-simplifying the problem if we are expecting to find a close correlation between the activity of the acetics and butyrics. If one studies the principles involved in the effect of these compounds on plants, there are at least three factors to consider. Firstly, the chemical must get into the plant; such penetration depends on the physical properties of the molecule which in turn depends on its molecular structure. Now the molecular structure and physical properties of the butyrics are different from those of the acetic derivatives so that you would expect penetration into any plant to occur with these compounds to different extents. When you come to a population of different plants the situation, of course, becomes even more complex. In some instances, one might expect the butyric acid to enter the plant more readily than the acetic because of its lower surface tension - we have already heard that one can get better covering with the butyrics than with the acetics. But suppose one has a plant with a waxy cuticle; the butyric acid is more soluble in the wax than the acetic - is this going to mean that the butyric acid can pass through the cuticle more readily, or does it mean that the compound will be held back in the wax? All these problems have to be resolved, but the operation of factors such as these make it possible to understand certain apparent anomalies as for example in Mr. Roach's example this morning with strawberries. Again, there are cases where certain weeds are more readily controlled by the butyric than the acetic derivative, whilst in other cases the acetic/butyric ratio is very wide indeed.

Once the molecule has penetrated into the plant, the chemical has to get to the site of action within the cells and it must have adequate stability to do so. If it gets broken down en route to something that is useless, then the extent to which that occurs will determine the activity. Once the chemical has got to the site of action at cell level it will initiate growth responses which might lead to gross distortion and perhaps the death of the plant. The break-down of the chemical in the soil, and the various factors which affect this process such as temperature, amount of organic matter, etc., may also affect the degree to which activity is shown. Then there is the question of rainfall after spraying which might well follow quickly in one experiment and not another. You will see that we are dealing with a very complex problem which will call for a series of experiments extending over a considerable period before we can compare the herbicidal activities of the acetics with those of the butyrics on any rational basis. Some of these problems are being investigated. Furthermore, new chemicals are being prepared and studied in a number of centres. In the A.R.C. Unit at Wye we have prepared some twenty different homologous series of ω-phenoxy acids and they are all being studied from the point of view of β-oxidation. In chemical and biological experiments such as these one gets a lot of interesting problems thrown up, and one must certainly agree with Sir John when he told us in his opening address that whenever one embarks on a programme of research it is bound to turn up many other problems to keep our colleagues busy. It is perfectly true in this case.

THE PLACE OF MCPB AND 2,4-DB IN BRITISH AGRICULTURE*

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Note. Throughout this paper the abbreviations MCPB and 2,4-DB refer to the sodium salt of 4-(2-methyl-4-chlorophenoxy)-butyric acid and 4-(2,4-dichlorophenoxy)-butyric acid, MCPA to the sodium or potassium salts of 2-methyl-4-chlorophenoxyacetic acid and 2,4-D to the alkanolamine salt of 2,4-dichlorophenoxyacetic acid; all chemicals being applied in aqueous solution without wetting agent.

There comes a time when those concerned with the development of every new weedkiller must decide how it can best aid the agriculture of the country. When the weedkiller is as novel and as outstanding as are MCPB and 2,4-DB and when so many experimental results are available from so many sources, it is particularly important that surveys of the available evidence are made from time to time. This Conference affords an excellent opportunity for examining the progress that has been made during the two years following the introduction of MCPB and 2,4-DB by Professor Wain in 1954.

Before making such a survey using all available evidence, may we remind you that MCPB and 2,4-DB are toxic to plants because they are broken down within the plant to MCPA and 2,4-D respectively. Some plants can carry out this transformation more efficiently than others and therefore MCPB and 2,4-DB are more specific than are MCPA and 2,4-D. It follows, too, that they are unlikely to be more toxic to a given weed than are MCPA and 2,4-D.

The enhanced selectivity between crop and weeds is the most interesting feature of the phenoxybutyrics. It is important to have a fairly clear idea of what effect these chemicals have on important weeds; just as they cause less injury to some crops than MCPA and 2,4-D, so they are less effective on certain weeds.

Effect of MCPB and 2,4-DB on weeds

During the last two years a special study has been made at Oxford comparing the toxicity of MCPB and 2,4-DB to common weeds with that of MCPA and to a lesser extent 2,4-D. We felt that it was most important to relate the toxicity of these new weedkillers to that of one or both of MCPA or 2,4-D, because the toxicity of the latter are well known to vary according to conditions and because knowledge of relative toxicity would be essential for any study of the relative selectivity of these compounds. The main results of these investigations have been described in the research report by Fryer and Chancellor.

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* This paper is based on the experimental results presented by a number of authors in the research reports printed in full elsewhere in these proceedings.

From the chart given in that report it will be seen that for many weeds, two to three times the dose of MCPB compared with MCPA is required to give equivalent effects, but for other weeds, MCPB is nearly as active as MCPA, and for a few weeds, notably charlock, wild radish and mayweed, MCPB is much less effective than MCPA. Tables 1 and 2 summarise the relative toxicity of MCPA, MCPB and 2,4-DB to a number of important weeds.

Table 1

The toxicity of MCPB (sodium) to weeds relative to that of MCPA (sodium)
(Results of experiments by A.R.C. Unit)

The amount by which the dosage must be increased for MCPB to give similar results to MCPA

Factor 1.0-1.5	1.6-2.5	2.6-3.5	>3.5
Corn buttercup	Black bindweed	Annual nettle	Charlock
Creeping thistle (Long term control in grassland)	Broad-leaved dock	Bulbous buttercup	Field pennycress
Curled-leaved dock	Common hempnettle	Fathen	Scentless mayweed
Fumitory	Creeping buttercup	Orache	Wild radish or runch
Knotgrass	Creeping thistle (Shoot kill)	Shepherd's needle	
March horsetail	Field poppy		
Pale persicaria	Spring sowthistle		
Persicaria			

Table 2

The toxicity of 2,4-DB (sodium) to weeds relative to that of MCPB (sodium)
(Results of experiments by A.R.C. Unit)

Species for which:

the dose of 2,4-DB required to give equivalent effects is half, or less than half that of MCPB.	approximately similar doses of MCPB and 2,4-DB are required to give equivalent effects.	the dose of 2,4-DB required to give equivalent effects is twice, or more than twice that of MCPB.
Black bindweed	Annual nettle	Common hempnettle
Broad-leaved dock	Charlock	Curled-leaved dock
Corn buttercup	Creeping buttercup	Fumitory
Field poppy	Creeping thistle	Marsh horsetail
Knotgrass	Fathen	Wild radish or Runch
Pale persicaria	Orache	
Persicaria	Ragwort	
	Scentless mayweed	
	Spiny sowthistle	

Table 1 shows the amount by which the dosage must be increased for MCPB to give results equal to those obtained with MCPA and it will be seen that important weed species fall into all four categories.

Table 2 lists (1) those weeds to which 2,4-DB is at least twice as toxic as MCPB, (2) those to which 2,4-DB and MCPB are of approximately equal toxicity, and (3) those to which 2,4-DB is less than half as toxic as MCPB.

In addition to the information from this programme of experiments by the A.R.C. Unit of Experimental Agronomy, there is, of course, evidence from the results of other research organisations. We have attempted to bring all the available information in the form that we hope will be of special use for the formulation of practical recommendations in the Appendix Table. It is pleasing to be able to report that there is, in general, a good measure of agreement in the weed information obtained from these many sources.

Although the resistance of weeds to MCPA, MCPB, 2,4-D and 2,4-DB increases with age, as shown for charlock in Table 3, there is no evidence from field experiments that the relative toxicity of these chemicals changes markedly with stage of growth. This is in line with the results of pot-culture experiments by Holly working at the University Field Station Oxford. Several investigators comment, however, that MCPB and 2,4-DB act more slowly than MCPA and 2,4-D, and there is limited unpublished experimental evidence to support this. It is clear that further experimental work is required on this important aspect.

Table 3

Dosage in lb/ac of MCPA and MCPB required to give 90% kill of charlock at various stages of growth

	(1)	(2)	(3)
MCPA	0.045	0.079	0.170
MCPB	0.650	1.320	1.950

(1) Cotyledon to 2 true leaves, height up to 1 in.

(2) 3-4 leaves, 1-2.5 in. high.

(3) 5.5-7 leaves, height up to 15 in. pre-flowering.

NOTE: The information is taken from five field experiments.

Since all annual weeds are more easily and economically killed in the young seedling stage and many can only be effectively controlled at this stage by MCPB and 2,4-DB, early treatment is always desirable and often essential, although under certain weather conditions spraying too early may be followed by a second flush of weeds.

MCPB and 2,4-DB for selective weed control in agricultural crops

One of the outstanding features of MCPB and 2,4-DB is their relative safety compared with MCPA and 2,4-D, when applied to certain crops, the most important of which are: cereals, clovers and peas. Other important agricultural crops appear to be too susceptible to MCPB and 2,4-DB to warrant further investigation, with the exception of forage legumes, field beans, celery and potatoes, which have shown considerable resistance in preliminary trials. The tolerance of grass crops, with the exception of cereals, has not yet been investigated.

Cereals

With the exception of 2,4-D on spring oats, it is generally considered that neither MCPA nor 2,4-D has any appreciable effect on the three main cereal crops, provided that the time during which treatment is made is limited to the period between the six leaf stage and the beginning of shooting. Treatments made earlier than this are liable, with the exception of spring oats, to cause severe deformity of the ears and possibly reduced yield. The recent realisation that the safe period for treating spring oats with MCPA may be extended to any time between the emergence of one leaf and the beginning of shooting has been welcomed as giving an opportunity to spray at the time most suitable for weed control. It allows early treatment of the weeds when they are in the most susceptible stage of growth, and gives a better control of the more resistant weeds and just as good a control at a lower dose (and therefore cost) of the more susceptible weeds. Greater yield increase can also be obtained by removal of weed competition before it has affected the growth of the crop(1).

With the introduction of MCPB and 2,4-DB, these benefits of early spraying can now be extended also to wheat and barley. From the results reported to this Conference, the following tentative conclusions can be drawn: (1) On spring wheat, MCPB at doses up to 48 oz/ac and possibly higher, can be applied at any time from the one leaf stage of the crop to the beginning of shooting without any reduction in yield or appreciable deformity of the ears. 2,4-DB, on the other hand, is liable to reduce the yield of spring wheat and to cause serious head deformity when applied during the one to five leaf stages at doses above 12 oz/ac. There is evidence of a slight interaction between variety and effect, but so far this does not appear of practical significance. On winter wheat, a single experiment indicates that treatment with MCPB at any time during the winter and following spring has no appreciable affect on the crop irrespective of stage of growth, whereas 2,4-DB is liable to cause tubular leaves when applied during the autumn and early winter, and deformed heads when applied in the late winter and early spring. (2) On spring barley, MCPB has also been completely safe at the early stages of growth at doses up to 48 oz/ac, except in a single experiment where a small decrease in yield occurred when this dose was applied. The evidence, as a whole, suggests that barley is very resistant to MCPB and can, in fact, tolerate doses higher than 48 oz/ac without appreciable deformity or yield reduction, even when treated in the one to five leaf period. Barley is much more resistant than spring wheat to 2,4-DB and it appears that this chemical can also be applied safely when the barley is in the one to five leaf stage or older, provided the dose does not exceed 32 oz/ac. Doses up to 64 oz/ac at the one to five leaf stage have not reduced the yield but have caused slight deformity which might be undesirable in crops intended for malting. There is no evidence of any difference between the susceptibility of barley varieties to MCPB or 2,4-DB. (3) Less attention has been given to the effects of MCPB and 2,4-DB on spring oats because MCPA can be used at the one to five leaf stages on this crop without danger. The available evidence suggests that 2,4-DB is about as safe as MCPA and, therefore, is likely to be more efficient for those weeds which are more easily killed by it (see the Research Report by Fryer and Chancellor). MCPB appears to have a greater margin of safety on spring oats than MCPA or 2,4-DB.

The present position concerning the safe treatment of cereals by MCPA, MCPB, 2,4-D and 2,4-DB is summed up tentatively in Table 4.

Table 4

Suggested maximum doses and safe times of application for MCPA, MCPB, 2,4-D and 2,4-DB to cereals

	Winter Wheat		Spring Wheat		Spring Barley		Spring Oats	
	Autumn and winter applications	Spring applications	1	2	1	2	1	2
MCPA (sodium)	NO?	YES (32)	NO	YES (32)	NO	YES (32)	YES (24)	YES (24)
MCPB (sodium)	YES (48)	YES (48)	YES (48)	YES (48)	YES (48)	YES (48)	YES (48)	YES (48)
2,4-D (amine)	NO	YES (24)	NO	YES (16)	NO	YES (16)	NO	NO
2,4-DB (sodium)	NO	YES (48)	NO	YES (48)	YES (32)	YES (48)	YES (24)	No information

Stage 1 = 1-5 leaf stage

Stage 2 = 6 leaf stage to shooting

The figures in brackets indicate the maximum permissible doses in oz/ac. Those for MCPA and 2,4-D are taken from the Weed Control Handbook 1956; those for MCPB and 2,4-DB are estimations based on the evidence so far available.

While the increased dose of MCPB or 2,4-DB necessary for most weeds of cereals, compared with MCPA or 2,4-D, (Table 1) may at first seem to make their use unattractive because of increased cost, the advantages should not be overlooked of being able to spray MCPB and 2,4-DB at the time most suitable for weed control. The dose of MCPB or 2,4-DB applied to young weed seedlings may not have to be much greater than that of MCPA or 2,4-D applied to the same weeds when they are older at the usual time of spraying. The advantage of the early removal of weed competition in terms of increased cereal yield may, in any case, allow an increased cost of materials per acre to be economic. This is illustrated by the figures in Table 5, which summarise the increase in yield from early spraying of oats with MCPA compared with applications at the normal time. It will be seen that as a result of spraying early (1-4 leaf stages) an extra 4 cwt/ac of oats were obtained over and above the increase due to the later spraying (6-7 leaf stages). It follows, therefore, that the use of MCPB and 2,4-DB on wheat and barley offers, under some circumstances, the prospects of a greater net return than could be obtained by the use of MCPA or 2,4-D.

Table 5

Yields of Sprayed Oat Crops, 1955 (1)

(Means for each treatment of six experiments of similar design)

		Early Spraying (Oats 1-4 leaf stage)		Normal Spraying (Oats 6-7 leaf stage)	
		lb/ac MCPA (potassium)		lb/ac MCPA (potassium)	
		0.75	1.5	0.75	1.5
Yield (cwt/ac)	25.3	30.7	30.8	27.0	26.3
Yield as percentage of unsprayed control	100	121	122	107	104

Clover

The absence of a really safe selective weedkiller for use on undersown cereals has been all too evident in the last few years judged by the large number of weedy crops seen around the countryside. Unshielded white clover seedlings, while being more resistant to 2,4-D than to MCPA can be severely damaged by doses as low as 8 oz of either compound, although it seems that red clover seedlings can stand this dose of MCPA, but not 2,4-D, without serious damage. In the field the susceptibility of clover seedlings is often masked because a high proportion of the applied spray is retained by the crop and weed foliage and little reaches the clover. The risk of damage is, nevertheless, a real one and many farmers do not spray their undersown corn or direct-sown leys because of it, or they delay spraying until the weed and cover-crop provides a canopy by which time much weed competition has occurred. The effects of shielding are illustrated by the following Table of results from a series of experiments conducted by the N.A.A.S. in 1955.

Table 6

Effect of shielding on the damage to undersown clover caused by MCPA

(presence of clover in stubble as % of control)

MCPA (oz/ac)	8	16	32	64
Shading recorded as appreciable (mean of 6 experiments)	108	101	106	103
Shading not appreciable (mean of 4 experiments)	99	80	59	33

MCPB and 2,4-DB are much less toxic to seedling clover and allow the safe treatment of undersown crops and direct-sown leys for the control of many weeds. The relationship between the relative toxicity of MCPB and 2,4-DB to red and white clover respectively appears to follow that of MCPA and 2,4-D, MCPB having proved less toxic than 2,4-DB to red clover but more toxic to white. With the exception of 2,4-DB in spring wheat, both MCPB and 2,4-DB can be used safely on cereals from the one leaf stage onwards and when treating undersown corn, there is only the stage of growth of weeds and clover to consider.

Up to the present it has been recommended that spraying undersown crops with MCPB should be delayed until the clover has developed one trifoliate leaf, by which time rather resistant weeds, such as redshank and black bindweed, have often become difficult to control. The tentative recommendation in the Weed Control Handbook 1957, based on all available evidence from pot-culture and field experiments is that the treatment of undersown clover with MCPB may take place as soon as the spade leaf has developed in the majority of plants; this will allow earlier treatment and, therefore, more efficient control of weeds. For direct-sown leys, the recommendation is as for the last season that clover should not be sprayed with MCPB before the one trifoliate leaf stage. The stage of growth problem with MCPB and 2,4-DB appears to be very complex and certainly warrants further critical investigation, and, in view of the irregular germination of clover seed, information is also required on the effects of MCPB and 2,4-DB on clover when applied pre-emergence.

The maximum safe dose of MCPB or 2,4-DB on red and white clover seedlings under field conditions is still not clear. While a slight check has sometimes been reported for 24 oz MCPB and 2,4-DB at the one to three trifoliate leaf stages, the effect does not seem to have been much more severe with 48 oz. This absence of change of response with increasing dose appears to be a characteristic of MCPB and 2,4-DB in clover and makes any assessment of relative toxicity for 'acetics' and 'butyrics' difficult. As a general guide, however, it appears that the relative toxicity of MCPA and MCPB to seedling red clover is about three to one and to white clover about eight to one.

It appears then that MCPB and 2,4-DB can be used safely on red and white clovers, once they have passed the cotyledon stage, at doses in the range of 24-48 oz/ac. On white clover MCPB is about eight times less toxic than MCPA. It would, therefore, be more selective for all weeds given in Table 1, except charlock and wild radish, for which MCPA or better still 2,4-D, which give a good control of these weeds at low doses, might be a preferable, if not completely safe, treatment. On red clover MCPB is about three times less toxic than MCPA and would be more selective only for the weeds in the first two columns of Table 1. It may be concluded that while MCPB is almost invariably more selective than MCPA for undersown or direct-sown white clover, it is only more selective on red clover for weeds which are almost as susceptible to MCPB as to MCPA. For instance, since the relative toxicity of MCPA:MCPB is 10:1 for charlock and about 3:1 for red clover seedlings, MCPA is in this case about three times as selective as MCPB, but for fumitory which has a relative MCPA:MCPB toxicity rating of 1.5:1, MCPB is twice as selective as MCPA.

The majority of annual weeds in direct-sown leys can be controlled by spraying or mowing and chemical weed control is only important in the case of chickweed (Stellaria media) and knotgrass (Polygonum aviculare). A good control of the latter in the young seedling stage may be obtained with 48 oz 2,4-DB or MCPB, but otherwise dinoseb has to be used. The safety of MCPB and 2,4-DB on clovers does, however, offer an excellent opportunity for the control of seedling perennial weeds such as docks and rushes and of creeping thistle before they become established and difficult to kill.

In established leys or permanent pasture, MCPA and 2,4-D are being extensively used for the control of such weeds as buttercups, rushes, ragwort, plantains and dandelions. Frequently no persistent damage to the clover seems to occur but, on occasion, damage to white clover has been serious and long-lasting. Recent investigations, reported to this Conference, have shown that the suppression of white clover due to treatment with MCPA may, in fact, persist for one or two years or more. There is, however, insufficient evidence to say what are the conditions which contribute to damage and its persistence, and the farmer is in the unfortunate position of having to take a risk when he uses MCPA or 2,4-D. MCPB or 2,4-DB, on the other hand, appear to be a good deal safer and from the results available are unlikely, at doses up to 48 oz/ac, to have an appreciable effect on white clover (and also probably red, although more information is required).

For the long-term control of creeping thistle there is no increased price to pay for this added safety, since MCPB is just as effective as MCPA. For several other important weeds of grassland MCPB or 2,4-DB can give as good control as with MCPA or 2,4-D but a higher dose is required, and this will mean a greater cost per acre in return for the assurance that no serious depression of the vigour or abundance of clover will follow the weed control treatment.

Clover for seed

Only three experiments have been reported on the effect of MCPB and 2,4-DB on clover for seed, but they show quite clearly that these compounds can be most harmful to the production of seed. The time of application in relation to flowering appears to be an important factor in the amount of damage that occurs and cases have been reported where broad red clover sprayed with 24 oz of MCPB before the first cut of the season yielded satisfactory seed crops later on. In view of the need for a selective herbicide in clover seed crops further investigations are warranted.

Peas

For several years, dinoseb (ammonium) and, more recently, dinoseb (amine) have been used extensively and successfully for the control of a wide range of annual weeds in peas, but they have several disadvantages from the user's point of view. There is a definite need for an alternative weedkiller for peas and there is little doubt that MCPB will meet that requirement, at least for specialised aspects of weed control in this crop.

Much of the research work with MCPB has been directed at finding out which varieties can be treated without loss of yield. The results are summarised in the following table.

Resistance of Pea Varieties to MCPB

Very resistant to 48 oz/ac	Resistant to 48 oz/ac but results not as conclusive as for varieties in Group I	Susceptible - yields reduced by 48 oz or less
Alaska	Canners Perfection	Gregory's Surprise
Dark Skinned Perfection	Clipper	Kelvedon Wonder
Lincoln	Shastar	
Onward	Meteor	
Perfected Freezer		

Other varieties which have been little affected by 36 oz MCPB, but concerning which insufficient evidence is available to draw definite conclusions, are: Servo, Emigrant, Big Ben, Lincoln, Rondo, Harrison's Glory and Zelka. The results with Thomas Laxton have been variable.

The crops on which these results are based varied in stage of growth having from two to about eight expanded leaves, and there appears to be no reliable evidence on the relationship between stage of growth, variety and the effects of MCPB. Since it is important that treatment is made when annual weeds are small information is urgently required on the youngest stage at which peas can safely be sprayed with MCPB.

Apart from the resistance of peas as measured by yield, two other criteria of possible damage by MCPB must be considered. Firstly, it appears that treatment may cause some epinasty and a temporary slight check to growth and it is desirable that growers are warned that this may occur. Secondly, there may be a smaller effect on the maturity of the peas. On occasion, maturity, as measured by suitability for deep-freezing or canning, has been advanced by one to two days after treatment with 48 oz MCPB/ac.

Much less attention has been given to the effects of MCPA, 2,4-D and 2,4-DB on peas; all three compounds have been shown in laboratory tests to be more toxic than MCPB. In the field, 2,4-D is generally recognised as being far too toxic, but MCPA at low dosages has been used successfully, and at low cost, for the control of charlock, and for this purpose it is almost certainly more selective than MCPB. While the relative toxicity of MCPA to MCPB to peas has by no means been established under field conditions, there is little doubt that there is insufficient margin of safety for the widespread usage of MCPA on this crop.

There is little information concerning the toxicity of 2,4-DB to peas, but as there is general agreement that it is more toxic than MCPB, it is unlikely to be of much value, except possibly for the control of weeds to which it is considerably more toxic than MCPB (see Table 2).

Summing up the case for MCPB, there seems little doubt that this chemical should have a definite place in the cultivation of peas, being capable of controlling many weeds in at least a considerable number of varieties without injury to the crop. The main limitations, apart from the varieties which may prove too susceptible, seem to be its specific and slow action on weeds compared with dinoseb, making it unsuitable for use on mixed stands of susceptible and resistant weeds. Satisfactory overall weed control should follow a correctly timed application of 48 oz/ac MCPB, provided the main weeds are among the following: annual nettle, black mustard, charlock, corn buttercup, creeping thistle, fathen, fumitory, hempnettle, pennycress, poppy and treacle mustard.

Conclusions

One thing shown up in this review very clearly is the enormous complexity of what at first sight may seem a fairly straightforward subject. Two years work representing a large proportion of our available research effort in the herbicide field has resulted in no more than a rough working knowledge of MCPB and 2,4-DB and has raised enough problems to fill research programmes for several years to come.

Much remains to be done on the effects of these chemicals on weeds (a subject, which as we get to know more about it, demands specialised experimental techniques and equipment). With the latitude in the time of spraying allowed by the butyrics on cereals it becomes of greatly increased importance to find out the minimum doses required to kill or suppress common weeds at various stages of growth and also under different conditions. If we can show that by spraying early, the farmer can get good control of weeds at a considerably reduced dose and at the same time have all the benefits of early spraying, we shall really have done something to help him cut his production costs.

On undersown clover as well, the butyrics are of great importance, but much more information is required on the relative toxicity of the acetics and butyrics to seedling red and white clover at different stages of growth before we can assess accurately the most efficient chemical to use for a particular problem. This is a very large subject indeed. On seedling red clover, for example, it seems that MCPB has very little advantage over MCPA, even at greater cost per acre, while on white clover, it is much more efficient.

The problem of clover in established grassland is also a difficult one. MCPA and 2,4-D are undoubtedly suspect to the extent that they can under some conditions result in a considerable and persistent suppression of white clover. MCPB and 2,4-DB are less toxic to established clover, but except for creeping thistle, it appears that a higher dose of the butyrics is necessary to kill the weeds. How can this information be used to advise the farmer, who wishes to improve his grassland as cheaply and quickly as possible? Clearly, more research is required before advisory problems such as this can be answered with any emphasis.

With peas, the story seems fairly clear-cut as far as it goes and MCPB should be particularly useful for the control of creeping thistle, fathen and seedling charlock. There does not appear, however, to be a very large safety margin with the crop as a whole, some varieties having proved susceptible to MCPB, and with a crop so notoriously variable in its reaction to weedkillers, we shall clearly have to continue our experimental work with MCPB for a number of seasons before we can be sure that it is absolutely reliable.

We must not forget the other crops, which have shown resistance to the butyrics: celery, lucerne and other forage legumes, beans, potatoes and of course several horticultural crops. Altogether a great deal of research is required if we are to develop these new chemicals so that they can be of greatest use to the agricultural industry in this country. We can conclude with every justification that MCPB and 2,4-DB must surely have come up to the expectations of Professor Wain when he told us at the last Conference that "Our results suggest that further work would not be a waste of time". He did not, we are certain, at that time realise just how many problems he was asking his colleagues in the agricultural research service and in industry to solve.

Reference

(1) ELLIOTT, J. G. (1956) Agriculture, Lond., 62, 574-577.

Appendix Table

The susceptibility of weeds to MCPA, MCPB and 2,4-DB

Introductory Note

The following Table is based on the results of the programme of weed experiments described in the research report by Fryer and Chancellor (No. C.10) but information from all available sources (England and Wales only) has been freely used. In view of the small amount of evidence for some species, the susceptibilities indicated in the Table should be regarded as tentative.

The reaction of each weed species to MCPA* at 12 and 24 oz and to MCPB* and to 2,4-DB* at 24 and 48 oz/ac is indicated by one of the three response categories:

'S' - complete or near complete mortality with effective suppression of survivors

'C' - partial mortality and severe check to survivors

'R' - no useful effect from treatment.

Each species is marked A, B or P according to whether it is an annual, biennial or perennial.

The reaction of annual weeds to a given dose of MCPA, MCPB or 2,4-DB is influenced markedly by stage of growth at the time of spraying; for each annual species two growth stages are given:

S - seedling stage

I - intermediate stage between seedling and flower bud stages.

It must be emphasised that this Table does not apply to annual weeds at or after the flowering stage.

The stage of growth of biennials or perennials, except where specified, can be assumed to be in the period between active growth of the rosette and the flower bud stage. The response categories, except where stated otherwise, refer to the reaction of biennials or perennials in the year of treatment. Few long-term results are yet available.

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* This Table refers to the use of aqueous solutions of MCPA (sodium or potassium), MCPB (sodium) and 2,4-DB (sodium) without added wetting agents.

Species		Stage	MCPA 12	MCPA 24	MCPB 24	MCPB 48	2,4-DB 24	2,4-DB 48 oz/ac	Remarks
Anthemis cotula (Stinking mayweed)	(A)	S	R	C	R	R	R	R	
		I	R	R	R	R	R	R	
Atriplex patula (Common orache)	(A)	S	C	S	C	S	C	S	
		I	R	R	R	R	R	R	
Brassica nigra (Black mustard)	(A)	S	S	S	S	S	S	S	Resistant to MCPB and 2,4-DB after the opening of flowers.
		I	S	S	C	S	C	S	
Capsella bursa-pastoris (Shepherd's purse)	(A)	S	S	S	S	S	-	-	
		I	C	S	-	-	-	-	
Carduus nutans (Musk thistle)	(B)		S	S	S	S	C	S	4-6 in. high (1 expt).
Chenopodium album (Fathen)	(A)	S	S	S	S	S	S	S	
		I	S	S	C	S	C	S	
Chrysanthemum segetum (Corn marigold)	(A)	S	R	R	R	R	-	-	
		I	R	R	R	R	-	-	
Cirsium arvense (Creeping thistle)	(P)	SK	S	S	S	S	S	S	SK = Shoot kill in arable crops
		LTC	C	S	S	S	S	S	LTC = long-term control in grassland.
Cirsium vulgare (Spear thistle)	(B)		S	S	S	S	-	-	Sprayed in year of flowering.
Equisetum arvense (Common horse-tail)	(P)	SK	S	S	S	S	S	S	SK = Shoot kill.
Equisetum palustre (Marsh horse-tail)	(P)	SK	S	S	S	S	S	S	SK = Shoot kill.
Erysimum cheiranthoides (Treacle mustard)	(A)	S	S	S	C	S	C	S	
		I	S	S	R	R	R	C	

Species		Stage	MCPA 12	MCPA 24	MCPB 24	MCPB 48	2,4-DB 24	2,4-DB 48 oz/ac	Remarks
Fumaria officinalis (Fumitory)	(A)	S	C	S	C	S	C	S	
		I	R	C	R	C	-	-	
Galeopsis tetrahit (Common hemp-nettle)	(A)	S	C	S	C	S	R	R	
		I	R	C	-	-	R	R	
Galium aparine (Cleavers)	(A)	S	R	R	R	R	R	R	
		I	R	R	R	R	R	R	
Matricaria maritima ssp. inodora (Scentless mayweed)	(A)	S	R	C	R	R	R	R	
		I	R	R	R	R	R	R	
Matricaria matricarioides (Rayless mayweed)	(A)	S	R	R	R	R	R	R	
		I	R	R	R	R	R	R	
Medicago lupulina (Black medick)	(A)	S	R	C	R	R	R	R	
		I	R	R	R	R	R	R	
Mentha arvensis (Corn mint)	(P)		R	C	R	R	-	-	
Papaver rhoeas (Corn poppy)	(A)	S	C	S	C	S	C	S	
		I	R	C	R	C	R	C	
Plantago lanceolata (Ribwort)	(P)		C	S	C	S	-	-	
Plantago major (Greater plantain)	(P)		C	S	C	S	-	-	
Polygonum aviculare (Knotgrass)	(A)	S	R	C	C	C	C	S	
		I	R	R	R	R	-	-	
Polygonum convolvulus (Black bindweed)	(A)	S	R	C	R	C	C	C	
		I	R	R	R	R	R	R	
Polygonum lapathifolium (Pale persicaria)	(A)	S	R	C	R	C	C	S	
		I	R	R	R	R	R	R	

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Species	Stage	MCPA 12	MCPA 24	MCPB 24	MCPB 48	2,4-DB 24	2,4-DB 48 oz/ac	Remarks
Polygonum persicaria (Persicaria) (A)	S	R	C	R	C	C	S	
	I	R	R	R	R	R	R	
Ranunculus acris (Meadow buttercup) (A)	TK	S	S	S	S	-	-	TK = Top kill.
Ranunculus arvensis (Corn buttercup) (A)	S	C	S	S	S	S	S	
	I	-	-	-	-	-	-	
Ranunculus bulbosus (Bulbous buttercup) (P)	TK	C	S	S	S	-	-	TK = Top kill. No information on long-term effect by butyrics.
Ranunculus repens (Creeping buttercup) (P)	TK	S	S	S	S	S	S	TK = Top kill.
Raphanus raphanistrum (Wild radish) (A)	S	S	S	R	C	R	R	
	I	C	S	R	R	R	R	
Rumex crispus (Curled dock) (P)	S	S	S	-	S	-	-	SK = Shoot kill in arable crops.
	SK	C	S	C	S	C	S	
Rumex obtusifolius (Broad-leaved dock+) (P)	S	S	S	C	S	-	-	SK = Shoot kill in arable crops.
	SK	C	S	-	-	-	-	
Scandix pecten-veneris (Shepherd's needle) (A)	S	R	C	R	R	R	C	
	I	R	R	R	R	R	R	
Senecio jacobaea (Ragwort) (B or P)	SK	C	S	R	R	R	R	SK = Shoot kill.
Senecio vulgaris (Groundsel) (A)	S	R	C	R	R	-	-	
	I	R	R	R	R	-	-	

Species		Stage	MCPA 12	MCPA 24	MCPB 24	MCPB 48	2,4-DB 24	2,4-DB 48 oz/ac	Remarks
Sinapis alba (White mustard)	(A)	S	S	S	R	C	-	-	
		I	S	S	R	R	-	-	
Sinapis arvensis (Yellow charlock)	(A)	S	S	S	S	S	S	S	MCPB ineffective at or after the flowering stage.
		I	S	S	C	S	-	-	
Sonchus arvensis (Perennial sowthistle)	(P)	SK	C	S	C	S	-	-	SK = Shoot kill.
Sonchus asper (Spiny sowthistle)	(A)	S	C	S	C	S	-	-	
		I	R	C	R	C	R	C	
Thlaspi arvense (Field pennycress)	(A)	S	S	S	C	S	-	-	
		I	S	S	-	-	-	-	
Urtica urens (Annual nettle)	(A)	S	C	S	C	S	C	C	
		I	R	C	-	-	-	-	

DISCUSSION ON THE PREVIOUS PAPER

Mr. K. Carpenter

There is just one point I would like to raise on the question of these compounds in seed crops. We still do not have anything like enough evidence to be sure whether they can or cannot be used in all circumstances. The reductions in yield noted by Mr. Ormrod from spraying in the middle of June when flowering is beginning confirms work which was published at the last Conference. We have since found that spraying much earlier in May has no noticeable effects on yield, but the question of germination, percentage hard seed etc., has to be worked out. In white clover seed it does appear to be possible to use these chemicals for removing some of the weeds.

Mr. W. Ochiltree

Having heard the research papers on the use of MCPB I would greatly appreciate comments from contractors or farmers who have a wide practical experience on the use of this chemical over the past year.

Mr. M. Bradford

We have done a fairly considerable amount of contract work using MCPB over the past two years. To get comparable control it is essential to step up the total volume applied. We have found that using low volume a safe minimum would be 15 gallons as opposed to a possible 10 gallons using MCPA. Also we have noticed that one has to attack creeping thistle at a very much earlier stage than one would have thought necessary to get comparable results. We have had no cases of damage to clovers even when we have been urged to spray in the earlier stages of development, against our better judgment, to catch more difficult weeds at an earlier stage.

Mr. F. Wright

Like the previous speaker, I have never sprayed MCPB at less than 20 gal/ac. I find this gives me the best results. I have found that at nearly all stages flowering of clover sprayed with MCPB has been suppressed. In some instances, it has been a moot point whether the same results on new leys could not have been obtained with MCPA.

Mr. W. R. R. Lucas

I strongly support the last speaker. Over the past three years we have sprayed a considerable acreage of undersown cereals with MCPA, and we have never had any complaint of damage caused.

Prof. R. L. Wain

It has been suggested to me that there is some confusion in farmers' minds between MCPA and MCPB. I would remind you that there is another interesting selective herbicide in this series, the phenoxy caproic acid and that is logically referred to as MCPC. I should imagine by now that most people are familiar with the term MCPB. If there is any difficulty I must take the blame because it was, I think, my suggestion when I first spoke of these compounds at the Jubilee Meeting of the Association of Applied Biologists, that the term MCPB should be adopted.