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In trials laid down in 1960, at four of the sites, 4-CPA was applied at 5 and 10 lb/acre between the last week in July and the second week in August. Assessment of these treatments in 1961 showed that in no case was the reduction in the density of fronds greater than 40 per cent.

Effects of varying the time of application. It is possible that the effectiveness of the treatment in these trials was inadequate because they were applied when the fronds were not at the stage of development giving maximum susceptibility to the chemical. In a small trial in the East of Scotland in 1959 Erskine found that the degree of control achieved by treatment with 4-CPA was markedly influenced by the time at which the treatment was applied (Erskine 1960). It can be seen from Fig. 3 that spraying with 7½ lb/acre of the nonyl ester in early July caused a reduction in the number of fronds of 47 per cent, but where the application was made in early August frond density was reduced by 82 per cent.

Although trials in the Oxford area have shown that the susceptibility of the plant to the chemical varies with the stage of growth they have also demonstrated that application of the chemical at the period of maximum susceptibility does not ensure a satisfactory level of control. In the 1960 trials at Blenheim Park and Charlbury, Oxfordshire, where 10 lb/acre was applied to different plots at approximately weekly intervals from the end of June until mid-September, themaximum reductions in the number of fronds in the year after treatment were 30 and 18 per cent at Blenheim and Charlbury respectively.

In the more detailed trial laid down in 1961 at Finstock, Oxfordshire, the treatments extended over an even longer period, starting at the time of frond emergence and continuing until the fronds were showing signs of senescence. Before spraying each plot a visual assessment, expressed as a percentage, was made of the amount of ground covered by the bracken canopy. The effects of treatment with both the "phytotoxic" ('K.E.B.') and "non-phytotoxic" ('Aromosol H') oil formulations were assessed in August 1962 and the results are shown in Fig. 4. For both formulations themaximum reduction in the number of fronds was achieved when the applications were made at or about the time when the emergence of fronds was complete and when the rapid expansion of the bracken canopy had ceased. As the fronds matured and approached sporulation the bracken became increasingly resistent to the chemical. Maximum reductions in the density of fronds were 60 and 53 per cent respectively when the chemical was formulated in 'Aromosol H' oil and 'K.E.B.' oil. In neither case could the control be considered to have reached a satisfactory level. The results of the West of Scotland trials reported at the 1962 Weed Control Conference (Kirkwood 1962) were largely in agreement with the Oxford results.

Effects of formulation. Formulation has received considerable attention in trials since 1959. The nonyl and butyl esters, formulated as both conventional and "invert" emulsions, have been extensively tested and comparisons have been made between formulations containing the so called phytotoxic and non-phytotoxic oils. The amine formulation has also been included in a number of trials and various granular formulation of the esters have been included, both as pre- and post-emergence applications in screening trials. From all the information available there is no indication that method of formulation will consistently increase the efficacy of the treatment. It has been shown that under dry conditions the

amine formulation is equally as effective as the ester formulations but when applied to wet bracken, or when rain falls soon after spraying, the efficiency of the amine formulation is considerably reduced. When the "invert" formulations of 4-CPA were tested by A. H. Marks and Co. Ltd., in 1958 they gave a consistantly high reduction in frond density (approx. 90 per cent) at all five Scottish sites (1960 Report) but in trials in subsequent years, both by A. H. Marks & Co. Ltd., and other organisations, it has not been possible to reproduce these results. In some instances the "invert" formulation has given a lower level of control than the oil in water formulations. On the information available, it is not possible to explain these variations from year to year in the effectiveness of this formulation.

Effects of respraying in consecutive years. Respraying with 4-CPA in the year following initial treatment has given disappointing results. In the commercial trials in Scotland respraying did cause some further reduction in frond density but the effects were small when compared with those of the initial treatment. In three of the A.R.C. Weed Research Organisation's trials in England and Wales, all those plots which had been treated with 4-CPA in 1959 were re-treated in 1960 with 10 lb/acre of the chemical. As in the Scottish trials, respraying caused only a slight further decrease in thedensity of fronds in the following year when compared with the effects of the initial treatment (Fig. 2). It is possible that there are insufficient fronds present on the spraying area to provide an adequate canopy for retention of the spray or to transport the absorbed chemicals to the rhizome system.

Persistence of treatment. Three of the 12 trials laid down by the A.R.C. Unit in 1959 had been abandoned by 1962. One (Bruton) was abandoned in 1961 as the area was required for reclamation. In 1962 the sites at Lydney and Machynlleth were lost; the former was abandoned as the site had been heavily burnt and subsequently used as part of a course in a motor cycle race and the latter had been ploughed out in July as part of a reclamation scheme. As the plots at three of the surviving sites had been resprayed in 1960 persistency of treatment can only be considered at the six remaining sites. In these six trials all 4-CPA treatments, other than the 10 lb/acre dose applied at the earlier date, had given a very poor control when assessed in 1960 (Fig. 2) and by the second season after spraying, in practically each case, the bracken had recovered. Where the plots had been sprayed with 10 lb/acre at the earlier date of application the reduction in the bracken population was quite small at two of the sites (Pontesbury and Barden) and by 1962 the treated plots could not be distinguished from the unsprayed plots. At the remaining four sites, where the treatment had caused an initial reduction in the density of bracken of approximately 60 per cent, the regrowth of the bracken was variable in subsequent years. At Eggleston, where the chemical caused an initial reduction of 64 per cent, the density of fronds was still 58 per cent below that of the control plots in 1962 but at Capheaton, where the stand of bracken was initially reduced by 59 per cent, there was no visible effect of treatment by 1962.

To summarise - 1. Although 4-CPA has given extremely good control of bracken in a number of trials, its effectiveness has varied considerably both from year to year and from site to site.

2. It has not yet proved possible to overcome these variations in effect by different methods of formulation.

3. It has been shown that the susceptibility of bracken to the chemical varies with the stage of development of the plant but treatment at the optimal time does not necessarily ensure a high degree of control.

4. The persistency of treatment varies from site to site and the speed of recovery of the bracken does not appear to be directly related to the level of the initial "kill".

5. Although it has been shown that, under certain conditions, 4-CPA is toxic to bracken there seems to be little hope, in the near future, of it being developed as a reliable herbicide. To treat bracken infested land on a commercial scale with 7.5 lb/acre 4-CPA would cost £6. 10s. 0d. - £7. 10s. 0d. per acre, depending upon the method of application. It is most doubtful that the value of any improvements which might be gained would warrant the application of a higher dose.

Commercial Sales of 4-CPA. In 1960 it was estimated from the commercial sales of "Weedone Brackontrol" and "Teridox" that some 2,000 acres of bracken had been sprayed with 4-CPA during 1959. So many of the applications proved to be unsatisfactory that, from 1960 onwards, the manufacturers discouraged further sales of their products.

(c) AMITROLE Although Forrest (1959) reported little success with amitrole as a herbicide for bracken in Scotland, Bylterud (1958) demonstrated its effectiveness at low rates in Scandinavia and for this reason it was included in the "International type" trials agreed upon at Stuttgart.

It had been shown in the U.S.A. that with certain species, such as Agropyron repens, the addition of ammonium thiocyanate greatly increased the effectiveness of the amitrole. In all the "International type" trials made in the United Kingdom in 1959 and in the majority of trials laid down since 1959 in this country the amitrole was formulated as a mixture with ammonium thiocyanate in the proportion of 2.0 lb of 3-amino-1,2,4-triazole and 1.85 lb. ammonium thiocyanate per gallon (Weedazol. T.L.)

Amitrole (Weedazol) and amitrole/thiocyanate (Weedazol TL) were compared as bracken herbicides during 1961 at the five Scottish sites of A. H. Marks & Co. Ltd., in an A.R.C. Weed Research Organisation trial in Hampshire and in the trials laid down by the West of Scotland Agricultural College. Assessment of these trials in 1962 indicated that the addition of the ammonium thiocyanate did increase efficiency but the "activating" effect was far less marked than for some other weed species.

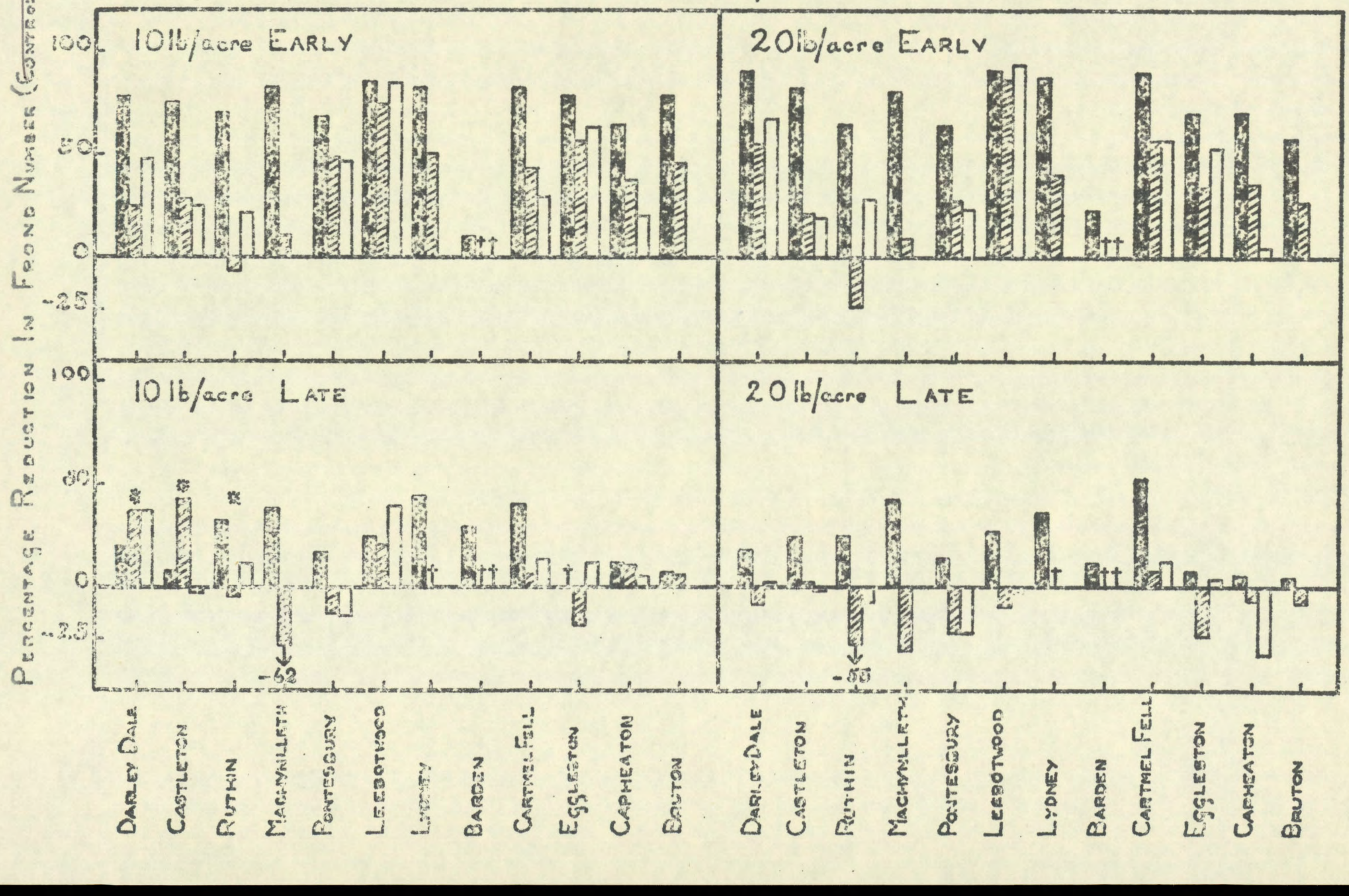
Fig 5. The Effect Of Amitrole On Bracken. Assessments Made One, Two And Three Years After Treatment.

† No Visual Effect Of Treatment. No Count Made.

* Plots Resprayed In July 1960 At 10 Lb/Acre.

Year Of Assessment

1960 1961 1962



The effects of the two formulations of amitrole are compared in Table 3 which has been prepared from the results of trials carried out by the West of Scotland Agricultural College in 1961.

Table 3. The effects on bracken of amitrole with and without the addition of ammonium thiocyanate (from Kirkwood 1962). Bracken sprayed between 4-13 July, 1961; assessment made July, 1962.

Site	Reduction in frond numbers expressed as per cent of control	
	Amitrole/sesquicarbonate (Weedazol) 6 lb/acre	Amitrole/thiocyanate (Weedazol TL) 6lb/acre
Douglas, Lanark.	9	16
Eskdalemuir, Dumfries	81	86
Auchencairn, Kirkcud.	45	67
Luss, Dumbart.	62	58
Appin, Argyll.	49	75
Port of Menteith, Perth.	55	77
Bolmaha, Stirling	51	58

At only one of the sites did the amitrole/thiocyanate fail to give a better level of control than the "unactivated" formulation. At the other six sites the addition of ammonium thiocyanate increased the effectiveness of the chemical to a varying degree. At two of the sites, Douglas and Bolmaha, the effect of "activation" was negligible but at Appin the amitrole/thiocyanate gave a markedly better control than the amitrole/sesquicarbonate.

Effects of changing the dose. In the 12 A.R.C. trials in England and Wales those plots which had been treated with the amitrole/thiocyanate in 1959 gave most encouraging results when assessed in 1960 (Hodgson 1960). Frond counts indicated that the 10 lb/acre application had given a high degree of control at the earlier date of spraying and that, in general, increasing the dose to 20 lb/acre had not effectively increased the "kill" (Fig. 5.) A reduction in density of fronds of over 80 per cent was recorded at several sites for both doses and at only one site was the reduction below 60 per cent.

The effectiveness of the herbicide was considerably reduced when the applications were made at the later date and the variation from site to site was appreciably greater. For example, at one site the number of fronds was reduced by over 50 per cent, in contrast to several of the trials where there was no appreciable control.

Those fronds which had emerged on treated plots showed the characteristic chlorosis associated with amitrole and on those plots treated in the period June-July many of the pinnae were badly deformed. In many cases the pinnules were completely absent and usually, where present, they had failed to expand.

None of the treatments appeared to have had any adverse effect upon the associated grasses and shrubs.

At the Weed Control Conference in 1960 Erskine (1960) reported that in a trial in the East of Scotland in 1959 the amitrole/thiocyanate applied at 10 lb/acre had given reductions in frond density of 92 per cent and that even where the dose was reduced to 5 lb/acre the number of fronds was still reduced by 90 per cent. At the same conference Kirkwood (1960) reported little success in two trials in the West of Scotland where both amitrole/sesquicarbonate and the amitrole/thiocyanate had been applied during 1959 at 10 and 20 lb/acre on two spraying occasions. At one site where the "unactivated" chemical was applied at 20 lb/acre at the earlier date the maximum reduction in the number of fronds was 50 per cent. The corresponding reduction with the "activated" material was 38 per cent. At the second site the chemical was ineffective at both doses on both spraying occasions. Kirkwood suggested that the chemical had been applied when the fronds were already mature and less susceptible than younger fronds to the treatment.

Although in 1960 in a number of instances treatment with amitrole/thiocyanate gave very good control in the year following spraying, in general the results of trials were not quite as impressive as those of the previous season. Applications were made at four of the A.R.C. sites in both 1959 and 1960 and at two sites treatments were applied in the three consecutive seasons 1959-61. The results of these treatments are compared in Table 4. The early applications were made at approximately the same time in each year but in 1960 the second spraying occasion was considerably earlier than in 1959. Where the treatments were applied at the same time in each year they were less effective in 1960 than in 1959. Delaying the treatment by three to four weeks in 1960 considerably reduced the level of control.

At the five sites of A. H. Marks & Co. in Scotland applications of amitrole/thiocyanate gave more promising results than those recorded for England and Wales (Table 5). At four of the sites a most satisfactory control was achieved even when the dose was reduced to 5lb/acre, and at three of the sites applications of 10 lb/acre reduced the density of fronds by 90 per cent or more. At the fifth site, at Tobermory, the control was relatively poor at all doses except where 10 lb/acre had been applied in August. It is interesting to note that the July applications were most effective at two of the sites whereas the later spraying gave the better control at the other sites.

Table 6 shows the results of treatment with amitrole/thiocyanate at 5 and 10 lb/acre in 1961 at three of the sites in England and Wales and it can be seen that where a dose of 10 lb/acre was applied, on both spraying occasions, the level of control was of the same order as in 1960. At each site, decreasing the dose to 5 lb/acre considerably reduced the effectiveness of the treatment.

TABLE 4

The effect of amitrole on bracken. A comparison of the effectiveness of the chemical when applied at the same sites in three different years - 1959, 1960 and 1961. Assessments made in the autumn of the year following treatment.

Site	Date of application						Reduction in the number of fronds expressed as a percentage of control											
	Early			Late			20 lb/acre Early		20 lb/acre Late		10 lb/acre Early			10 lb/acre Late			5 lb/acre Early	5 lb/acre Late
	1959	1960	1961	1959	1960	1961	1959	1960	1959	1960	1959	1960	1961	1959	1960	1961	1961	1961
Ruthin	30.6	6.7	-				64	59			70	49						
				3.9	26.7	-			27	63				32	61			
Machynlleth	1.7	7.7	-				80	14			82	9						
				3.9	26.7	-			42	-10				38	-18			
Leebotwood	2.7	8.7	7.7				91	74			85	63	77				56	
				2.9	27.7	24.8			27	62				24	50	24		31
Barden	7.7	12.7	27.7				23	28			38	5	37				11	
				15.9	16.8	30.8			12	28				29	8	22		15
Cartmel Fell	8.7	-	27.7				90				82		69				58	
				15.9	-	29.8			53					40		33		40

Table 5 : **The effects of amitrole on bracken in 1960. A comparison of the** effectiveness of the chemical at five different sites in the West of Scotland (taken from Joice, R. & Norris, J. 1962). Assessment made in September, 1961.

Site	Time of application	Redn. in frond no. as per cent of control					
		10lb/acre		7.5 lb/acre		5 lb/acre	
	July	Aug.	July	Aug.	July	Aug.	July	Aug.
Langholm	22	5	97	71	84	60	80	57
Moffat	20	4	68	48	70	81	85	89
Callander	17	3-4	72	90	74	91	78	72
Kilmelford	12	1	91	62	77	79	73	61
Tobermory	15	2	47	73	39	38	49	54

Effects of varying the time of application. It was quite clear from the results of the 1959 trials that the timing of the application was an important factor in determining the effectiveness of the treatment and in 1960 this aspect of the problem was studied by the A.R.C. Weed Research Organization in two trials at Charlbury and Blenheim Park and by A. H. Marks and Co. Ltd., at Ramsgill in Yorkshire. In the two A.R.C. trials, although applications were made at weekly intervals between the end of June and mid-September, when assessed 12 months after spraying, none of the treatments had given a satisfactory control at either site. At Blenheim a maximum reduction in the number of fronds of 55 per cent was recorded on plots which had been sprayed on July 24th and at Charlbury the treatment had virtually no effect, irrespective of the time of application.

FIG 6. THE EFFECT OF AMITROLE ON BRACKEN. THE INFLUENCE OF DATE OF APPLICATION IN TWO TRIALS IN YORKSHIRE MADE A. H. MARKS & CO. LTD ASSESSMENT MADE ONE YEAR AFTER TREATMENT

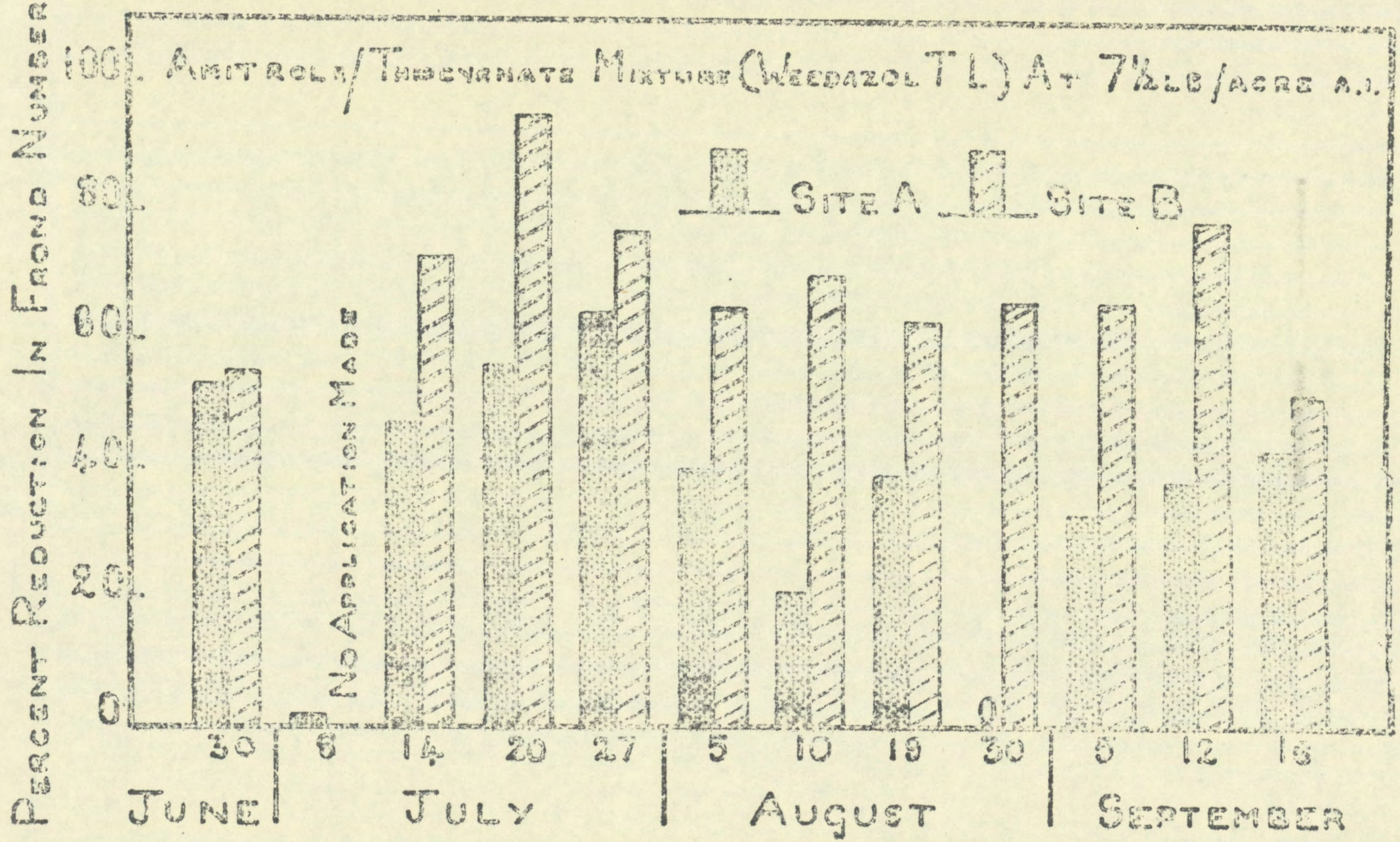


Fig 7. The Effect Of Amitrole On Bracken — The Influence Of Date Of Application.

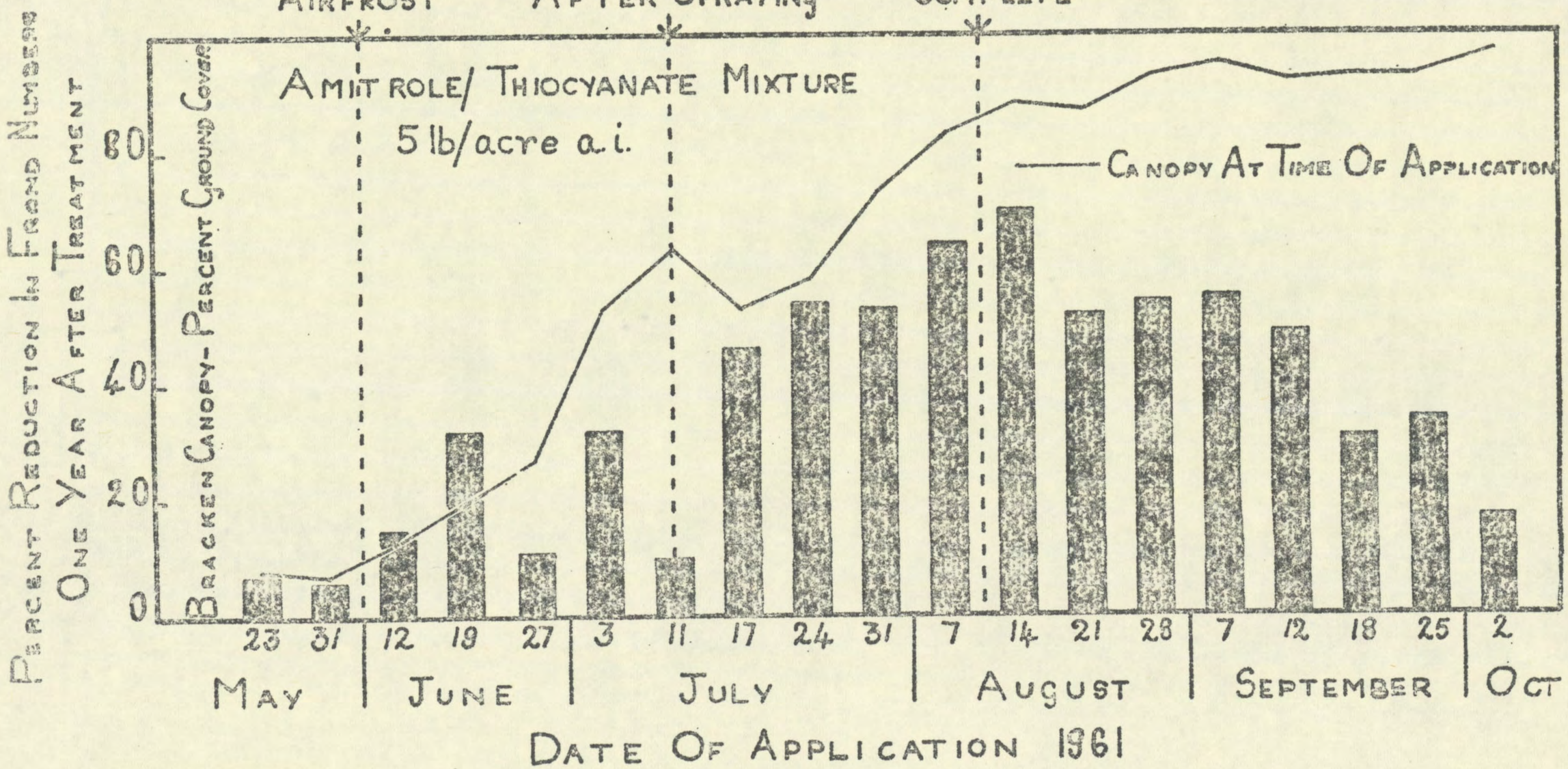


Table 6

The effect of an amitrole/thiocyanate mixture on bracken as assessed in the year following treatment

Site	Date of Application		Date of Assessment	Reduction in frond numbers expressed as a percentage of control - ~~Control = 100~~			
	Early	Late		5 lb/acre Early	5 lb/acre Late	10 lb/acre Early	10 lb/acre Late
Leebotwood	7.7.61		5.9.62	56		77	
		24.8.61			31		43
Barden	27.7.61		23.7.62	11		37	
		30.8.61			15		22
Cartmell Fell	27.7.61		17.7.62	58		69	
		29.8.61			40		33

The trials at Ramsgill demonstratedthat the timing of the application of the chemical was an important factor in determining the effectiveness of the treatment. Fig. 6 shows that at both sites the effect of the chemical was increased by delaying the application until the third or fourth week in July. When the amitrole/thiocyanate was sprayed after this period the efficacy of the treatment was greatly reduced.

Although the two trials were within a short distance of each other, on either side of a small valley, the level of control achieved at the various dates of application were markedly different and at Site A the treatments were consistently more effective than at Site B. It has not been possible to find a satisfactory explanation to account for these wide differences.

The effect of the timing of application was studied in much more detail during 1961 by the A.R.C. Weed Research Organisation in a trial at Finstock. In this trial, where the first applications of the chemical were made before the first fronds emerged and continued until the fronds were showing signs of senescence, detailed observations were made on the stage of development of the bracken canopy and of the emergence of fronds on each spraying occasion, (severe air frosts at the end of May and at the beginning of June 1961 seriously damaged those fronds which had emerged and greatly retarded the development of the canopy during June. Again in 1962 air frosts occurred at the end of May but due to the lateness of the spring very few fronds had emerged and the damage to the stand was less disastrous than in the previous year). The relationship between the stage of development of the bracken stand and the efficiency of the treatment a year after application is presented in Fig. 7.

With the amitrole/thiocyanate the general pattern of the 'susceptability' of the bracken was very similar to that previously described for the 4-CPA treatments in that the efficiency of the treatments increased progressively with the date of spraying until mid-August. Spraying during this period caused a 70 per cent reduction in frond density as compared to the control plots.

It can readily be seen from Fig. 7 that maximum control was achieved by treatment at the time when frond emergence was complete and the canopy was almost fully expanded.

Persistence of treatment. To gain some measure of the persistence of the treatment, all those plots in the A.R.C. trials which had been sprayed with amitrole/thiocyanate in the summer of 1959 were reassessed in 1961. The results of this assessment indicated that there were very wide variations in the rate at which the bracken had recovered in the second year of treatment. Fig. 5 shows that where applications had been made at the earlier date in 1959 there had been considerable regrowth at many sites and in some instances recovery was virtually complete. Only at one site, at Leebotwood in Shropshire, did the treatment remain fully effective in this second season after treatment.

In spite of this regrowth of the bracken there were still fronds at most sites showing symptoms of amitrole toxicity.

Assessment of the treated plots in 1962, the third season after treatment, showed that, although the speed of recovery of the bracken had not been maintained, there had been further regrowth and at many of the sites the treatment had become completely ineffective. As in 1961, the treatment still maintained outstanding control on the site at Leebotwood. Where either 10 or 20 lb/acre of amitrole/thiocyanate had been applied at the earlier date the plots were virtually clear of bracken and rhizome material dug from these plots was dead.

Affects of formulation. The work to assess the "activating effect" of ammonium thiocyanate has been described previously and apart from this, no further attempt had been made until recently to increase the activity of amitrole by different methods of formulation. In 1963 an invert emulsion formulation was applied in two A.R.C. trials but no assessment of the treatment can be made before the summer of 1964.

Conclusions. There is no doubt that at certain stages of growth bracken is most susceptible to treatment with amitrole, but in someinstances, even when the chemical has been applied at the optimum time, bracken has shown a remarkable degree of resistance to the treatment. Up to the present time it has not been possible to determine the factors which influence this "resistance to treatment" of the bracken in some areas. Similarly where the treatment has been initially successful the rate of regrowth of the bracken, in subsequent years, has varied from site to site. As yet no serious study has been made to determine the causes of these variations in the speed of recovery of treated bracken growing in different habitats. Until these difficulties have been investigated and overcome neither amitrole/sesquicarbonate or amitrole/thiocyanate can be considered to be reliable herbicides in the control of bracken.

(d) Dichlobenil. There would be obvious advantages to a chemical which could be applied to bracken as a pre-emergence treatment; not only would many of the hazards of working in a mature stand of bracken be overcome but the labour requirements for the application of the chemical would occur at a time of year when the pressure of work on most farms is not great.

It appeared from the work in Holland in 1959 that dichlobenil might fulfil this role and in both the following year and in 1961 the A.R.C. Weed Research Organisation and the West of Scotland Agricultural College tested the chemical formulated (a) as a 50 per cent wettable powder and (b) as granules containing 5 per cent of the active ingredient.

These trials, in which the treatments were applied at all times of year, have shown that, although the wettable powder formulation will give a certain degree of control in the year of application, if applied at 9 - 10 lb/acre before the fronds emerge, it is not as effective as the granular formulations. When the granules were applied at a similar dose during April or May frond emergence was completely suppressed for the remainder of that season. However, with both the formulations, in the year after spraying, it was not possible to distinguish between the treated and untreated areas.

It seems that the chemical volatalizes in the upper layer of bracken litter to form a toxic barrier. The frond buds are killed as they develop and pass through this barrier. In the course of the winter following treatment the barrier disperses and the bracken appears to develop normally in the following year.

Apart from providing only a temporary control dichlobenil also suffers from the disadvantage that any sward which may be present below the bracken is also completely suppressed. Because of these characteristics of the chemical it seems that its only application would be in circumstances where suppression of bracken is required for a limited number of years and treatments could be made annually, as say in reafforestation schemes containing species which are not susceptible to the chemical.

(e) MCPA In past trials, by both the A.R.C. Unit of Experimental Agronomy and by the Scottish Colleges, bracken has not proved to be particularly susceptible to treatment with MCPA up to doses of 10 lb/acre but more recently H. Fail of Kings College, Newcastle has suggested that applications of 10 - 20 lb/acre of MCPA may give excellent control.

In view of the encouraging results in Fail's trials, Messrs. Fisons Pest Control Ltd. laid down 21 trials in Northumberland and Scotland during 1960. Six of these trials were subsequently discarded; at three sites the method of application had proved to be unreliable and in a further three trials the growth of bracken on the control plots in the year following application was too uneven to allow reliable assessment. Assessment of the remaining 16 trials in 1961 showed that at ten sites doses of 10 lb/acre MCPA, applied when the fronds were approaching maturity had given an acceptable control. At four of the sites some areas were treated with either 15 or 20 lb/acre of MCPA, and where the chemical was applied at those rates the control was considered to be excellent.

There is little evidence on the persistence of treatment with MCPA but in a private communication Fisons state that "Fail's trials have shown that 15 lb/acre MCPA on dense bracken has exerted control for four years and 10 lb/acre MCPA on 'moderate' bracken showed a three year persistency."

It is difficult to explain the conflicting evidence of earlier trials, but from experience gained in the recent trials with other chemicals, it is reasonable to suggest that the susceptibility of bracken to treatment with MCPA varies considerably at different stages of growth. It is possible that in these earlier trials the MCPA was applied at a time when the bracken was not at a stage of growth giving maximum susceptibility to the treatment.

Before accepting or rejecting MCPA as a suitable herbicide for the control of bracken it seems necessary to study the effectiveness of the chemical on bracken at various stages of development.

Little attention has been given to the effects of formulation. In 1961, Erskine in the East of Scotland investigated the effects of varying the proportion of the 2-methyl-6-chloroisomer in MCPA. He reported that MCPA and the isomer mixed in the ratio of 95:5 gave a more effective control than the pure chemical when applied at 5 lb. total acid equivalent per acre. As the proportion of the isomer was increased the effectiveness of the mixture declined and when 20 per cent of the isomer was added to the pure chemical the treatment gave no significant control. Erskine intends to examine the effects of these mixtures at higher doses.

(f) DICAMBA-SODIUM. In 1961 dicamba-sodium* was applied as a post-emergence treatment at 4lb/acre in a screening trial at Charlbury. In the following year it caused a considerable reduction in the density of fronds and those which did emerge showed considerable deformities; many failed to expand and subsequently died. Fronds outside the perimeter of the treated plots also showed similar deformities, indicating that the chemical had been translocated to the fronds in the untreated areas. Applications of this chemical were made at three sites during 1962 and the trials were assessed in August, 1963.

From the results given in Table 7 (page 23) it is clear that at each site, irrespective of the time of application, a dose of 8lb/acre had reduced the number of fronds by over 90%. In addition, those few fronds which did emerge were so stunted that they provided virtually no ground cover. The pinnule segments of these fronds were greatly diminished in size; in a very high percentage of these fronds expansion of the pinnule segments was completely inhibited.

Table 7 also shows that when the dose was reduced to 4lb/acre the effectiveness varied from site to site and was seemingly dependent upon the time of application. At Finstock applications of 4lb./acre made in either mid-July or late August gave a satisfactory control but when spraying was carried out in early August the treatment was apparently less effective. At Cartmel Fell, too, an excellent control was achieved by spraying in mid-July. On the other hand 4lb/acre at Wytham, in either mid or late August, only reduced the number of fronds by 30%. However, as

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* Applied as "Banvel D"

as Finstock, the later application caused a far greater reduction in the height and vigour of those fronds which did emerge.

Table 7

The effects of dicamba-sodium when applied to bracken at various times during 1962. The assessments were made between late August and mid-September in the following year. The results are expressed as percentage reductions when compared with control plots (~~control~~ = 100).

Time of application	Dose lb/acre	Finstock			Wytham			Cartmel Fell		
		% Reduction in:-			% Reduction in:-			% Reduction in:-		
		Frond No.	Cover	Ht.	Frond No.	Cover	Ht.	Frond No.	Cover	Ht.
Mid-July	2	24	15	33				47	86	75
	4	71	85	55				89	99	75
	8	93	100	70				99	100	94
Early-August	2	0	0	26	15	33	7			
	4	27	50	48	31	55	13			
	8	94	100	85	92	99	80			
Late-August	2	41	70	55	39	41	20			
	4	82	95	63	30	70	43			
	8	100	100	100	95	100	90			

A dose of 2lb/acre was relatively ineffective at two of the three sites, but at the third site (Cartmel Fell) although the number of fronds was reduced by less than 50%, the height of the fronds and the size of the pinnule segments was so decreased that the fronds present provided only little ground cover.

In each trial it was observed that surrounding those plots treated in the previous year were many fronds which had pinnule segments much reduced in size. In many instances such deformed fronds were located several feet from the nearest treated areas, indicating that the compound or some derivative had been translocated over far greater distances than has ever been observed by the Unit for any other chemical so far tested for the control of bracken.

In autumn 1963 samples of rhizomes from the Finstock trials were dug up and examined. Those rhizomes from plots that had been treated with 8 lb/acre exhibited many signs of phytotoxicity and there was no sign of normal development in the apical or frond buds. At doses below this level although some of the rhizome material appeared to be injured, many frond and apical buds seemed to be following a normal pattern of development. It is still too early to assess whether these developing buds will emerge in spring 1964 and if they do emerge whether they will be abnormal. The trials will be reassessed to gain a measure of the density and vigour of the regrowth in the various treatments.

Further trials to test this chemical were laid down during 1963.

(g)"Tordon" The results of the trials laid down in 1962 by Dow Agrochemicals Ltd. were most promising. Doses of 4lb/acre or more, applied either when the fronds had one pair of pinnae unfurled or when the fronds were fully expanded, gave almost complete control in 1963. Where the treatments were made as pre-emergence applications in April 1963 those plots sprayed with 2, 4 or 8lb/acre were virtually free of fronds when assessed in the following July. The trials will be reassessed in 1964 to gain information on the persistency of the effects.

Further trials were laid down in 1963 by both Dow Agrochemicals Ltd. and the A.R.C. Unit of Experimental Agronomy.

(h) Gibberellic Acid Attempts to stimulate the development of quiescent frond buds by treating individual fronds with gibberellic acid did not prove successful. Treated fronds were examined regularly in the year of treatment and, at intervals during the following spring and summer, both treated and untreated rhizomes were extracted and examined. Even where fronds had been treated on five occasions with 2,000 p.p.m. there was no indication that the treatment had affected bud development on the rhizomes associated with the treated fronds.

DISCUSSION

The four chemicals, dalapon, 4-CPA, amitrole and MCPA have been extensively tested since 1959 and none has provided a consistently satisfactory control of bracken. Although it has been shown that the timing of the application may be critical in determining the efficacy of the treatment this factor alone does not account for the variations observed.

A fifth chemical, dichlobenil, will provide a complete control of bracken for one season but since all grass species and most broad leaved species are also eliminated it shows no promise for the control of bracken in grassland. It might be of limited value in reafforestation schemes.

a) Importance of locality. From the results of the numerous trials since 1959 it has become quite clear that the location of the trial site is a major factor in determining the effectiveness of any particular chemical : none of the chemicals tested has given a consistant level of control from site to site. It is not surprising that such variations do occur considering the ubiquity of the bracken plant in the United Kingdom and the wide range of habitats in which it grows. The wet, relatively frost free, infested areas of the extreme west of Scotland contrast sharply with the bracken areas of the Norfolk Brecklands, which are almost annually subjected to summer drought and late winter frosts. It is not unreasonable to expect that these widely differing patterns of climate will have some influence in the growth habit of the plant and hence on its susceptibility or resistence to chemical treatment.

The edaphic, as well as the climatic factors must also have a pronounced effect upon the growth habit and vigour of the bracken rhizome system. Soil depth, nutrient status, and soil water relations will all play an important role in determining the developmental pattern of a plant with such a complex and penetrating system of underground parts. Thus it is reasonable to assume that such characteristics as the number of frond buds per unit area, the ratio of active to dormant frond buds, the density of emerged fronds per unit area and the seasonal potential of productivity of these fronds must all be largely determined by the habitat.

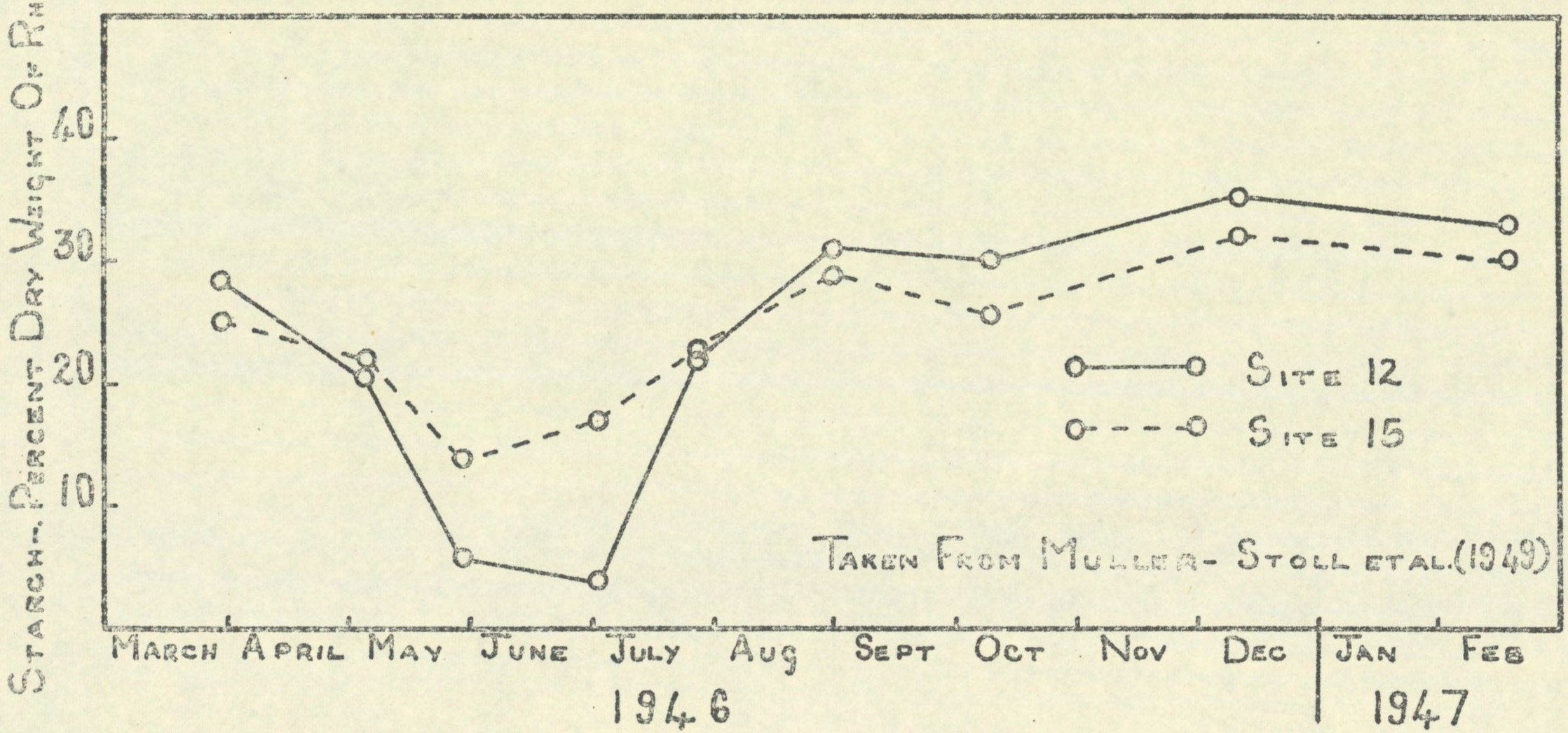
It is not known to what extent genetic differences occur in the bracken growing in the various areas of the British Isles. The occurrence of different strains of bracken could account for a large proportion of site to site variations in the effectiveness of chemical treatment.

In this connection in 1961 clonal material from several sites was planted in the weed garden of the A.R.C. Weed Research Organisation, Oxford. Transplanted bracken rhizomes are slow to establish but it is hoped that during the next year or so sufficient material will be available to allow some assessment of any clonal differences.

In the A.R.C. trials it has been shown that at certain sites a particular treatment may be very effective and that the results can be repeated from year to year whereas at other sites the same treatment has virtually failed to exert any control. In particular theresults have shown that at Leebotwood in Shropshire treatment with amitrole has consistently given a high degree of control and samples of rhizome taken in 1962 from those plots sprayed in 1959 were dead. On the other hand at Charlbury, Oxford, the bracken has shown a high degree of resistence to this treatment. A serious study of these two habitats might well reveal the factors which influence the reaction of bracken to chemical treatment and with such investigations in mind, rhizomes from both areas have been included in the clones being established by the A.R.C. Weed Research Organisation.

b) Time of application. The trials carried out by A. H. Marks and Co. Ltd. in 1957 had strongly suggested that, for 4-CPA, the time of spray application could influence considerably the level of control achieved and so, in all those trials

Fig 8 The Starch Content Of Bracken At Various Times Of The Year



laid down in 1959 by the A.R.C. Unit of Experimental Agronomy, all three chemicals, - dalapon, 4-CPA and amitrole - were applied on two occasions during the year. Assessment of the treatments, in 1960, fully confirmed the results of the previous trials and also demonstrated that the timing of application was an equally important factor in determining the effectiveness of both dalapon and amitrole; the level of control achieved with amitrole was particularly dependent upon the time of application.

In subsequent years the results of the numerous trials laid down to gain more specific information on the influence of timing of application on the effectiveness of chemical control were in close agreement. It has been shown for amitrole and for two different formulations of 4-CPA that the general "pattern of susceptibility" of bracken is the same, in that the efficiency of the treatments is increased by delaying the application until frond emergence is complete and the fronds are almost fully expanded. Delaying treatment beyond this stage progressively reduces the level of control.

During the phase of frond emergence and rapid frond expansion it would be expected that most or all of the materials synthesised by the plant would be retained by the aerial portions and that the downward movement from stem to rhizome would be negligible. As the fronds cease to expand and start to mature their demand for carbon substrates will decrease and the downward translocation of these materials will become more rapid and provide transport from frond to rhizome for any chemical which is translocated in the phloem.

There is little information on the annual rhythm of translocation in bracken but indirect evidence of these variations in the rate of downward movement is provided from Germany by Müller-Stoll et al (1949) who, in an investigation of the reserve materials in the bracken rhizome have shown that the starch reserves vary considerably during the year (Fig. 8). Determinations were made on both stunted bracken from a dry location at high altitude (Site 12) and on vigorous bracken growing in a more fertile, moist position (Site 15). In both cases, in spring, the rhizomes contained between 25-30 per cent of starch but these reserves were rapidly depleted during the period of bud development and frond emergence. Where the rhizomes were growing under less fertile conditions the starch content had fallen to less than 5 per cent by the beginning of July but under the more favourable environmental conditions the reduction was not so pronounced, namely 14 per cent.

During July and August, when the phase of most rapid expansion of the fronds is over, the starch reserves were rapidly restored and by the beginning of September samples from both sites contained a slightly higher percentage of starch than that recorded in March. From September until the end of the year there was a further very gradual rise in the reserves followed by a gradual decline during the remainder of the winter.

Thus on the basis of the information available it would seem that when a chemical is applied to bracken in the early summer (a) the Leaf Area Index*

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* Leaf Area Index (L.A.I.) = Leaf area per unit area of land.

is low and a proportion of the spray is wasted by falling directly to the ground, (b) the young and tender filoage is extremely sensitive to scorch which interfers with the translocation of the chemical which has penetrated, (c) in any case, most of the translocation, at this time is in an upward direction. Therefore little of the chemical applied will reach the rhizome system. A later application when the L.A.I. is almost at its maximum, when frond emergence is complete and when the foliage is more mature, allows optimum conditions for the retention of the chemical whilst assimilates are still being transported rapidly to the rhizome system. Finally there is evidence, that for the bean, as the leaves age less chemical is able to penetrate (Sargent and Blackman 1962). Thus towards the end of the season, as the bracken fronds age, it might be expected that penetration of the chemical could become the limiting factor.

The detailed trials have been restricted to two chemicals only, but as far as is known their modes of action are very different. Therefore it is reasonable to assume that other chemicals toxic to bracken may well be most effective as post-emergence sprays if applied at the stage of growth described for amitrole and 4-CPA and, in future screening trials, it might be advantageous if treatments were applied at this time. As yet there is insufficient information on granular materials to allow any statement to be made as to the optimum time of application for this type of treatment.

(c) Formulation. Since 1957 A. H. Marks and Co. Ltd. have actively investigated the possibility of increasing the effectiveness of 4-CPA as a herbicide for bracken by different methods of formulation but none of those investigated has proved consistently more successful than the oil in water emulsion formulation of the nonyl ester of 4-CPA applied in the earliest trial in 1956. In 1958 applications of the nonyl ester, formulated as a water in oil emulsion (invert emulsion) gave an exceptionally high level of control but it has not been possible to repeat those results in subsequent years.

The relative merits of phytotoxic and non-phytotoxic oils in the formulation of 4-CPA have been investigated but there has been no indication that the oil employed seriously effects the level of control achieved.

A number of different ester and amine formulations of 4-CPA have been compared with the nonyl ester, but have proved no more successful. Granular formulations of the free acid, the nonyl ester and the ethylene glycol ester, applied as both pre- and post-emergence treatments have proved less effective than applications of the nonyl ester applied as the oil in water emulsion.

The A.R.C. Weed Research Organisation has tested an ester formulation of dalapon and an ester and a hydrazine formulation of MCPA in screening trials but none of these preparations proved to be effective.

(d) Husbandry factors. Up to the present little attention has been given to the management problems which would be associated with the rapid elimination by chemical treatment of the bracken on infested areas. Where the bracken is growing in association with grasses the clearance of the bracken would permit the rapid

development of a sward which could be improved and up graded by current methods of grassland husbandry. On the other hand in many areas the bracken has become so dense and the layer of litter so deep that other species are almost completely absent; in these circumstances the sudden destruction of the bracken cover in one year would leave the land completely devoid of vegetation and covered by a layer of undecayed organic matter. These conditions would be wholely unsuitable for the establishment of grass species and more undesirable pioneer species such as bramble might well become established. In these areas where the bracken is completely dominant it may be necessary to consider pre-spraying treatments designed to produce an environment favourable for the establishment of grass species immediately the bracken has been eliminated. The application of lime and basic slag one or more years before the application of a herbicide might encourage the break down of undecayed organic matter and the addition of a nitrogenous fertilizer might further encourage the bacterial breakdown of this organic layer.

It is not possible to forecast whether such pre-treatment would render the bracken more or less susceptible to chemical treatment. Long term research would be necessary to assess the effects of such treatment on both the habitat and on the susceptibility of the bracken to chemical treatment and it might be appropriate to consider this aspect of the problem in the near future.

It is obvious that, with our present knowledge of grassland, the chemical treatment of these densely infested areas would not lead to increased productivity but might easily produce denuded areas subject to erosion and eventual colonisation by the more undesirable species.

In passing, it may not be irrelevant to note that many bracken areas are situated in the country's "beauty spots" and action without careful consideration might well mar this beauty. On the other hand, it may be stated that as far as is known bracken is not the essential food supply for any of our fauna. Whilst it does provide cover for nesting game birds it also attracts vast numbers of the common fly, is poisonous to cattle and often hinders the shepherd in his search for sick animals.

(e) Future Research In connection with the further study of the problems and aspects which have been discussed the Scottish Colleges and A. H. Marks & Co. Ltd. have given some indication of their future research programmes in private communications. The future plans of the Edinburgh School of Agriculture are not sufficiently defined to allow detailed comment, but D.S.C. Erskine suggests that there are a number of chemical types yet to be tested, including those of the "Erbon" group. He also states that chemicals sprayed on land previously dressed with lime and basic slag gave interesting results and sometime will be devoted to further investigations in these areas. Some attention will also be given to the granulation of growth regulating chemicals and other herbicides on limestone.

At the West of Scotland Agricultural College, R. C. Kirkwood will continue to test chemicals as potential herbicides for the control of bracken. Any chemicals showing promise in these preliminary screening trials will be incorporated into a programme of widespread trials carried out in co-operation with the County Advisory Service.

Fundamental studies on the penetration and translocation of amitrole, were initiated in 1962 and were continued during 1963 but Kirkwood states that controlled growth chambers or cabinets are essential if the scope of this work is to be expanded. The possibility of biological control in bracken will be given some attention.

In 1963 A. H. Marks and Co. reduced drastically their trials with herbicides for bracken and as far as is known they have no intention of increasing their efforts in the foreseeable future.

f) The Subsidy Problem. In the last report the question of financial assistance for the chemical control of bracken was considered in some detail. At that time it seemed likely that chemical treatment would give a level of control better than, or at least equal to, that attainable by a three years programme of cutting. It has been adequately proved during the last few years that none of the chemicals under consideration are sufficiently reliable to be considered for commercial use. The manufacturers fully agree with these findings and it is thus unlikely that any pressure will be brought to bear in the near future for the present subsidy arrangements to be extended to cover chemical control.

CONCLUSIONS AND RECOMMENDATIONS

The enthusiasm stimulated in the mid- and late 1950's by the almost simultaneous discovery of the three potential bracken herbicides, dalapon, 4-CPA and amitrole, has waned to some extent. It has not been possible to determine the factors which cause the variation in the effectiveness of the chemicals from site to site or from year to year and, in general, the commercial organisations involved in the problem are not equipped for the investigation of such ecological and physiological problems. Moreover it is doubtful whether the possible revenue from any future sales of a bracken herbicide justifies expensive research programmes. After five years of quite extensive trials, A. H. Marks and Co. have virtually abandoned bracken research and Dow Agrochemicals will undoubtedly proceed cautiously with the development of "Tordon" because of the extremely potent nature of this herbicide.

The testing and development of a potential bracken herbicide is, of necessity a slow process. A preliminary assessment cannot be made until one year after application and to gain information on the persistancy of the treatment observations must continue for at least a further two years. Furthermore, because of the ubiquity of bracken, proving trials of initially successful chemicals must be laid down in a wide variety of environmental conditions. Because of the time and cost incurred in testing any particular chemical it seems that, if a reliable evaluation is to be made with a minimum of delay, official organisations will have to take an active part in the investigation.

Now that the author's period of secondment to the A.R.C. Weed Research Organisation has ended, consideration will have to be given as to what future action, if any, is taken to investigate the outstanding problems outlined in this report or what steps should be taken to co-ordinate investigations relating to the assessment of potentially useful herbicides. It may not be out of place to suggest that since satisfactory techniques have been evolved much of the work

could be undertaken by an Experimental Officer and assistants provided that careful supervision were ensured.

It is clear that the most imperative requirement is the further testing of dicamba-sodium and "Tordon." Although these herbicides have shown promise in initial tests, it would be unwise, in view of past experience, to place too much faith in the fulfilment of such promise. If present trials prove successful, both chemicals will have to be tested on an extensive scale before their effectiveness and reliability can be evaluated with confidence. Even if one or both chemicals should prove successful the cost of application at the optimum dose might prohibit their use on a commercial scale.

It must also be bourne in mind that the development of a successful herbicide would only provide a primary tool in the reclaimation of bracken infested areas. After eradication of the bracken the problem of land improvement arises; this may not present an unduly difficult task where the bracken is already associated with some grass species and the grasses are not killed by the herbicidal application. On land where the bracken is completely dominant and overlays a thick mat of undecayed litter it presents a serious obstacle. At the present time there is no knowledge on the management of such areas and if successful herbicides were developed it might require several years to determine methods of improvement which could be applied in such cases. Whether the potential productivity of such sites would warrant the cost of eradication and reclaimation will also have to be resolved.

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APPENDIX TABLE 1

Description of the main A.R.C. Weed Research Organisation bracken sites established in 1959.

Site No.	Location	Approx. height above sea level ft.	Aspect and contour
1	Darley Dale Derbyshire	1000	Moderate S. slope without shade or shelter.
2	Castleton Derbyshire	1300	Moderately steep S. slope without shade or shelter.
3	Ruthin Denbighshire	400	A very slight slope almost on the brow of a ridge. No shade or shelter.
4	Machynlleth Montgomery	400	Steep S. slope without shade or shelter.
5	Pontesbury Shropshire	1500	Moderate E. slope. Sheltered to the N. and E. by trees. No shade.
6	Leebotwood Shropshire	1200	Moderate N.W. slope without shade or shelter.
7	Lydney Gloucestershire	300	Moderate E. slope without shade or shelter.
8	Barden Yorkshire	1000	Moderate S. slope without shade or shelter.
9	Cartmel Fell Lancashire	500	Moderate N.E. slope without shade or shelter.
10	Eggleston Durham	1200	Level site with no shade or shelter.
11	Capheaton Northumberland	700	Slight S. slope without shade or shelter.
12	Bruton Somerset	500	Steep N. slope in fairly narrow valley. Ridge of valley provides some shelter. No shade. The bracken has been cut annually for many years previously.

APPENDIX TABLE 2(a)

Notes on chemicals tested in A.R.C. screening trials

Chemical	Dose in lb/acre	Dates of application	Year	Site	Remarks
Phenoxyacetic acids					
2-CPA	10	4.8	1960	Aldershot	No effect
4-CPA butyl ester	5 and 10	19.8 and 9.9	1959	Charlbury	5 and 37% reductions respectively.
4-CPA nonyl ester invert emulsion in Carnea oil.	5 and 10	19.8 and 9.9	1959	"	0 and 35% reductions respectively.
4-CPA nonyl ester 9.3% granules	10	28.4 and 1.5	1961	"	Applied as pre-emergence treatment. No effect.
4-CPA ethylene glycol 8.9% granules	5 and 10	28.4 and 1.5	1961	"	Applied as pre-emergence treatment. No effect.
4-CPA free acid 6.5% granules	5 and 10	28.4 and 1.5	1961	"	Applied as pre-emergence treatment. No effect.
MCPA acid	$2\frac{1}{2}$,5 and 10	25.8	1958	"	21, 21 and 33% reduction respectively.
"	10	19.8 and 9.9	1959	"	-14% reduction.
MCPA butoxy ethanol ester	$2\frac{1}{2}$,5 and 10	25.8	1958	"	3, 38 and 23% reduction respectively. No effects by 1960.
MCPA hydrazine	10	19.8 and 9.9	1959	"	No effect.
2,4-D acid	$2\frac{1}{2}$,5 and 10	25.8	1958	"	10, 2 and 15% reduction respectively.
	10	19.8 and 9.9	1959	"	-30% reduction.
2,4-D butoxy ethanol ester	$2\frac{1}{2}$,5 and 10	25.8	1958	"	10, 0 and 0% reduction respectively.
2,4-D hydrazine	10	19.8 and 9.9	1959	"	25% reduction. No effects visible by 1961.
2,4,5-T acid	$2\frac{1}{2}$,5 and 10		1958	"	10, 15 and 22% reductions respectively. No effects visible by 1960.
2-chloro, 4-fluoro phenoxyacetic acid	10	19.8 and 9.9	1959	"	No effect
4-fluoro phenoxy-acetic acid	10	19.8 and 9.9	1959	"	Delays emergence to some extent but bracken develops normally later in the season.

Appendix Table 2(a) (contd)

Chemical	Dose in lb/acre	Dates of application	Year	Site	Remarks
Phenoxypropionic acids					
CMPP hexyl ester	½,5 and 10	25.8	1958	Charlbury	6, 9 and -16% reductions respectively.
Fenoprop-butyl ester	5 and 10	4.8	1960	Aldershot	No effect.
Fenoprop-butyl ester as an invert emulsion	5 and 10	4.8	1960	"	No effect.
2-CPP	10	4.8	1960	"	No effect.
4-CPP butyl ester	5 and 10	4.8	1960	"	"
4-CPP butyl ester as an invert emulsion	5 and 10	4.8	1960	"	"
Phenoxybutyric acids					
2-CPB	10	4.8	1960	"	"
Phenylacetic and Benzoic acids					
Fenac	10	19.8 and 9.9	1959	Charlbury	Emergence is delayed to some extent but no effect is apparent later in the season.
	10 and 20	28.4 and 1.5	1961	"	
2,3,6-TBA	½,5 and 10	25.8	1958	"	0, 2 and 28% reductions respectively one year after treatment. No effect by 1960.
Amiben as triethyl-amine	5 and 20	18.7	1961	"	Emergence is delayed and frond numbers are reduced by approx. 20%.
Methoxydichlor-benzoic	1 and 4	18.7	1961	"	Number of fronds is greatly reduced in season following application. Those fronds which emerge are very distorted. This chemical is being tested further.
Methoxytrichlor-benzoic	2 and 8	18.7	1961	"	No effect.
Halogenated Aliphatic acids					
Dalapon-butyl ester	10 and 20	4.8	1960	Aldershot	No effect.
Dalapon-butyl ester as an invert emulsion.	10 and 20	4.8	1960	"	No effect.
Carbamates					
Barban	10	19.8 and 9.9	1959	Charlbury	No effect.

Appendix Table 2(a) (contd)

Chemical	Dose in lb/acre	Dates of application	Year	Site	Remarks
Ureas					
Fenuron	10 and 20	28.4 and 1.5	1961	Charlbury	No effect
Triazines					
Atrazine	10 10 and 20	19.8 and 9.9 28.4 and 1.5	1959 1961	" "	No effect with either pre- or post-emergence applications.
Isodiazine	10	19.8 and 9.9	1959	"	No effect.
Atraton	10 and 20	28.4 and 1.5	1961	"	No effect with either pre- or post-emergence applications.
Chlorazine	10	19.8 and 9.9	1959	"	No effect.
Methoxypropazine	10	19.8 and 9.9	1959	"	No effect.
Atrazine	10 and 20	28.4 and 1.5	1961	"	No effect with either pre- or post-emergence applications.
Prometryne	10 and 20	28.4 and 1.5	1961	"	No effect with either pre- or post-emergence applications.
Substituted phenols					
Dinoseb-amine 9.0% granules	5 and 10	28.4 and 1.5	1961	"	No effect as a pre-emergence treatment.
Quarternary ammonium compounds					
Diquat	2 and 8	25.8	1958	"	30 and 68% reductions respectively in June 1959. Effect had largely disappeared by the late season. No effect by 1960.
Paraquat	2,4 and 8	28.6	1960	"	No effect in season following application.

APPENDIX TABLE 2(b)

Notes on chemicals tested in a screening trial laid down by The West of Scotland Agricultural College

Chemicals applied on 2nd May, 1961
Assessment made on 5th October, 1961
Site - North facing site near Glasgow.

Chemical	Dose in lb/acre a.e. or a.i.	Remarks
4-CPA Free acid 6.5 and 7.0% granules	5 and 10	No effect
4-CPA nonyl ester 9.0 and 9.3% granules	5 and 10	No effect
Fenoprop	7.5 and 15	No effect
Fenac	7.5 and 15	No effect
Amiben	7.5 and 15	No effect
"Daquapon"	15 and 30	30 lb/ac gave 52% control
Mixture containing 78% sodium dalapon + 8% sodium 2,2,3-trichloropropionate ("Dalacide")	10 and 20	20 lb/ac gave a 46% control
Mixture of diuron + chlorpropham ("Residuren")		No effect
Diuron	40 and 80	No effect
Prometryne	5 and 10	No effect
Dinoseb	5 and 10	No effect
Mixture of BiPC + OMU ("Alipur")	10 and 20	No effect