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CHEMICAL CONTROL OF BRACKEN

A Progress Report (Jan. 1964) on Research  
During the Years 1959-63

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### SUMMARY

1. In the mid-1950's interest in bracken control was stimulated by the almost simultaneous discovery of three compounds with potential for the eradication of bracken - dalapon, 4-CPA and amitrole. In 1959, at the time of the author's appointment to the A.R.C. Unit of Experimental Agronomy, several official and commercial organisations in this country were investigating the possibilities of chemical control of bracken. An agreement had been reached with several Continental and Scandinavian countries that the three chemicals should be tested at sites throughout Europe in trials of a standard design.

Extensive field research was carried out in the years 1959-63 and the extent of the research programmes of the various organisations, both official and commercial, is described.

The evidence collected during the period under review reveals that although, under some circumstances, dalapon, 4-CPA and amitrole are toxic to bracken at the doses tested, they have not proved sufficiently reliable for commercial application. The effectiveness of each chemical has varied markedly from trial to trial and according to the year in which it has been applied. It has not yet proved possible to determine the factors which cause this variability.

2. Another herbicide dichlobenil, has been tested and although a very satisfactory control may be achieved for one year the treatment is not persistent. The chemical may have limited application in re-afforestation schemes.

3. The results of earlier trials with MCPA at doses up to 10 lb/acre had indicated that this chemical had no application as a herbicide for bracken. More recent work suggests that treatment at higher doses may give satisfactory control and further tests are required.

4. In initial trials dicamba-sodium and "Tordon" have shown promise and these two chemicals are being studied but as yet there is insufficient information to allow an assessment of their usefulness.

5. In the discussion the following aspects of the problem are considered:-  
(a) the importance of locality (b) the timing of applications (c) formulation  
(d) husbandry factors (e) future research (f) subsidies.

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6. The following conclusions are drawn:-

(a) That commercial interest in the problem is, to some extent, waning since the expense of extensive research may not be justified by future revenue. Official organisations will have to play a major role if potential herbicides are to be adequately proven.

(b) The outstanding problems are (i) the evaluation of dicamba-sodium and "Tordon" (ii) the screening of chemicals as potential herbicides for bracken (iii) the development of agronomic techniques which will allow successful reclamation.

(c) Any future grants extended for the eradication of bracken should be linked with comprehensive improvement schemes.

#### INTRODUCTION

In March, 1960 (Fryer and Hodgson 1960) a report was prepared on the chemical control of bracken for the information of official organisations interested in this problem. At the time extensive programmes of research had been initiated, by both official and commercial organisations, to investigate the suitability of dalapon (sodium 2,2-dichloropropionate), 4-CPA (4-chlorophenoxyacetic acid) and amitrole (3-amino-1, 2, 4-triazole) as bracken herbicides. The object of the present report is to present and discuss (a) the main results of these investigations and (b) the results of subsequent trials with these and other chemicals.

Survey of early developments. (a) 4-CPA In the immediate post-war period only scant interest was shown in the chemical control of bracken. Various chemicals, including the recently discovered growth regulating compounds, were tested in England by the A.R.C. Unit of Experimental Agronomy and in the West of Scotland by Dr. Elsie Conway of the Department of Botany, University of Glasgow and by J. D. Forrest of the West of Scotland College of Agriculture. None of the chemicals tested showed any particular promise.

During the mid-1950's interest in the problem was stimulated by the discovery of three potential bracken herbicides, namely 4-CPA, dalapon and amitrole. In 1953 at a convention organised by the American Chemical Paint Co., U.S.A., (now Amchem Products Inc.) it was stated that 4-CPA had shown promise as a herbicide for bracken in preliminary work in Virginia. In this country little interest was taken in this statement until 1956 when the nonyl ester of the chemical was tested in a small unreplicated trial in the Southern Uplands. In the following year, the A.R.C. Unit of Experimental Agronomy tested a sodium salt formulation of the chemical in a trial near Oxford.

The results of the Scottish trial were promising and in 1957 Messrs. A. H. Marks and Co. Ltd., of Bradford, acting as agents for Amchem Products Inc., U.S.A., started an experimental programme to investigate the effectiveness of 4-CPA. Dr. Elsie Conway and J. D. Forrest co-operated with Marks and Co. Ltd. in an advisory capacity. Several formulations of the chemical were studied in plot trials at five sites in the West of Scotland. The results of these trials appeared most encouraging and a further series of trials was laid down at the same sites in 1958. At a number of the sites the chemical was also sprayed on a commercial scale by helicopter. When these trials were assessed in 1959 Marks and Co. considered that a satisfactory control had been achieved and on the evidence of the two years trials they marketed a restricted amount of an oil emulsion formulation of the nonyl ester, under the trade name "Woodone Brackontrol".

In 1957 the Mirvale Chemical Co., Mirfield, Yorks., and their distributors Messrs Killgerm and Co., Cleckheaton, Yorks., having seen reports of work in New Zealand with 4-CPA, decided to lay down a trial (on the Isle of Bute) to study the chemical. After assessment of this trial in 1958 and 1959 the company considered that the treatment was sufficiently effective to warrant the introduction of a commercial product in the summer of 1959. This product, an oil formulation of the butyl ester of 4-CPA was sold under the trade name "Teridox".

(b) Dalapon. Preliminary tests with dalapon (as "Dowpon") applied at 20 and 40 lb/acre a.e\* to mature bracken were made by the A.R.C. Unit of Experimental Agronomy in 1956. The chemical showed promise and in 1957, the Unit, in co-operation with the National Agricultural Advisory Service, started a series of 18 trials in several regions of England and Wales to obtain further experience under a variety of conditions. The results in the following year were very variable; although 10 lb/acre gave an excellent control at some sites 20 lb/acre failed to give acceptable control at others. It was not possible to account for these variations.

(c) Amitrole. Amitrole was tested in screening trials in this country in the mid-fifties both by the A.R.C. Unit of Experimental Agronomy and by the West of Scotland College of Agriculture. Because of the high cost of the dose required no further work was carried out. However, in 1959 continental reports claimed that very promising results had been obtained in several countries for the control of bracken prior to planting forest trees.

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In view of the promise shown by the three chemicals, dalapon, 4-CPA and amitrole, it was agreed at a meeting of the International Research Group on Weed control, held in Stuttgart in March, 1959, that trials of a standard design should be laid down on the Continent, in Scandinavia and in the United Kingdom to compare the effectiveness of these three chemicals under a wide range of experimental conditions. In June, that year, the author was appointed to the A.R.C. Unit of experimental Agronomy and seconded to the A.R.C. Weed Research Organisation for a period of three years to investigate the possibilities of the chemical control of bracken and to co-ordinate the research on bracken in this country.

SYNOPSIS OF RESEARCH PROGRAMME 1959-63  
(For full details see Table 1)

Both non-commercial and commercial organisations are involved in bracken research and for clarity the experimental programmes of the various bodies are considered under the two main headings (1) Official Organisations (2) Commercial Organisations.

It should be noted that in the accounts which follow only the major trials known to the author are described. It is not claimed that the programme of any individual organisation has necessarily been fully reported.

\* a.e. = acid equivalent

TABLE 1

Details of the programmes (1959-1963) of  
 (a) The A.R.C. Unit of Experimental Agronomy  
 and the A.R.C. Weed Research Organisation,  
 (b) The Edinburgh School of Agriculture and  
 (c) The West of Scotland College of Agriculture.

(a) A.R.C. Unit of Experimental Agronomy.  
 (All trials taken over by the A.R.C. Weed Research Organisation on its formation in April 1960)

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre, (a.e. or a.i.) <sup>1</sup>	Date of application				
1959	Darley Dale, Derbyshire Castleton, Derbyshire Ruthin, Denbighshire Machynlleth, Montgomery Pontesbury, Shropshire Leebotwood, Shropshire Lydney, Gloucestershire Barden, Yorkshire Cartmel Fell, Lancashire Eggleston, Durham Capheaton, Northumberland Bruton, Somerset Euston Park, Suffolk	Randomized block design. Treatments replicated three times.	4-CPA (nonyl ester) <sup>2</sup> , dalapon <sup>3</sup> and amitrole/thio- cyanate <sup>4</sup> were tested at all 12 sites.  4-CPA (butyl ester) tested at Ruthin, Lydney, Eggleston and Capheaton.  4-CPA (nonyl ester, invert emulsion) <sup>5</sup> tested at Ruthin, Lydney, Barden, Cartmel Fell, Eggleston and Capheaton.  At Euston Park only 4-CPA (nonyl ester) and dalapon were tested.	4-CPA (nonyl and butyl esters) 5 and 10	29.6 and 17.9 10.7 and 17.9				
				4-CPA (invert emulsion) <sup>10</sup>	30.6 and 3.9 1.7 and 3.9				
				dalapon 10 and 20	2.7 and 2.9 2.7 and 2.9				
					3.7 and 24.8 8.7 and 15.9				
					8.7 and 15.9 9.7 and 16.9				
					10.7 and 16.9 23.7 and 24.8				
					15.7 and 27.8				
				1959	Charlbury, Oxon	Screening trial. Treatments replicated three times.	See Appendix Table 2(a) for details		

TABLE 1(a) (contd)

sheet 2

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre (a.e. or a.i.)	Date application
1960	Ruthin, Denbighshire Machynlleth, Montgomery Leebotwood, Shropshire Barden, Yorkshire	} Randomized block design. Treatments replicated three times.	} 4-CPA (nonyl ester),	5 and 10	6.7 and 26.7
	} 4-CPA (nonyl ester, invert emulsion)		5 and 10	7.7 and 26.7	
	} dalapon and amitrole/thio- cyanate		10 and 20	8.7 and 27.7	
				12.7 and 16.8	
1960	Charlbury, Oxon Blenheim, Oxon	} Randomized block design. Treatments replicated three times.	} 4-CPA (nonyl ester)	10	At approx. weekly inter- vals from 28.6 to 13.9
			} amitrole/thiocyanate	5 and 20	
1960	Charlbury, Oxon	Randomized block design. Treatments replicated three times.	dichlobenil as a 50% wetable powder	3 and 6	14.3, 31.3, 14.4, 16.5 and 7.6
1960	Wytham Wood, Oxon	Randomized block design. Treatments replicated three times.	dichlobenil as a granular formulation.	10	1960-25.8, 1.11 and 2.12 1961-At month- ly intervals from January until July.
1960	Aldershot, Hampshire	Screening trial. Randomized block design. Treatments replicated three times.	See Appendix Table 2(a) for details		
1961	Finstock, Oxon	Randomized block design.	4-CPA (nonyl ester) in K.E.B. oil.	10	At weekly intervals between 23.5 and 2.10 19 occasions.
			4-CPA (nonyl ester) in "Aromosol H" oil.	10	
			amitrole/thiocyanate	5	
1961	Leebotwood, Shropshire Barden, Yorkshire Cartmel Fell, Lancashire	} Randomized block design. Treatments replicated three times.	} 4-CPA (nonyl ester)		7.7 and 24.8
			} amitrole/thiocyanate	5 and 10	27.7 and 30.8
			} amitrole/thiocyanate + wetting agent		27.7 and 29.8



TABLE 1(a) (contd)

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre (a.e. or a.i.)	Date of application	
1961	Odiham, Hampshire	Randomized block design. Treatments replicated three times.	Various formulations of 4-CPA (nonyl ester) and amitrole with and without various wetting agents.	4-CPA 10 amitrole 5	15.6, 20.7 and 18.8	
1961	Charlbury, Oxon	Screening trial. Randomized block design. Treatments replicated twice.	See Appendix Table 2(a) for details			
1962	Finstock, Oxon Wytham Woods, Oxon  Cartmel Fell, Lancashire	Randomized plots. No replication. Randomized block design. Treatments replicated 3 times. Randomized block design. Treatments replicated three times.	dicamba-sodium <sup>6</sup> . (sodium 3,6-dichloro 2-methoxybenzoate).	2, 4 and 8	12.7, 2.8 and 24.8. 2.8 and 24.8  17.7	
1962	Finstock, Oxon	Single frond treatments. Treatments replicated ten times.		Gibberellic acid	2000 p.p.m. applied to "run-off". Treatments include single and repeated applications.	21.6 and at weekly intervals until 15.7.
1963	Leebotwood, Shropshire	Randomized block design. Treatments replicated three times.		4-CPA (nonyl ester) 4-CPA (nonyl ester) + straw mulch. amitrole/thiocyanate amitrole/thiocyanate + straw mulch.	10  5	10.7 and 28.8
1963	Charlbury, Oxon	Randomized block design. Treatments replicated three times.	4-CPA (nonyl ester) 4-CPA (nonyl ester) + litter layer removed amitrole/thiocyanate + litter layer removed.	10  5	12.7 and 23.8	
1963	Leebotwood, Shropshire Charlbury, Oxon	Randomized block design. Treatments replicated twice.	amitrole/thiocyanate amitrole/thiocyanate (invert emulsion) "Tordon" (4-amino-3,5,6-trichloropicolinic acid).	10 5 and 10 1, 2 and 4	10.7, and 28.8	

TABLE 1(a) (contd)

sheet 4

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre (a.e. or a.i.)	Date of application
1963	Leebotwood, Shropshire Charlbury, Oxon	} Large plot trial - 9 x 8 yd. } No treatment replication	dicamba-sodium	2, 4 and 8	31.7, 28.8 and 17.9 30.7, 23.8 and 16.9
1963	Leebotwood, Shropshire Charlbury, Oxon	} Randomized block design. } Treatments replicated } three times.	4-CPA (nonyl ester) 4-CPA (butyl ester)	} 10	31.7 and 28.8 30.7 and 23.8
1963	Finstock, Oxon	Single frond treatments replicated four times.	dicamba-sodium "Tordon"	} 1 per cent } solution. Sprayed to "run- off".	29.7 and 5.9

## (b) The Edinburgh School of Agriculture

1959	Caeretton Hill, Midlothian	Large plot trial - 10 x 10 yd. plots. Unreplicated.	4-CPA (nonyl ester) 4-CPA (diethanolamine salt)	} 7.5 in 50 gal/ } acre water	30.6 - 23.9 at approx. weekly intervals.
1959	Portmoie, Peeblesshire	Replicated trial with 40 sq.yd plots.	4-CPA (nonyl ester) 4-CPA (butyl ester) 4-CPA (diethanolamine salt) dalapon amitrole/thiocyanate	10 and 7.5 8 and 6 10 and 7.5 20, 15, 10 and 5 15, 10, 7.5 and 5	4-CPA formula- tions applied 1.8. dalapon and amino- triazole applied 1.7.
1959	Gilmanscleuch, Selkirkshire Bickholm, Roxburg' shire Carie, Perthshire.	} Unreplicated plots of } 1 acre.	4-CPA (nonyl ester) 4-CPA (butyl ester) dalapon amitrole/thiocyanate	7.5 } Applied in 30 6 } gal/acre water 15 } by tractor 7.5 } sprayer.	4-CPA formula- tions applied between 17.8 and 3.9 dalapon and aminotriazole applied between 14.7 and 28.7.

TABLE 1(b) (contd)

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre (a.e. or a.i.)	Date of application
1960	Portmore, Peeblesshire Bankfoot, Perthshire Ardeonig, Perthshire	To investigate effects of time of application. To investigate effect of drift spraying. To investigate effects of additives to existing formulations.	4-CPA (nonyl ester) 4-CPA (invert emulsion of nonyl ester) 4-CPA (diethanolamine salt) Amitrole/thiocyanate	Details not known	
1960	Carie, Perthshire	Large plot trials. Details unknown			
1961	Lammernuir Hills, East Lothian	1. To compare various formulations of 4-CPA. 2. To assess the effect of varying the proportion of the 2-methyl-6-chloro isomer in MCPA.	ester, salt, amine, acid, invert emulsion, and granular formulations of 4-CPA. MCPA with the addition of 0, 5, 10, 15 or 20% of the 2-methyl-6-chloro isomer.	Not known. 5 lb in a 100 gal/acre.	When the fronds were unfurling.
1961	Tweedsmuir, Peeblesshire	To investigate the effect of time of application.		Details not known.	
1961	Bankfoot, Perthshire Ardeonig, "	Continuation of trials started in 1960.			
1962	Lammermuir Hills, Tweedsmuir		Extension of trials initiated in 1961.		
1962	Dunkeld, Perthshire	Development of new trials site.	Details not known.		

## (c) West of Scotland Agricultural College

1959	Dunoon, South Argyll Ballachulish, North Argyll	Randomized block design. Treatments replicated three times.	4-CPA (nonyl ester) Amitrole/sesquicarbonate <sup>2</sup> Amitrole/thiocyanate Dalapon	5 and 10 10 and 20 10 + 20	30.7 and 30.8 31.7 and 31.8
1959	Lock Striven, South Argyll Ballachulish, North Argyll	To compare the nonyl and butyl esters of 4-CPA with control by cutting.	4-CPA (nonyl ester) 4-CPA (butyl ester)	Details not known.	

TABLE 1(c) (contd)

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre (a.e. or a.i.)	Date of application
1960	Milngavie, Stirling	Randomized block design. Treatments replicated three times.	2-CPA (2-chlorophenoxyacetic acid) 2-CPE (2-chlorophenoxybutyric acid) 2-CPP (2-chlorophenoxypropionic acid) 4-CPA (nonyl ester) Dichlobenil - 50% wettable powder.	5, 10 and 20	Monthly intervals, mid May - August.
1960	Dunoon, South Argyll	Randomized block design. Treatments replicated three times.	Area sprayed with butyl ester formulation of 4-CPA in 1959. In 1960 grazing, seeding, litter removal or fertilizer treatments were superimposed.	10	
1961	Eskdalemuir, Dumfries Coalburn, Lanark Luss, Dunbarton Balmaha, Stirling Port of Monteth, Perthshire Benderloch, Argyll Dunoon, Argyll	Co-operative trials with the County Advisory Service of the College.	4-CPA (nonyl ester) 4-CPA (invert emulsion of the nonyl ester) Amitrole/thiocyanate 4-CPA/4CPA mixture Dichlobenil as 50% wettable powder or granules.	5 and 10 5 and 10 3 and 6 $1\frac{1}{4}:1\frac{7}{8}$ and $2\frac{1}{2}:3\frac{3}{4}$ $2\frac{1}{2}$ : and 5	
1961	Milngavie Stirling	Unreplicated plots - 1/200 acre	See Appendix Table 2(b)		2.5
1962	Milngavie Stirling	To assess effects of varying the time of application.	4-CPA (nonyl ester) Amitrole/thiocyanate	10	Weekly intervals after bracken emerged.

Notes: 1. a.e. = acid equivalent, a.i. = active ingredient.

2. 4-CPA (nonyl ester) was applied as "Weedone Brackontrol".

3. Dalapon was applied as "Downon".

4. Amitrole/thiocyanate has been used to denote a mixture of amitrole and ammonium thiocyanate containing 2 parts of amitrole to 1.85 parts of ammonium thiocyanate (Weedazol TL); similarly amitrole/sesquicarbonate denotes a mixture of amitrole and sodium sesquicarbonate containing each component in equal parts by weight (Weedazol).

5. An invert emulsion is a water in oil emulsion as opposed to an oil in water emulsion.

6. D-camba-sodium was applied as "Banvel D".

1. Official Organisations. The A.R.C. Unit of Experimental Agronomy, the A.R.C. Weed Research Organisation, the Edinburgh School of Agriculture, the West of Scotland Agricultural College and the National Agricultural Advisory Service are considered in that order.

(a) A.R.C. Unit of Experimental Agronomy and A.R.C. Weed Research Organisation. Details of the trials laid down between 1959 and 1963 are given in Table 1a.

1959 During the summer, 13 trials of the standardized design agreed upon at Stuttgart were laid down in co-operation with the N.A.A.S. in 12 counties of England and Wales. One site at Euston Park, Suffolk, proved unsuitable and was abandoned. Brief details of the remaining 12 sites are given in Appendix Table 1.

A number of potential herbicides, details of which are given in Appendix Table 2a, were tested at Charlbury, Oxon.

1960. Preliminary assessment of the "International type trials" in June 1960 suggested that there was considerable variation in results from site to site and to test the reproducibility of results at a particular site new trials of the standard design were laid down at four of the existing sites. This first assessment also showed that the timing of treatment with 4-CPA and amitrole/thiocyanate\* might be quite critical in determining the degree of control and two trials were laid down to test the effect of varying the time of spraying.

A small trial to test the effectiveness of dichlobenil (2,6-dichlorobenzonitrile) was also laid down during 1960. Treatments were made at monthly intervals between March and June and on each occasion half of each treated plot was cleared of bracken litter before spraying. This litter was replaced immediately after the application had been made. During 1960 those areas which had been raked free of litter prior to spraying remained free of bracken for the greater part of the season and to test further this chemical a more extensive trial was initiated in August, 1960.

1961 The chief object of the programme was still to define the main factors which determine the susceptibility of bracken to 4-CPA and amitrole/thiocyanate. To study further the effect of altering the timing of application of these two chemicals a detailed trial was laid down. The first treatments were sprayed in the third week of May, before any fronds had emerged and a succession of plots were treated at approximately weekly intervals until the beginning of October, by which time most fronds had been damaged by autumn frosts.

In previous trials it had been noted that application of the oil emulsion formulation of 4-CPA caused severe scorching of the treated pinnae and it seemed likely that such damage to the frond tissue would impair translocation of the chemical. To assess the effects of scorching, in the above trial, two oil emulsion formulations of 4-CPA were included as treatments; one containing the phytotoxic crude oil (K.E.B. oil) and the other formulated with a non-phytotoxic oil ("Aromosol H").

\* See Note 4, Table 1.

Various formulations of 4-CPA, amitrole/thiocyanate and amitrole were tested in four trials, three at existing sites and one at Odiham, Hants., and the screening of chemicals continued at the trials site at Charlbury. (Appendix Table 2a).

1962 It was considered that no further advantage would be gained by continuing field type trials to test 4-CPA and amitrole and future trials should be designed to give more fundamental information on the physiology of the bracken plant.

In any one season a large proportion of the frond buds on the rhizome system remain dormant and therefore less susceptible to chemical treatment. In an attempt to induce these quiescent buds to develop, individual fronds were treated with gibberellic acid. In June all the selected fronds were sprayed and subsequently, at weekly intervals, a proportion of these treated fronds was resprayed on one, two, three, four or five occasions.

In 1961 dicamba-sodium (3, 6-dichloro 2-methoxybenzoate) was applied as a post-emergence treatment in a screening trial at Charlbury. In the following year the treatment was sufficiently effective to warrant further investigation and pilot trials were laid down at three sites.

1963 Experimental results have shown that the bracken at Charlbury is particularly resistant to chemical treatment whilst at Leebotwood it has proved most susceptible. Examination of soil profiles has revealed that the rhizome system at Charlbury grows entirely in the soil layer which in turn is covered by a deep layer of undecomposed litter. At Leebotwood, although the main rhizome system is in the soil layer, a very high proportion of the frond-bearing rhizomes lie in a relatively narrow and well decayed litter layer. It is possible that low temperatures, in the winter following spraying, may increase the efficiency of chemical treatment where the shallow rhizome system has little surface protection. To gain information on this aspect of the problem, a trial was laid down at each site. At Charlbury the undecayed litter was removed from treated plots whilst at Leebotwood sprayed plots were protected by a straw mulch.

In 1962 Messrs. Dow Agrochemicals, Ltd., Kings Lynn, tested 4-amino - 3, 5, 6 - trichloropicolinic acid ("Tordon") in a number of trials. Results in the following year were most promising and this chemical was included in a trial at both Charlbury and Leebotwood. An invert emulsion formulation of amitrole and a new formulation of the butyl ester of 4-CPA were also included in these trials. Dicamba-sodium was tested further in a trial at each site.

No results will be available from the trials laid down in 1963 until the autumn of 1964.

(b) The Edinburgh School of Agriculture. (D.S.C. Erskine) 1959. The College undertook a variety of trials in the five counties of Perthshire, Midlothian, Peebleshire, Roxburghshire and Selkirk (Table 1b). In three large scale trials applications of amitrol/thiocyanate and different ester formulations of 4-CPA (Weedone Brackontrol and Teridox) were made by field sprayer under normal farm conditions. At three further sites similar trials were put down but due to the limited areas of bracken available, the plots were smaller and the full range of herbicides was not applied. At another centre a fully replicated trial was carried out using a wide range of chemicals. Four preliminary, unreplicated,

screening trials with a variety of chemicals were also included in the College programme. Demonstration plots were sprayed at seven sites.

1960 At the site in Peebleshire further trials were laid down which included a trial to test the effect of varying the time of application of amitrole/thiocyanate and of 4-CPA when applied either as the amine, the nonyl ester or as the invert emulsion of the nonyl ester. An experimental site was established at Bankfoot, Perthshire, mainly for work on drift spraying and further trials were established at Ardeonig, Perthshire, to investigate the effects of various additives to existing formulations of amitrole/thiocyanate and 4-CPA. Further field trials were also laid down at one of the existing sites, Carie in Perthshire.

1961 Trials were laid down at a site in the Lammermuir Hills, East Lothian, to investigate a variety of formulations of 4-CPA. A trial was also undertaken at this site to test the effect on bracken of applications of MCPA and the 2-methyl-6-chloroisomer of MCPA mixed in different proportions. Trials to assess the effects of varying the timing of application were laid down at a site near Tweedsmuir, Peebleshire. Work was continued at Ardeonig and Bankfoot.

1962 A new trial site was developed at Dunkeld, Perthshire and more trials were carried out at Tweedsmuir and in the Lammermuir Hills.

Details of the College programme during 1963 are not yet known.

(c) West of Scotland Agricultural College (R. C. Kirkwood) 1959 In co-operation with the A.R.C. Unit of Experimental Agronomy, two trials of the standard type already described in the Unit's programme were laid down in Argyllshire (Table 1c). In another two trials, also in Argyllshire, oil emulsion formulations of the nonyl and butyl esters were compared and in one of these trials cutting of the fronds was included as a treatment. In addition, the County Advisory Staff of the College set out to their own specifications eight demonstrations with a butyl ester formulation of 4-CPA.

1960 4-CPA, 2-CPA, 2-CPB, 2-CPP\* and dichlobenil were tested in a trial in Stirlingshire and a trial was laid down in Argyllshire, to investigate the effect of both pre and post-spraying management of bracken areas. A number of chemicals were listed in a screening trial.

1961 To evaluate the influence of environment on the effectiveness of chemical spraying seven trials were laid down, in co-operation with the County Advisory Staff of the College, in six counties of Scotland. A variety of chemicals were again screened (See Appendix Table 2b).

1962 Experiments designed to give information on the penetration and translocation of herbicides were made in the glasshouse. In these experiments plants derived from fragments of rhizome were studied after treatment with radio active amitrole.

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\* 2-CPA = 2-chlorophenoxyacetic acid, 2-CPB = 2-chlorophenoxybutyric acid  
2-CPP = 2-chlorophenoxypropionic acid

In the field a trial was laid down to assess the effects of applying 4-CPA and amitrole/thiocyanate at various times of year.

1963 The physiological studies on penetration and translocation of herbicides in bracken were continued but details of the full programme have not yet been received.

(d) The National Agricultural Advisory Service Since 1959 the N.A.A.S. have co-operated with the A.R.C. Unit and with the A.R.C. Weed Research Organisation in finding suitable trials sites, in laying down the trials and in the field assessment of the treatments. In some regions, from time to time, demonstration plots have been laid down with those chemicals which have appeared to give a commercially acceptable control.

2. Commercial Organisations. The programmes of the following firms are described:- A. H. Marks and Co. Ltd., Mirvale Chemical Co. Ltd., Fisons Pest Control Ltd and Dow Agrochemicals Ltd.

(a) A. H. Marks and Co. Ltd., 1959. The Company continued to lay down extensive trials at their five sites in the West of Scotland and a new trial site was acquired at Ramsgill in Yorkshire. Several formulations of 4-CPA and MCPA were tested (Table 2).

To examine the effectiveness and feasibility of aerial spraying two formulations of 4-CPA were applied by helicopter at four sites in Scotland.

1960 All these trials laid down in 1959 were assessed and to gain information on the effects of repeated applications some of the plots were retreated. New trials were laid down at each site to test various formulations of 4-CPA and amitrole/thiocyanate.

As an extension of the work at Oxford on non-phytotoxic carriers 4-CPA was formulated with seven different oils. The seven formulations were compared in a trial at Ramsgill. In addition, two trials were undertaken to examine the effects of timing of application with 4-CPA and amitrole/thiocyanate. Treatments, which were the same as those applied at the Scottish sites, were made at approximately weekly intervals on 13 occasions between the last week in June and mid-September. Methods of application and the effects of applying 4-CPA at various volume rates were also studied at the Yorkshire site.

1961 4-CPA formulated with either a phytotoxic or a non-phytotoxic oil as both the oil in water emulsion and the invert emulsion was tested at each of the five sites in the West of Scotland. Treatments were also made with two formulations of amitrole.

1962 The programme of work was drastically cut in 1962 and only one formulation of the butyl ester of 4-CPA was tested at two of the Scottish sites. In addition the owner of each of the five sites in Scotland was given a sufficient quantity of this material to treat 10 acres of bracken which was later assessed by the company.

No details are known of work carried out in 1963.



TABLE 2

Details of A.H. Marks &amp; Co. trials programme 1959-1962

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre (a.e. or a.i.)	Date of application
1959	Langholm, Dumfries Moffat, Dumfries Callander, Perthshire Kilmelford, Argyll Tobermory, Argyll	Unreplicated plot trials	4-CPA (nonyl and butyl esters)	5, 7.5 and 10	Late July and Late August
	4-CPA (diethanolamine salt)		5, 7.5 and 10		
	4-CPA (invert emulsions of the nonyl ester)		5, 7.5 and 10		
	At Langholm and Callander only - MCPA (butyl ester)		7.5 and 10		
			MCPA (diethanolamine salt)	7.5 and 10	
			At Moffat and Kilmelford only 4-CPP (butyl ester)	7.5 and 10	
1959	Ramskill, Yorkshire	Unreplicated plot trials	4-CPA (nonyl ester)	5 and 7.5	29.7, 13.8, 19.8 and 7.9
			4-CPA (invert emulsion of nonyl ester)	5 and 7.5	29.7, 13.8, 19.8 and 7.9
			4-CPA (diethanolamine salt)	5 and 7.5	13.8, 19.8 and 7.9
			4-CPA (butyl ester)	8	19.8
			MCPA (butyl ester)	7.5 and 10	19.8
			MCPA (diethanolamine salt)	7.5 and 10	19.8
			MCPA (invert emulsion)	2.5, 5 and 7.5	19.8
			4-CPP (diethanolamine salt)	7.5 and 10	19.8
			4-CPA + ammonium thiocyanate	7.5 + 7.5	19.8
			MCPA (butyl ester) + ammonium thiocyanate	7.5 + 7.5	19.8
1959	Moffat, Dumfries	Aircraft spraying - 10 acre blocks	4-CPA (invert emulsion)	6.25 lb/acre at 4 gal/acre total volume	July
	Moffat, Dumfries	Aircraft spraying - 5 acre blocks	4-CPA (invert emulsion) 4-CPA (nonyl ester)	6.7 lb/acre) At 4 7.5 lb/acre) gal/ac. total volume	" "
1959	Langholm, Dumfries	Aircraft spraying - 5 acre blocks	4-CPA (invert emulsion) 4-CPA (nonyl ester)	5 and 7.5 lb/acre in 4 gal/acre total volume	July
1959	Dunkeld, Perthshire	Aircraft spraying - 10 acre blocks	4-CPA (invert emulsion)	5 and 7.5 lb/acre in 4 gal/acre total volume	July

TABLE 2 (contd)

Year	Site	Type of trial	Chemicals tested	Dose in lb/acre (a.e. or a.i.)	Date of application
1960	Langholm, Dumfries Moffat, Dumfries Callander, Perthshire Kilmelford, Argyll Tobermory, Argyll	Unreplicated plot trials	4-CPA (nonyl ester) formulated with (a) K.E.B. oil, (b) with "Aromosol H" oil.	7.5 and 10	} July and August.
	4-CPA (invert emulsion) formulated with (a) K.E.B. oil, (b) with "Aromosol H" oil.		7.5 and 10		
	Amitrole/thiocyanate.		5, 7.5 and 10		
1960	Ramskill, Yorkshire - 2 sites	To investigate effects of spraying at various stages of growth.	As at Scottish sites		Approx. weekly intervals from the last week in June to mid-September.
		Randomised block design - two replicates.	4-CPA (invert emulsions formulated with seven different oils).	7.5	22.7
		Unreplicated plot trials duplicated on adjacent sites.	4-CPA (nonyl ester) applied in 5, 20, 50 or 100 gal/acre total volume.	7.5	25.7
		Trials to test spraying methods - "Motoblo" and conventional boom.	4-CPA (nonyl ester) 4-CPA (invert emulsion)	7.5	July
1961	Langholm Moffat Callander Kilmelford Tobermory	} treatments replicated three times.	4-CPA (nonyl ester) formulated with (a) K.E.B. oil, (b) "Aromosol H" oil.	} 5, 7.5 and 10	} July
	4-CPA (invert emulsion)		5, 7.5 and 10		
	Amitrole/thiocyanate Amitrole/sesquicarbonate		5, 7.5 and 10 5, 7.5 and 10		
1962	Langholm Moffat	Not known	4-CPA (butyl ester)	5, 10 and 20	July

(b) Mirvale Chemical Co. Ltd. As far as is known, the Mirvale Chemical Co. has not undertaken any large scale research on the control of bracken since 1959 when they introduced "Teridox", a formulation of the butyl ester of 4-CPA. However, the company has made available sufficient funds to the East of Scotland College of Agriculture to allow one worker to study the problem as a special project. Dr. R. Jacks is engaged on this work and his programme is closely related to that previously described for the College.

(c) Fisons Pest Control Ltd. In 1958, Fails at Kings College, Newcastle University, carried out trials in which bracken was treated with high doses of MCPA. These preliminary trials gave encouraging results and to further test the effectiveness of this chemical, Fisons laid down 21 trials in Northumberland and Scotland in 1960. Treatments were made in July and August with 5 and 10 lb/acre of MCPA. At one site at Thetford in Norfolk MCPA (applied as Phenoxylylene +) was compared with 4-CPA, dalapon and amitrole. MCPA was applied at 5, 10, 20 and 40 lb/acre, 4-CPA at 10 lb/acre, dalapon at 10, 20 and 40 lb/acre and amitrole at 2, 4 and 8 lb/acre. All these trials were assessed in 1961.

(d) Dow Agrochemicals Ltd. 1962 Dow agrochemicals Ltd., tested "Tordon" as a herbicide for bracken in three small plot trials. To study the chemical under a variety of environmental conditions one trial was laid down in the dry Brecklands, another was situated in an area of high rainfall in Scotland and for the third trial a site was chosen in the mountainous area of mid-Wales. The chemical was applied at  $\frac{1}{2}$ , 1, 2, 4 and 8 lb/acre and treatments were made on three occasions. The first application was made when the fronds had one pair of pinnae expanded (early to mid-summer). The second treatments were sprayed onto fronds which were almost fully expanded (mid-to late-summer) and a further treatment was made in the following spring (1963) while the frond buds were still approximately 1" to  $1\frac{1}{2}$ " below ground.

1963 Four large scale trials with plots 20 x 20 yd. were laid down. As in the previous year, the trials sites were chosen to provide a wide range of environmental conditions. A site in Norfolk represented Breckland conditions. A humid mountain side was selected in mid-Wales and in Scotland a trial was laid down in Kirkcudbright in relatively moist and mild conditions. A site in the Border Uplands of Scotland was chosen for the fourth trial.

Doses of 1, 2, 3 and 4 lb/acre were applied when the pinnae were almost fully expanded.

#### NOTES ON EXPERIMENTAL TECHNIQUES

(a) Size of plot In determining the most desirable area for plots in the field trials a number of factors had to be considered. Plots are observed for at least two years after treatment and the encroachment of the surrounding untreated bracken may mask the true effects of treatment. On the other hand, where a large number of plots are involved, the total area required for a trial becomes very great and it is often most difficult to find a uniform stand of bracken of sufficient area. In deciding the dimensions of plots the width of the sprayed swath must also be taken into consideration.

The A.R.C. Unit and the West of Scotland Agricultural College decided on a plot area of 24 sq. yd. with dimensions of 6 x 4 yd. Plots were separated by paths 1 yd. wide. With a spraying swath of 2 yd. spraying could be carried out without the operator entering the plot. With this size of plot it was possible to replicate treatments three times and this pattern was used throughout the programmes of the A.R.C. Unit and the College with the exception of five trials. In two of the Oxford pilot trials with dichlobenil the plots were reduced in size to 4 x 4 yd. as the supply of herbicide was restricted and in 1963, in trials with dicamba-sodium, plots 8 x 9 yd. were treated. In the West of Scotland, in a trial with dichlobenil, the plots were reduced to 4 x 3 yd.

In practice, 6 x 4 yd. plots proved satisfactory. Encroachment from the margins of the plots was surprisingly small and in trials where the control measures were successful, the plots retained their shape and size for more than four years after treatment.

A. H. Marks and Co. considered that encroachment from the untreated areas surrounding plots was a serious factor and preferred plots with an area of either 120 sq. yd. or 60 sq. yd. The dimensions of these plots were 10 x 12 yd. or 10 x 6 yd. As a general rule the treatments were not replicated.

In the East of Scotland programme the size of plots was varied from trial to trial and where the dimensions are known they have been recorded in Table 1c.

(b) Methods of application Apart from those trials to investigate various methods of application treatments were made with the Oxford Precision Sprayer. Applications were made with a boom 4ft. 6ins. in length equipped with four 00 fan jets giving an effective spray swath of 6 ft. With all aqueous and oil in water formulations spraying was carried out at 30 lb/sq. in. In applying the more viscous water in oil emulsion (invert. emulsion) formulations pressures had to be adjusted to deliver the correct volume of liquid. In general treatments were applied at a volume rate of 20 gal/acre. Applications made at other volume rates are recorded in Table 1.

(c) Methods of assessment. In trials where single fronds were treated, applications were made with a "Quickmist" hand sprayer. Individual fronds were sprayed until the point of "run off" was reached. In the most uniform stand of bracken the distribution of fronds is somewhat uneven and it is important to avoid subjective bias when making frond counts. In the A.R.C. Units and West of Scotland College trials assessments were made by placing a quadrat centrally within the plot to allow an 18 in. border within the perimeter of the plot. Thus when the size of the plot was 6 x 4 yd. all those fronds within a 5 x 3 yd. quadrat were counted.

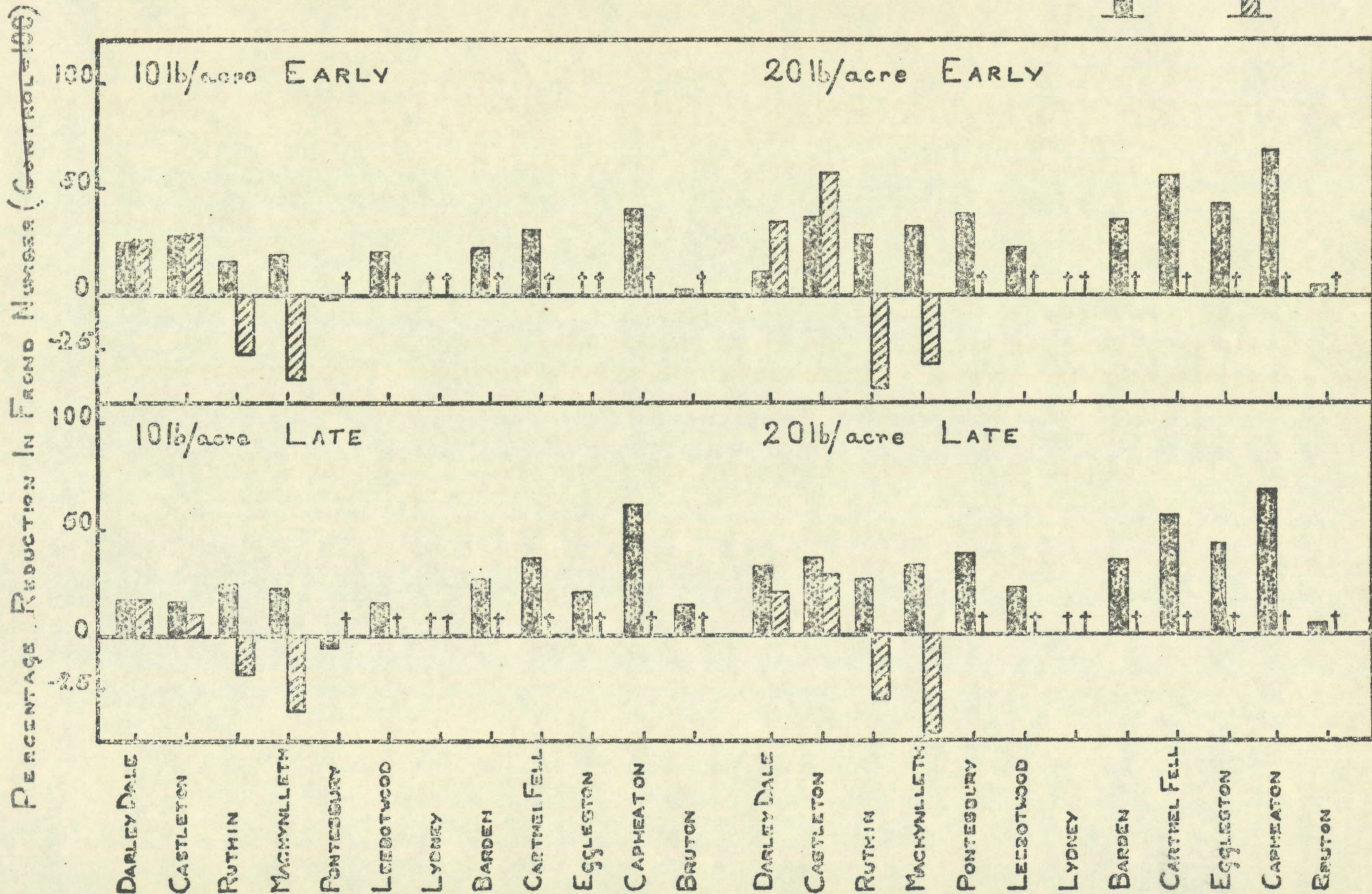
Where plots were too large to allow the counting of all the fronds on the area, as in the Marks and Co. trials and many of the East of Scotland College trials, a number of counts were made within a 1 x 1 yd. quadrat placed at random within the plot. In the Marks and Co. trials, it was usual to assess six quadrats for each plot. To assess the untreated bracken, six quadrat counts were made in the untreated areas surrounding the treated plots.

FIG. 1. THE EFFECT OF DALAPON ON BRACKEN. ASSESSMENTS MADE ONE, AND TWO YEARS AFTER TREATMENT

YEAR OF ASSESSMENT

† No VISUAL EFFECTS OF TREATMENT. NO COUNT MADE.

1960 1961



### EVALUATION OF CHEMICAL TREATMENTS

Considerable data has now accumulated as a result of the experimental programmes described and it is now possible to evaluate accurately the chemicals concerned. In this report, in general, the results of the A.R.C. Weed Research Organisation's trials will be quoted but the findings of other organisations will be given either to amplify these or where the evidence is conflicting.

Chemicals are considered in the following order : dalapon, 4-CPA, amitrole, dichlobenil, MCPA, dicamba-sodium, "Tbrdon" and gibberellic acid.

(a) DALAPON The 18 trials carried out in 1957 by the A.R.C. Unit working in collaboration with the National Agricultural Advisory Service demonstrated that the results in the year following spraying were very variable (Fryer, Chancellor and Evans 1959). They ranged from an excellent control at 10 lb/acre to negligible control from 20 lb/acre. By 1959 appreciable control had been maintained at only one or two sites and it was concluded that there was little promise for the existing sodium salt formulation.

The results of the series of trials initiated in 1959 by the A.R.C. Unit fully confirm these earlier results. Counts made in June 1960, twelve months after treatment, showed that there was a very wide variation in results from site to site as well as between treatments at individual sites. At one site an early application of 10 lb/acre gave a 91 per cent reduction in frond density when compared with control plots but at seven other sites the decrease in density was less than 30 per cent. Similar anomalies were recorded in each of the other treatments. The results of the assessment later in the year (Aug. - Sept.) showed that the number of fronds had increased greatly on treated plots and that, whilst the variations from trial to trial were still great, the difference due to the various treatments was much reduced (Fig. 1.) In general all treatments caused a reduction in the height of the bracken but in a few instances the treatment had had no visible effect on the height of stand. In all treatments grasses, where present below the bracken, were completely killed, irrespective of the time of application.

The early counts (June) did indicate that delaying the application of 10 lb/acre from July until September had increased the effectiveness of the chemical but where the dose was increased to 20 lb/acre the effects of varying the time of application were far less marked. In the later assessment these differences were very much reduced. (Fig. 1).

By September 1961, two years after treatment, at ten of the sites, it was not possible to distinguish between the control plots and those which had been treated with dalapon. At the other two sites at Darly Dale and Castleton in Derbyshire the reductions in frond density were 34 per cent and 57 per cent respectively where the chemical had been applied at 20 lb/acre at the end of June or early July. By 1962 it was not possible to detect any effect of the chemical on the treated plots at Darly Dale but at Castleton the density of fronds on the sprayed plots was still only 50 per cent of that on the control areas, and due to the reduced vigour of the fronds, this gave an effective reduction in the ground cover provided by the bracken of approximately 70 per cent. It is not possible to



give any explanation for the persistency of the treatment at this particular site.

Where new trials were laid down at four of the existing sites in 1960, spraying with dalapon gave very similar results to those described for the 1959 trials and by 1962 there was no visual effect of treatment.

The results reported by both Scottish Colleges are in agreement with those described (Erskine 1960, Kirkwood and Fletcher, 1961).

In 1960, in a screening trial, the A.R.C. Weed Research Organisation tested the butyl ester of dalapon formulated both as an oil in water emulsion and as an invert emulsion. The chemical applied at 10 and 20 lb/acre at the beginning of August proved to be ineffective when assessed in the year following treatment.

It is quite apparent that the sodium salt formulation of dalapon at 20 lb/acre or less is ineffective as a herbicide for bracken. Although, on occasion, the chemical has given a high degree of control, the main effect of treatment has been to increase the length of the dormancy period of the frond buds thus delaying frond emergence by three to four weeks. This effect decreases rapidly in succeeding seasons and, in general, by the third season after treatment, the effect has completely disappeared. It would seem now that the only possibility for dalapon would be the development of a formulation which would indefinitely prolong bud dormancy. Such alternative formulations have received little attention, but there is no evidence to suggest that variations in formulation would significantly increase the dormancy period of the frond buds. The one ester formulation tested gave results inferior to those for the sodium salt and it is most doubtful that further research in this direction would prove fruitful.

(b) 4-CPA. Effects of changing the dose. At the time of the last bracken report (1960) practically all the information available regarding the use of 4-CPA as a bracken herbicide in the United Kingdom came from trials in the West of Scotland made by A. H. Marks and Co. Ltd. Their trials had indicated that a kill of 60 - 90 per cent might be expected from applications of  $7\frac{1}{2}$  lb/acre of the nonyl ester of 4-CPA.

In a further series of trials at these sites in 1960 the nonyl ester formulation again gave a satisfactory control in the year following application. At Tobermory on the Isle of Mull, the density of fronds was reduced by 82 per cent and at only two of the five sites was the reduction in density slightly below 70 per cent (Joice and Norris 1962).

In comparison with these Scottish trials, the 12 trials laid down by the A.R.C. Unit in 1959 and by the A.R.C. Weed Research Organisation in succeeding years gave disappointing results (Fig. 2). Where 10 lb/acre of the nonyl ester of 4-CPA was applied between the end of June and early July 1959 the greatest reduction in frond density in the following year was 67 per cent and at only three sites was the reduction over 60 per cent. At four sites the number of fronds was reduced by less than 35 per cent. When the chemical was applied at 5 lb/acre the maximum reduction recorded was 44 per cent.



FIG 3. EFFECT OF 4-CPA (nonyl ester) ON BRACKEN WHEN APPLIED AT DIFFERENT TIMES FROM A TRIAL MADE BY THE EDINBURGH SCHOOL OF AGRICULTURE COUNTS MADE IN JULY 1960

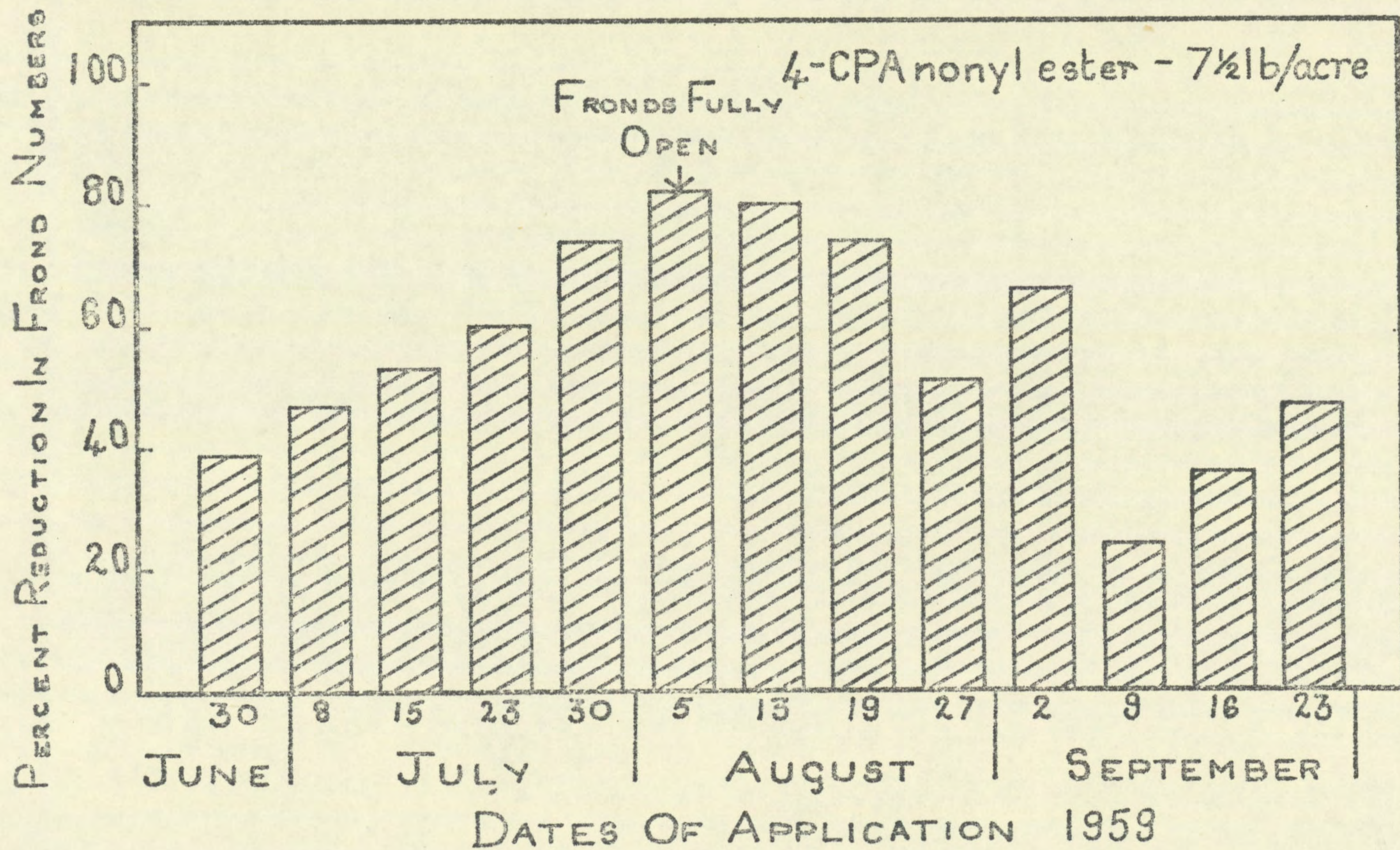


Fig 4 THE EFFECT OF 4-CPA (nonylester) ON BRACKEN - THE INFLUENCE OF DATE OF APPLICATION

