USE OF HERBICIDES IN THE SURFACE RE-SEEDING OF OLD PASTURE

I. The World Position and Some Research in the United Kingdom

by

J. G. ELLIOTT

(*A.R.C. Unit of Experimental Agronomy, Oxford University*)

This paper contains a review of the world literature on the use of herbicides in the surface reseeding of old pasture, and a discussion of the research approach to the many aspects that are involved. Since 1956, seven experiments have been started by the A.R.C. Unit of Experimental Agronomy to investigate the destruction of vegetation and surface root mats, and to compare the various farm implements that may be used to prepare a seedbed. The details are presented of two experiments in which preliminary results are available.

Introduction

'It is not ploughing, it is not digging, it is not harrowing . . . that we want: all these are the time honoured, time bothered means to a certain result. That result is — a seed-bed' (C. W. Hoskyns, 'Talpa or Chronicles of a Clay Farm', 1852).

The plough has survived through the ages, being modified and improved, until at the present time it is considered an essential part of the agriculture of the United Kingdom. Ploughing has a high power requirement and causes wear and tear on machinery; further it is limited in the land upon which it can be used. The great majority of the more productive land in the U.K. can be and is ploughed, but not all the land that cannot readily be ploughed is unproductive. A result of the central position of the plough in our agriculture is that pasture that cannot readily be ploughed is not usually considered to be worth the effort of re-seeding with more productive species: in this category is land which is too steep, wet or stony to allow the passage of heavy tillage implements. In recent years research workers have come to consider means where low-grade pastures might be improved by establishing more productive species without resort to ploughing. From America, New Zealand and Australia there have been reports of the oversowing of seeds and fertilisers and of the development of machines for sod-seeding old pastures. Now herbicides are being tested as a pre-treatment before the surface cultivation of land to be re-seeded.

Research work on the use of chemicals for this purpose has been in progress in three countries, the earliest experiments being reported from America. Sprague & Frans[1] and Sprague[2] carried out experiments in 1949–51 in which TCA at 25 lb./acre with and without 2,4-D at 0·5 lb./acre was applied to Kentucky bluegrass pastures. The treatments were followed by surface discing and the land was then sown with orchard and bromegrass, ladino clover and trefoil. In these experiments the effect of the herbicide treatment was to allow a considerable reduction in the number of discings that were necessary for a seed-bed. A satisfactory establishment of the more productive grasses was obtained. In 1952 Barrons & Fitzgerald[3] applied 1 lb. of 2,4,5-T/acre to ladino clover swards and followed the treatment with light discing. Wheat, maize, oats and flax were test drilled and produced yields comparable with the crops in the locality. Davidson & Barrons[4] carried out experiments in 1953–54 in which 5 lb. of dalapon/acre with 0·5 lb. of 2,4-D/acre was applied to one-half of a quackgrass sward, the other half being cultivated normally, and both were then sown with maize. The early growth of the maize was superior on the uncultivated area, an effect thought to be due to better moisture conservation, but there was no difference in final yield. More recently Vengris[5] reported on four years' experiments in the years 1952–55 in which a number of chemical treatments were used for killing grass swards in preparation for the sowing of legumes. Dalapon at 10–15 lb./acre and TCA at 30 lb./acre applied in mid-summer were found to be the most promising materials for the elimination of bent and bluegrass turf. The persistence of the chemicals in the soil was studied and an interval of 30 days between spraying and planting was found to be necessary in normal weather. In moist soils serious difficulty arose from volunteer stands of rough stalked meadow grass produced from dormant seed in the soil.

In New Zealand there is a need for a treatment that will allow the renovation of the steep browntop-dominant pastures and a considerable amount of experimental work on the problem has been done in the past few years. Blackmore[6] in 1957 summarised the work that has been done in New Zealand by himself and other workers. The three main objects in using herbicides prior to surface re-seeding should be to kill the existing vegetation, to mobilise plant nutrients through organic breakdown and to prepare a suitable seed-bed, fine and firm with enough soil to cover the seed. Dalapon at rates of 2·5–15 lb./acre, both alone and with a small quantity of aminotriazole, TCA at up to 20 lb./acre, maleic hydrazide at 8 lb./acre and diesel oil at 40 gal./acre are some of the treatments that have been applied. From these, the New Zealand workers appear to have standardised on a mixture of 5 lb. of dalapon and 1 lb. of aminotriazole/acre as being the best all-round treatment. Although aminotriazole has been found to increase the kill of grasses it has the disadvantage of being very toxic to clovers. The seed-bed cultivations have varied from none to surface discing. On swards that were comparatively short the establishment of introduced species was in proportion to the extent that the chemical treatment weakened the existing sward. Where a great weight of herbage was present at the time of spraying, a herbicide application followed by burning was found to be superior to burning alone or burning followed by spraying. Although the re-seeding after spraying has mainly been with grasses and clovers, turnips have also been direct-drilled with success.

Before 1956 few experiments took place in the United Kingdom. Norman[7] in 1954 applied 2,4-D at 1 and 2 lb./acre to a bent, fescue, cocksfoot downland pasture as a pre-treatment before sowing ryegrass and white clover: the early establishment of both ryegrass and white clover was significantly higher on the plots that received the herbicide treatment than on control plots. The proportion of perennial ryegrass on the herbicide-treated plots remained higher than on the control plots, but the level of white clover was low and eventually no different from the control. Later it was reported[8] that after two years the herbicide treatment had had no effect on the cover of sown ryegrass and white clover. One trouble was found to be the ingress of undesirable creeping grasses, an effect that was checked by close grazing. Davies & Evans[9] carried out experiments in 1954 in which TCA at 20, 40, 80 and 120 lb./acre was applied to undisturbed swards on the hills of Staffordshire and Shropshire, a mixture of grasses and white clover being sown after surface cultivations. They found that although the technique was promising there were many difficulties to be overcome. Amongst these was the problem of obtaining a seed-bed in a wet summer on clay that became compact after losing its cover of herbage, and difficulty in dealing with the broad-leaved weeds that emerged after re-seeding.

It is evident that the discoveries of dalapon and aminotriazole caused a decline in the research interest in using TCA for this purpose. The different properties of the chemicals are probably the reason. Unlike TCA which enters through the roots, dalapon and aminotriazole are taken up mainly through the leaves and their direct toxic action is therefore little influenced by soil type or cultivations: they also persist in the soil for a shorter time than does TCA. It remains to be seen whether this change in emphasis is in fact a correct judgment of the relative merits of the chemicals.

Experimental approach

While experiments of the type that have been reported are necessary for the acquisition of field experience, they cannot alone provide the basic information about the performance of the chemicals that will allow a successful application of the technique in a variety of different situations. A proper understanding can only be gained by the simultaneous development of three aspects of the enquiry:

(1) A critical assessment of the effects of dalapon and aminotriazole on all the species that are likely to be encountered, taking into account their habits of growth and their reactions under differing seasonal and climatic conditions. This very large investigation is being undertaken by Mr. Fryer (see p. 197).

(2) The examination of the persistence of the chemicals in the soil so that a reliable judgment may be made as to the necessary time interval between spraying and planting. The factors that have to be taken into account are the soil type and its organic matter content, temperature and rainfall, the effect of cultivations and the resistance of the species that are to be planted. Work on this aspect has been in progress for three seasons in co-operation with Dr. Holly, but it has not yet reached a stage at which the results may be published.

(3) The acquisition of field experience in selecting the best combinations of spraying, cultivations, seed mixtures and management to meet the requirements of any particular field. There is available a wealth of research and farm experience concerning re-seeding by traditional methods on all types of soils. It remains to be ascertained to what extent this must be modified in the rather different circumstances following a chemical destruction of the old turf prior to surface re-seeding.

Experiments on the re-seeding process

Between 1956 and the present time seven experiments have been started by the A.R.C. Unit of Experimental Agronomy with the object of gaining experience in the destruction of green vegetation and surface root mats and in comparing the various farm implements that may be used in the re-seeding process. The investigation is in its early stages and it is possible only to present details of two experiments in which preliminary results are available.

Experiment H.26.56 at Wytham, Berkshire

This pilot experiment took place on a Thames flood meadow that had not been ploughed within living memory. The dominant species in the sward, which has been grazed or hayed for many years, were red fescue (*Festuca rubra*), yorkshire fog (*Holcus lanatus*), cocksfoot (*Dactylis glomerata*), buttercup (*Ranunculus* spp.) and a small quantity of red and white clovers. These were growing on a surface root mat about 1–1½ in. in thickness which overlay an alluvial top soil on gravel. The object of the experiment was to ascertain whether such a sward could be destroyed by an autumn application of herbicides and if so, to compare various farm implements for obtaining a seed-bed in spring. Since it was a pilot experiment there were 11 unreplicated treatments applied to plots 20 yards square. The chemical treatments started with the application in June 1956 of 1·5 lb. a.e./acre of 2,4-D ester in 12 gal./acre to all plots to be sprayed: then in late September dalapon at 15 and 30 lb. a.e./acre in 80 gal./acre was applied to the two halves respectively of each plot to be sprayed. The cultivation treatments were:

Not sprayed
1. Not cultivated and re-seeded
2. Ploughed and disced in spring

Sprayed
3. Ploughed and disced in spring
4. Pitchpoled in autumn and spring
5. Pitchpoled in spring
6. Autumn pitchpoled and rotary cultivated in spring
7. Rotary cultivated in spring
8. Cultivated and disced in spring
9. Autumn pitchpoled and disced
10. Harrowed
11. No cultivations

The last operation of seed-bed preparation was a light harrowing (on plots 2–9 inclusive); a timothy, meadow fescue, white clover seeds mixture was then cross-drilled in 2 bushels/acre of mixed corn (on plots 2–11 inclusive). The sequence of events was as follows:

28.6.56	2,4-D applied. It killed or depressed all the broad-leaved species, and produced a nearly pure grass sward.
24.9.56	Dalapon treatments applied. About six weeks later there was no green matter visible on the sprayed plots.
16.11.56	Plots 4, 6 and 9 were pitchpoled. During the winter of 1956–57 the area was flooded twice.
10.4.57	It was observed that the dead grass had collapsed to form a thin scum separated from the mineral soil by the root mat. Occasional patches of moss were visible. In the absence of any cultivations the surface remained thus, until red fescue started to emerge in mid-May.
18.4.57	The spring cultivations started and were followed within a few days by drilling.

The cultivated plots may be considered in three groups according to the type of seed-bed that was produced. On the plots that received light harrowing or no cultivation, the seeds were drilled into the root mat. There was a satisfactory emergence of sown grasses and clovers but the plants did not thrive and were eventually in competition with an infestation of red fescue. On the plots that were disced or pitchpoled, the root mat was torn away from the soil surface and a firm natural tilth was exposed: the root mat lay loose on the soil surface and did not interfere with drilling. There was a good emergence of sown grasses and clovers and the weed population was low. On the plots that were ploughed or rotary cultivated, the root mat was incorporated into the soil and the resultant seed-bed was puffy and could not be compacted by any available roller. The seeds, particularly the white clover, were rather slow to emerge and there was a greater population of broad-leaved weeds than on the other treated plots. At this stage spraying did not influence the type of seed-bed produced by ploughing.

28.6.57	The cereal crop was mown for silage.
1.8.57	Grazing started, yearling bullocks being used, and continued on and off until the autumn.
Spring 1958	The area was harrowed and treated with 3 cwt./acre of complete fertiliser (9.9.15).
5.6.58	A silage crop was taken. Thereafter the area was grazed on three occasions until the autumn.

A year after sowing there were marked differences in the botanical composition of the plots. Where the mat was not moved (plots 10 and 11), the sward consisted mainly of red fescue, timothy and white clover. On the ploughed or rotovated plots (2, 3, 6 and 7) the broad-leaved weeds declined and the new seeds were dominant, as they were from the beginning on the disced or pitchpoled plots (4, 5, 8 and 9). On all the cultivated plots occasional plants of red fescue were visible. In June 1958 an assessment of yield and botanical composition showed that all the treated plots, except 10 and 11, were superior to the original sward and there was little to choose between the ploughed or rotary cultivated and the disced or pitchpoled plots, although the latter pair were slightly superior in content of timothy and white clover.

Experiment J.26.57 at Irchester, Northants.

This experiment took place on flood meadow that had been re-seeded during the war and had since degenerated into a dense infestation of tussock grass, *Deschampsia caespitosa.* The site was chosen because it represented a soil covered by a dense vegetative growth. The object of the experiment was to ascertain whether it was possible to cause the complete death of the vegetation and to gain experience in dealing with the large quantity of dead organic matter that might be expected.

The tussock grass was up to 3 ft. high at the start and provided about 60–70% of the ground cover of the experiment. The remainder of the area was occupied by *Agrostis* spp., buttercup (*Ranunculus* spp.), creeping thistle (*Cirsium arvense*) and perennial nettle (*Urtica dioica*). Six chemical treatments were applied to plots (20 yd. × 10 yd.) which were replicated twice. The plots were in randomised blocks. A ploughed control was not included because the farmer considered the operation to be impossible with his implements. The chemical treatments were 5, 10 and 15 lb. a.e. dalapon/acre of each mixed with 1 lb. a.e./acre of 2,4-D ester and three mixtures of dalapon and aminotriazole (2·5+2·5, 5·0+5·0, 7·5+7·5 lb. a.e./acre respectively), all applied in 24 gal. of water/acre.

The sequence of events was as follows:

11.10.57	The plots were sprayed.
Winter 1957–58	The area was flooded intermittently.
21.4.58	The dead vegetation was dry and was burnt.
2.5.58	The plots were rotary cultivated twice at about 1 in. depth of soil; 3 cwt. of complete fertiliser (9.9.15)/acre and a timothy, meadow fescue, white clover seeds mixture were broadcast and harrowed. The area was then rolled.
23.5.58	The seeds started to emerge and light grazing began soon afterwards.
28.6. to 10.7.58	The whole area was flooded to a depth of 1 ft.
5.8.58	The area was sprayed with 1·5 lb. of 2,4-DB/acre for broad-leaved weed control. Thereafter grazing continued on and off until the autumn.

At the start of the experiment the amount of vegetation was so great that it was considered unlikely that a single spray would result in the death of all the vegetation. However, in the spring of 1958 the plots presented a picture of dead brown organic matter. Closer inspection indicated that the two lowest dosages (5 lb. of dalapon and 2·5 lb. of dalapon+2·5 lb. of aminotriazole) were borderline and occasional green shoots of tussock and *Agrostis* could be found. The 2,4-D application did not result in a complete kill of all the broad-leaved weeds, because occasional shoots of buttercup and nettle could be seen. After the area was burnt over, only ash and the bases of the tussock clumps remained on the soil surface. The rotary cultivation, an operation that required little time or power since it was at a very shallow depth, caused the tussock bases to be torn from the ground and to lie loose on the soil surface. The seed-bed was fine and firm. A good emergence of seeds was accompanied by seedling buttercup, occasional *Agrostis* and irregular patches of creeping thistle. The flooding in June resulted in the death of all the white clover and creeping thistle and some of the meadow fescue. At the present time the sown grasses appear well established and the sward consists of timothy, meadow fescue, *Agrostis* spp. and occasional young tussock plants that have germinated from seed. Also present are young buttercup plants, burnet and perennial nettle, none in sufficient quantity to interfere with grazing by bullocks.

Discussion

The success of the surface re-seeding operation will depend to a large extent on the method of dealing with the live and dead organic matter on the soil surface. In the United Kingdom the three main types that are likely to be encountered alone or in combination are green vegetation, a surface root mat and a layer of peat overlying the mineral soil.

Since the effect of the herbicide is to kill the green vegetation, it must be expected that trash will result from the treatment. The method of dealing with it in preparation for a seed-bed will depend on the type and quantity that is present. If the trash is small in quantity it may be possible to disregard it, but a thick layer of dead vegetation would seriously interfere with cultivations, and it would therefore have to be removed by some means such as burning. The application of the herbicide in autumn, which allows an interval of up to 6 months before seed-bed cultivations, provides time for some breakdown of the trash to occur.

Little information is available about the direct effect of a herbicide on a root mat. It has been observed that the death of the live roots in the mat greatly decreases its attachment to the soil surface. In experiment H.26.56 the mat on the plots that received the herbicide was peeled off the soil surface by the disc or pitchpole. Providing the pieces of mat were small they could be disregarded. The traditional way of dealing with a mat is to plough it in, but such an operation is likely to result in a puffy seed-bed unless a really heavy furrow-press is available.

A layer of acid peat overlying the mineral top-soil is likely to be more difficult to handle because its presence is an indication that soil conditions are unsatisfactory for the species that are to be sown. It has been suggested that on upland pastures the peat layer should not be ploughed under but should be humified on the soil surface. The rectification of acidity, drainage and nutrient deficiency over a period of several years would lead to a natural change in the botanical content of the pasture.[10] As yet there is no experience of total herbicide application in this situation; but it might be that herbicides could be used to hasten the departure of the unproductive species once the process of humifying the peat has begun and more productive species could be broadcast and harrowed in to take their place.

It is clear that the development of herbicides for the surface re-seeding of old pasture is an involved subject that requires the attention of those experienced in herbicides, grassland husbandry and the problems of the marginal land upon which the technique appears most likely to be used. A successful application of the technique might greatly ease the cost and difficulties encountered in improving poor pasture.

Acknowledgments

The author wishes to thank Dr. E. K. Woodford of the A.R.C. Unit of Experimental Agronomy, Mr. J. O. Green of the Grassland Research Institute and Mr. J. F. Ormrod of the National Agricultural Advisory Service for their advice on the conduct of the experiments.

References

[1] Sprague, M. A., & Frans, R. E., *Down to Earth*, 1952, **8**, (3), 8
[2] Sprague, M. A., *Agron. J.*, 1952, **44**, 405
[3] Barrons, K. C., & Fitzgerald, C. D., *Down to Earth*, 1952, **8**, (3), 2
[4] Davidson, J. H., & Barrons, K. C., *Down to Earth*, 1954, **10**, (3), 2
[5] Vengris, J., *Proc. 10th North Eastern Weed Control Conf., 1956*, p. 54
[6] Blackmore, L. W., *Proc. 10th N.Z. Weed Control Conf., 1957*, p. 18
[7] Norman, M. J., *Proc. Brit. Weed Control Conf., 1954*, p. 77
[8] Norman, M. J., & Green, J. O., *J. Brit. Grassl. Soc.*, 1957, **12**, (2), 74
[9] Davies, J., & Evans, S. A., *Proc. Brit. Weed Control Conf., 1954*, p. 205
[10] Crompton, E., *J. Brit. Grassl. Soc.*, 1958, **13**, (3), 229

II. An Experiment with Dalapon, Aminotriazole and 2,4-D in conjunction with Oversowing of Old Pastures

by

J. O. GREEN, D. D. KYDD and LEWIS JONES

(*The Grassland Research Institute, Hurley, Berkshire*)

An old pasture, composed largely of red fescue and broad-leaved herbs, was sprayed in May 1957 with three chemicals singly and in all combinations, to control the indigenous vegetation before oversowing with ryegrass and white clover in July.

A limited suppression of *Festuca rubra* was obtained with dalapon at 1·5 or 3 lb./acre. Aminotriazole at 5 or 10 lb./acre had less and short-lived effect. Both chemicals increased the proportion of bare ground sufficiently to improve the early development of sown ryegrass: 2,4-D ester and aminotriazole suppressed broad-leaved species sufficiently to produce a similar result in ryegrass. Aminotriazole severely reduced indigenous white clover while 2,4-D ester did not.

Pre-sowing treatment with dalapon and 2,4-D ester together had an additive effect on development of ryegrass, without harm to indigenous clover. The most effective treatment, in terms of seedling development, was a mixture of dalapon at 3 lb. and 2,4-D at 1 lb./acre: in April 1958 following this treatment the specific frequency of ryegrass in point quadrats was 22%, compared with 9% in unsprayed plots. A greater degree of control of *Festuca rubra* is probably desirable.

Introduction

The productivity of a permanent pasture is related to its botanical composition. An increase in the proportion of more useful grasses and legumes may be achieved through manuring and improved management, but it can often be accelerated by introducing seed of the better species. Establishment of seedlings after oversowing is generally assisted by cultivation, one object of which is to reduce competition from established plants. It may, however, be possible to achieve this particular object by chemical treatment before oversowing. While this may not carry all the benefits of cultivation (e.g., aeration), it may have the advantage that, if selective herbicides are used, desirable botanical changes may be initiated even before seeds are sown.

In experiments at the Grassland Research Institute by Norman & Green[1] 2,4-D amine was used to control broad-leaved species, in a pasture largely composed of such species, before oversowing with ryegrass and clover. While the death of broad-leaved species left much open ground in which sown seeds germinated, the development of the seedlings was seriously hampered by rapid encroachment of the indigenous grasses into the same space. It was also found that the indigenous white clover was temporarily reduced by 2,4-D amine.

The experiment described in this paper was designed to study the effect of spraying the same pasture with 2,4-D ester (which has been found less harmful to white clover than the amine salt) and with two other chemicals which might be expected to give some control of indigenous grasses, before oversowing a seeds mixture. The experiment was carried out in collaboration with the Agricultural Research Council Unit of Experimental Agronomy, Oxford.

Experimental

The pasture was on a steep, north-facing chalk escarpment at the Grassland Research Institute. It was dominated by red fescue (*Festuca rubra*) and a great variety of broad-leaved herbs—the latter contributing over 50% of the total ground cover at certain times. The ryegrass content was negligible. The field had received no manures for at least 8 years.

The experiment began with spraying on 28th May, 1957. All combinations of the following chemical treatments were tested (all as acid equiv./acre): (1) 2,4-D ester: 0 and 1 lb.; (2) dalapon: 0, 1·5 and 3 lb.; (3) aminotriazole: 0, 5 and 10 lb. The herbicides were applied in water at 40 gal./acre. Aminotriazole was added from a water-soluble stock solution of 98% aminotriazole, dalapon from a similar solution containing 74% a.e. of dalapon sodium salt, and 2,4-D butyl ester as an emulsion in carnea oil and Lissapol NX. The plots were 6 × 4 yd. and the 18 treatments were repeated in three randomised blocks.

Eight weeks later, on 24th July, all plots were cross-harrowed with a spike harrow. A mixture of seed and granular fertiliser was then drilled into all plots from a corn drill with disc coulters 7 in. apart set to sow at 1–1½ in. depth. S.24 perennial ryegrass was sown at 15 lb., S.184 white clover at 5 lb., and compound fertiliser (12-12-15) at 1 cwt./acre. Drilling was followed by cross-rolling with a Cambridge roll.

The plots were contained in a single paddock. They were grazed by sheep for two days from 1st October and again for two days from 15th November, 1957. On 26th March, 1958, compound fertiliser (12-12-15) was broadcast over all plots at 3 cwt./acre.

A botanical assessment was made on 21st April, 1958, by the point quadrat method. A frame of ten points was set at right angles to the drilling, but otherwise at random, at ten sites within each plot. Specific frequency was recorded.

Results

All chemical treatments increased the proportion of bare ground. This made the harrowing more effective, but there was no marked difference among treatments in this respect.

The data given in Tables I and II show the situation in spring, 9 months after sowing. In Table I, specific frequency of ryegrass (mainly sown) and white clover (mainly indigenous) per 100 points is given. For the purpose of statistical analysis, specific frequency values were transformed to square roots, and these are presented in Table II to show the average effect of each herbicide, particularly upon indigenous species.

Table I shows that spraying with either 2,4-D ester or dalapon led to improved development of ryegrass, and that the effects of these two chemicals were additive. They had no significant effect upon the indigenous white clover. Aminotriazole had a slight effect on ryegrass development, but did not add to the effect of 2,4-D ester; and it drastically reduced the indigenous white clover.

From Table II it will be seen that the total herb content remained low after treatment with 2,4-D ester at 1 lb./acre or with aminotriazole at 5 lb./acre (but no lower at the 10-lb. rate).

In plots treated with 2,4-D, *Festuca rubra* and *Poa trivialis* had increased. At the same time, *Holcus lanatus* had declined slightly. After treatment with aminotriazole, *Festuca rubra* and *Poa trivialis* had not increased, but there was a marked increase in *Holcus lanatus* by the time the assessment was made.

Table I

Specific frequency of perennial ryegrass and white clover quoted as contacts per 100 points, on 21st April, 1958

2,4-D ester, lb./acre		Nil			1 lb.		
Aminotriazole, lb./acre		0	5	10	0	5	10
Dalapon, lb./acre							
0	Ryegrass	9·0	19·0	13·7	15·7	20·0	15·0
	Clover	21·7	5·7	1·3	25·7	3·7	2·0
1·5	Ryegrass	10·0	15·7	12·7	22·7	14·7	22·0
	Clover	30·0	3·3	1·7	23·3	3·7	4·3
3	Ryegrass	12·3	18·0	23·0	22·0	23·7	13·3
	Clover	24·7	5·3	2·3	23·7	4·0	4·7

Table II

Average effect of each herbicide, whether alone or in the presence of other herbicides

(Means of square root transformations of specific frequency, per 100 points, for major species, on 21st April, 1958)

	2,4-D			Dalapon				Aminotriazole			
lb./acre	0	1		0	1·5	3		0	5	10	
Perennial ryegrass	3·62	4·35	±0·168	3·65	3·86	4·45	±0·206	3·65	4·06	4·25	±0·206
Festuca rubra	6·23	6·50	±0·184	6·81	6·52	5·76	±0·226	6·35	6·71	6·03	±0·226
Poa trivialis	3·44	4·03	±0·182	3·73	3·77	3·71	±0·223	3·82	3·58	3·81	±0·223
Holcus lanatus	3·73	3·17	±0·179	3·95	3·71	2·69	±0·219	2·20	3·83	4·33	±0·219
All grasses	10·21	10·89	±0·120	11·05	10·78	9·82	±0·148	10·01	10·94	10·70	±0·148
White clover	2·76	2·85	±0·125	2·68	2·85	2·88	±0·153	4·88	2·00	1·53	±0·153
Ranunculus bulbosus	4·63	3·72	±0·111	3·79	4·10	4·63	±0·135	3·96	4·25	4·31	±0·135
All herbs excluding white clover	6·58	5·65	±0·149	5·34	5·86	7·14	±0·182	6·67	5·82	5·86	±0·182

Dalapon checked the indigenous grasses considerably, but in the space of 9 months the broad-leaved species had taken advantage of this, whether they had been sprayed with 2,4-D or not.

Discussion

The use of one or other of the selective herbicides (2,4-D ester or dalapon) appears to leave the oversown grasses and clovers exposed to increased competition from those indigenous species not affected by the herbicide.

The combined effect of 2,4-D ester and dalapon, giving a degree of control of most species present, enabled seedling ryegrass to attain a specific frequency of 22% within 9 months of sowing. This was considerably in advance of the 9% frequency in unsprayed plots. These values represent contributions to total cover of 12·9% and 4·7% respectively. Whether this differential warrants the use of the chemicals will depend on whether it can be maintained, and the contribution of ryegrass increased.

Since the spring data quoted in the previous paragraph, a further analysis has been made to show the position a year after sowing. The specific frequency of perennial ryegrass is now 36% after spraying with the dalapon and 2,4-D ester mixture. This figure is considerably in advance of 27% obtained after one year on the same original sward after harrowing and broadcasting seed. These figures may be compared with an increase from 2% to 20% induced on the same pasture after 6 years of rotational sheep grazing combined with nitrogen and phosphate manuring, but without cultivations of any kind or the sowing of seed.

A better control of red fescue is required for this pasture. Any increase in dalapon concentration will kill the useful species before attacking sufficiently red fescue. Higher dalapon concentrations might be used to advantage on a sward consisting almost entirely of red fescue (see following paper).

Acknowledgments

It is a pleasure to record appreciation of the help given by Mr. J. G. Elliott of the A.R.C. Unit of Experimental Agronomy, Oxford, who arranged the spraying of plots.

Reference

[1] Norman, M. J. T., & Green, J. O., *J. Brit. Grassl. Soc.*, 1957, **12**, 74

FIELD EXPERIENCES WITH DALAPON IN RE-SEEDING DIFFICULT LAND

by

J. F. ORMROD

(*National Agricultural Advisory Service, Shardlow Hall, Derby*)

In six trials in which dalapon at two rates plus 2,4-D ester was sprayed on poor permanent grass to kill the existing sward prior to re-seeding, a satisfactory kill was achieved in five of the six sites, except for broad-leaved species. Re-seeding was successful at two out of four sites. The value and limitations of the new technique are discussed.

Introduction

Elliott (see p. 234 above) has shown that it is possible to kill an existing turf by using a spray containing dalapon and to re-seed successfully after only light cultivations. The trials described here were designed to test this technique over a wide range of sward types and climatic conditions. The sites were mostly located on very difficult land in order to reveal possible limitations of the method and gain information on the kind of cultivations necessary.

Treatments

A simple standard lay-out was adopted for all sites, the treatments being:

A. Half-acre block sprayed with 10 lb. acid equivalent of dalapon as the sodium salt/acre plus 1½ lb. acid equivalent of 2,4-D ester/acre.

B. Half-acre block sprayed with 20 lb. of dalapon/acre plus 1½ lb. of 2,4-D ester/acre.

All sites were sprayed in October 1957 at 20 gal./acre using a Land Rover-mounted low-volume sprayer. The whole area was intended to be cultivated as one piece and re-seeded with a Cockle Park type mixture at 30 lb. of seed/acre.

The methods of cultivations and re-seeding were not standardised, but were left to the discretion of the farmer concerned.

Details of sites

No.	Situation	Altitude	Description of sward
1	Ingleby Derbyshire	120 ft.	Riverside pasture, frequently flooded, containing tussock grass (*Deschampsia caespitosa*), *Agrostis* and *Holcus* spp. with *Ranunculus* spp. and burnet (*Sanguisorba officinalis*) as the main weeds. No acid mat.
2	Grace Dieu, Leics.	600 ft.	Hill sward, mainly *Molinia* and *Nardus*, with an acid mat 3–4 in. thick over peat. Boulders up to soil surface.
3	Sudbury, Derbyshire	250 ft.	Felled woodland with frequent tree-stumps, almost pure stand of *Holcus mollis* with an acid mat 6 in. thick. Ungrazed for 20 years.
4	Belper, Derbyshire	500 ft.	Steep hillside pasture with shallow soil over rock. Boulders up to soil surface. A mixed sward of poor quality with *Agrostis*, *Holcus* and *Cynosurus* spp. and a wide range of broad-leaved weeds. No acid mat.
5	Matlock, Derbyshire	950 ft.	An open sward of heather (*Calluna vulgaris*) with *Nardus* spp., *Molinia* and other hill grasses and patches of rushes. Wet peat with many boulders projecting from soil.
6	Monyash, Derbyshire	1050 ft.	A mixed sward of fair quality on a shallow soil overlying limestone, which outcrops.

Effects of spraying

All sites were sprayed under good weather conditions except No. 6, where heavy rain began as spraying was finishing and continued for several hours. Here there was only a slight check to the grasses, and by the following summer no effect could be seen.

No doubt because the sites were sprayed in the autumn when plant growth was slow, the effects were also very slow, and it was not until the spring, 5 months after spraying, that the full effect was seen. At none of the sites did the 2,4-D ester give any control of broad-leaved weeds. Generally, the 10-lb. rate of dalapon was not quite as good as 20 lb., on which plots there was practically no sign of living grass in the spring. Taking this as 100% kill, the 10-lb. rate would be assessed about 95%. Tussock grass was very slow to die at site No. 1 but eventually both rates gave 100% kill. Site No. 3 showed what appeared to be an almost complete kill of *Holcus mollis* in the spring, but it was not cultivated and re-seeded and by mid-summer there was 100% recovery. At site No. 5 the effect was extremely slow, but eventually a complete kill was achieved of heather (*Calluna vulgaris*), rush (*Juncus effusus*) and the grasses, though the latter were re-colonising by mid-summer.

Cultivation and re-seeding

It was decided to attempt to re-seed sites 1–4. No. 6 was discarded because of failure of spraying and No. 5 because the large number of boulders and the wetness of the ground would have made mechanical cultivations hazardous. The subsequent history of the sites is summarised below.

No. 1.—The large amount of top-growth on the tussock areas was burned off, and the area rotovated. The first rotovation left a large number of tussock crowns on the surface and a second rotovation was necessary to produce a reasonable seed-bed. The seeds were then broadcast, harrowed and rolled. There was a good germination, but eventual establishment was marred by unusual and prolonged flooding and waterlogging in July and August. Even so the final ley was as good as would have been expected from the conventional method, and to date there has been no vegetative regrowth of the old tussocks, though some seedlings are now appearing. There was, however, more buttercup and burnet than would have been expected after really good ploughing.

No. 2.—Heavy top-growth on this site was burned off, but heavy discs failed to penetrate. A cultivator was then used, but it tore up the acid mat into strips and clods, which would have had to be disposed of before any seed-bed could be made. It was proposed to take up and burn them to avoid the heavy cost of carting off, but this was made impossible by the wet summer and the site has not yet been re-seeded.

No. 3.—The accumulation of ungrazed herbage was largely removed by burning, but the thick, springy acid mat underneath resisted any penetration by discs. A tine cultivator tore the mat up into long strips and clods, which were unmanageable for subsequent cultivations and which would have had to be carted off at considerable cost. Pressure of other farm work prevented this and the trial was abandoned.

No. 4.—This was pitch-pole harrowed three times. The dead turf, though there was no acid mat, was dense and tough, and the pitch-poling cut it up into small loose clods which thickly covered the surface of the soil. Broadcasting was therefore impracticable, but the seed was drilled with a corn-drill, whose discs were mostly able to push aside or cut through the small clods quite satisfactorily. The seeds established as well as could have been achieved by normal methods, but there were rather too many broad-leaved weeds which had survived spraying and cultivations.

Summary of results

1. At five of the six sites, spraying gave an almost complete kill of the sward, except for broad-leaved species. The effect at the sixth was spoilt by heavy rain after spraying.

2. At the four sites where re-seeding was attempted, two of the better swards were completed successfully and the two poorest abandoned because of the difficulty of dealing with a thick acid mat.

3. It is concluded that while most existing grass swards can be killed by dalapon, there are still problems to be solved in re-seeding poor swards thereafter.

General discussion

It was thought at the outset that the dalapon re-seeding method was only likely to fit in British farming where ploughing was impossible, excessively difficult or inadvisable for some reason, and six typical sites were chosen. Experience with these and other trials has confirmed this view, but has also shown that dalapon has considerable promise for these special conditions provided certain difficulties can be overcome.

There are two reasons why grassland is ploughed and cultivated prior to direct re-seeding: firstly to kill the old sward and secondly to prepare a seed-bed in which the new seeds can become established. How far does the dalapon re-seeding technique meet these requirements? It certainly seems that a sufficient rate of dalapon will kill most species of grasses commonly present in our swards, although there is evidence of appreciable variation in resistance between species. In this context the word 'kill' is used to mean 'inhibit top-growth for an appreciable period'. Unless spraying is followed by cultivations and re-seeding, most grass swards will become re-established after an interval of weeks or months according to circumstances, either from vegetative re-growth or from seedlings or both. Dalapon spraying is therefore a means of removing competition from the existing grasses for a period in which the new seeds may establish themselves, and its value is dependent on the success of the following cultivations in preparing a satisfactory seed-bed and on the rapid and vigorous growth of the new seeds.

It may be that the problem of eliminating any broad-leaved weeds in the sward will be a more difficult problem than that of killing the grasses. Neither in the series of trials now reported nor in the later ones using the same combination of chemicals but sprayed at different dates during the growing season has the combined spray been successful in killing broad-leaved weeds, even those normally susceptible to 2,4-D. Although further experience may show that this is not a general effect there is still the difficulty of dealing with those species resistant to most herbicides, such as established broad-leaved docks and bulbous buttercup. Once competition from grass is removed, any species which remain spread vigorously to colonise the bare ground, and light cultivations will not eliminate them as effectively as ploughing.

Whatever the difficulty in killing existing swards, it is small compared with that of preparing a seed-bed on the more difficult land. Where the sward is open and there is no acid mat, discs or harrows will probably work up a seed-bed fairly easily and cheaply. But on the poorer swards there is either an acid mat or the turf is dense and tough and even when dead is an effective barrier between the soil and the seed. Where the turf is fairly thin, as on site 4, ordinary farm implements can be used to break it up, though with some difficulty. At the other extreme, as on sites 2 and 3, no implement could deal with it, and removal or burning, at considerable cost, would be necessary. Mature tussock grass presents a problem of its own, since the dead crowns can cover considerable areas of ground and do not break up with normal cultivations. Here the rotovator has been used successfully. It is clear that dalapon re-seeding is easiest where conditions approximate most closely to those of normal lowland farming, and that as land becomes more and more difficult the technique becomes less and less practicable. This is unfortunate, because conventional methods are satisfactory on normal land and are likely to be cheaper than chemical methods, while it is on hill-land and other difficult land that a cheaper and more efficient method of improvement than ploughing is greatly needed. Since cultivations present such a problem on difficult land, is it possible to do without them yet still effect a worthwhile improvement by using dalapon? It should be possible to establish seeds on a dead turf by using stock management alone—this possibility will be investigated. Taking a long-term view of improving land with a thick acid mat, it would seem logical to lime over a period of years to break down the mat, then use dalapon plus fertilisers and re-seed when the improvement has reached a suitable stage. Another possibility is that a machine might be able to place the seed in the soil by cutting through the dead turf or mat, on the lines of the New Zealand sod-seeding technique.

At present the cost of dalapon application is far too high to make it an economic proposition for this purpose. If a complete kill is desired it seems probable that between 10 lb. and 20 lb. acid equivalent/acre will be necessary on most swards, which makes the cost £7–£14 per acre at present prices. Even ignoring the cost of MCPA or 2,4-D and the cost of application this is very much more than the cost of ploughing even difficult land, while after-cultivations, seed and fertiliser will cost the same in either case. The cost of the dalapon method would need to be halved before its use is likely to be considered by farmers on poorer land. The first need is a reduction in the price of the chemical. The cost might also be reduced if less material could be used. At present investigations are in progress on the effect of spraying at different times during the growing season. Spraying narrow bands only with dalapon and drilling within the band also offers economy and this is being investigated elsewhere. There is also the possibility that a complete kill may not be necessary for a satisfactory establishment, especially on poor land where the standard required is not high. Another economic obstacle in the way of the adoption of this method of re-seeding is that according to present legislation the farmer would not be entitled to the ploughing grant of £7 or £12 per acre.

To sum up, it appears that the dalapon re-seeding technique will have a definite, though limited, value for British agriculture provided certain requirements can be fulfilled. These are: (1) a substantial reduction in the cost of dalapon application; (2) economic methods of re-seeding the poorer types of land; (3) the elimination of broad-leaved weeds in the sward.

Acknowledgments

The author would like to thank a number of farmers for their valuable co-operation, and the N.A.A.S. District Officers concerned and Mr. A. J. Davies for their assistance in the work.

Discussion on the three preceding papers

Mr. L. Jones.—Could Mr. Elliott and Mr. Ormrod tell us what interval is necessary before sowing after a spring spraying with dalapon and 2,4-D for total kill? At Hurley we have sown a month after spraying, but during this time there was an influx of broad-leaved weeds on the sprayed area, which resulted in strong competition for the seedling grasses.

Mr. Elliott.—Dalapon at 10–15 lb./acre was applied a month before re-seeding. All things considered, an October spray programme was safest.

Mr. W. Moore.—Have the speakers any data regarding the effect of the treatments, especially dalapon, on *Poa annua* present in the swards before treatment, and to what extent had this grass re-established itself?

Mr. Ormrod.—*Poa annua* and most other grass seedlings are easily killed by the treatment with dalapon. After re-seeding, weed grasses of all kinds appeared, including *Poa annua.*

Mr. W. Moore.—What was the pH of the majority of the soils where these experiments were conducted? Presumably the majority of them were acid.

Mr. Ormrod.—In all experiments for re-seeding poor pasture, steps were taken to correct acidity.

Mr. P. A. Oram (Borax Consolidated Ltd.).—I am glad that the last question concerned the problem of pH, since I feel that unless such limiting factors are corrected, the value of this work may be short-lived. There are interesting possibilities for the use of such methods for the improvement of pastures not only in Britain but also probably in Africa. However, we should ask ourselves why the pastures are poor in the first place, since unless the fundamental cause, whether it be drainage, infertility or overgrazing, is discovered and corrected, the improved pasture is soon likely to revert back to its previous species composition. If it is overgrazing (as is often the case in Africa) or poor utilisation that is the cause, then future management will have to be very carefully controlled, and I hope that these studies will be maintained for a considerable period to enable the effects of management on the future of sprayed and re-seeded pastures to be observed.

Mr. R. Garrett-Jones (N.A.A.S.).—It is undesirable that in experimental work the effects of herbicides should be confused with those of subsequent mechanical cultivations. Where heavy cultivations, and particularly rotavation, can be carried out, there is no need for herbicidal treatment. In Breconshire, dense *Molinia* on shallow peat has been very successfully re-seeded after rotavating twice. On poor soils where such cultivation is difficult, we need a technique of herbicide re-seeding, with no or only light cultivation, and I consider that after effective herbicidal treatment, good seed establishment should be obtained at least in the higher rainfall areas.

AN ASSESSMENT OF SODIUM DIPHENYLBORINATE AS A SELECTIVE HERBICIDE

by

G. E. BARNSLEY and J. YATES

(*Woodstock Agricultural Research Centre, Shell Research, Ltd.*)

A preliminary field investigation has been made of sodium diphenylborinate, a compound of low mammalian toxicity, as a post-emergence herbicide. Toxicity to a range of crops and annual weeds was assessed, on the basis of seedling mortality or growth inhibition, in pure stands of crops and weeds.

Common seedling annual weeds were controlled by $1\frac{1}{2}$–5 lb./acre applied as aqueous solution by means of a logarithmic sprayer. Stage of growth influenced their susceptibility which diminished greatly with increasing age. Tolerant crops were cereals, grasses, onions, linseed and certain legumes and possibly conifers. Wheat, oats and barley and certain varieties of peas were substantially unaffected by 6 lb. and the other crops by 2–4 lb./acre.

The compound induces both acute and chronic phytotoxicity, effects which are thought to be related to its probable decomposition products.

Introduction

The phytotoxic nature of boron compounds was recognised[1] in 1876 some 50 years before Warrington[2] showed that this element was essential for plant growth. In spite of this early work, exploitation of boron compounds as herbicides has been limited to a few simple inorganic borates as soil sterilants. The phytotoxicity of these borates is relatively low in comparison with the more recent organic herbicides, perhaps by a hundred or more, and appears to be proportional to elemental boron content.[3]

Although wide differences exist in the tolerance of plant species to boron in the soil, and in the readiness with which they can absorb the compound[4] the borates have found no use as selective herbicides, probably because toxic residues of boron might accumulate in the soil, at the high dosages required for effective weed control.

Our interest in boron compounds as herbicides was stimulated not so much by the known toxicity of the borate ion, but rather by its physiological significance in plant nutrition, and especially by the increasing importance attributed to boron in carbohydrate metabolism.[5] This seemed to us to justify an investigation of the biological properties of organo-boron compounds, of which more than 100 have been synthesised and evaluated. Full results of this work will be reported elsewhere. It demonstrated that certain arylboronic and arylborinic acids were potent plant growth inhibitors, and sodium diphenylborinate, $(C_6H_5)_2BONa$, proved to have promising herbicidal properties. Results of initial field tests with this compound are presented in this paper.

Experimental

The experiments were essentially exploratory, the object being to determine the order of dosage required to control seedling weeds, and the tolerance of the borinate by a range of crops. About 5 lb. of material was available for the tests, which were therefore necessarily confined to small (0·01 acre) plots at a single site.

Pure stands of crops and annual weeds were established from seed, sown in rows and 12 in. wide bands respectively. These were maintained as homogeneous as possible by hoeing and hand cleaning.

Sodium diphenylborinate of 98% purity was formulated as a 30% w/v aqueous concentrate. Other herbicides included in some of the tests were commercially available formulations, namely MCPA (2·5 lb./gal. as K salt) and dinoseb (1·6 lb./gal. as ammonium salt).

Duplicate plots were sprayed in multi- or single dosages with a small track-mounted logarithmic sprayer, similar in construction to the apparatus described by Fryer.[6] Track length was 30 ft. and peak and half-dosage distances were 3 ft. and 12 ft. respectively.

The borinate and MCPA were sprayed at multi-dosage in 25 gal. of water/acre, and dinoseb and sulphuric acid at single dosage in 50 gal./acre. Dosages employed were 0·75–3·75 and 1·5–7·5 lb./acre of borinate, 0·25–1·25 lb./acre of MCPA (acid equivalent), 1·0 lb./acre of dinoseb and 25·0 lb./acre of H_2SO_4.

For compounds sprayed logarithmically the dosages quoted are geometric means of the highest and lowest values for the sample area.

Weeds were sprayed in the cotyledon and 4–8 true-leaf stage. Cereals and onions were sprayed at two stages, and linseed, legumes, conifers and grasses at a single stage of growth.

Toxicity to both weeds and crops was assessed on the basis of seedling mortality and growth inhibition, the latter as indicated by reduction in fresh weight or height of crop. Crop mortality occurred only in the conifers, so that seedling counts for these, but not the other crops, are presented.

Weed density in the controls ranged from 50 to 250 per sq. ft. Counts were made with a 6- or 12-sq. in. quadrat depending on weed density, in triplicate at each of five dosage levels. Dosage/mortality regression lines were constructed for the sensitive species at both spray dates, and for the less susceptible weeds at the cotyledon stage only. When sprayed at the 4–8 true-leaf stage the mortality of the latter species at a dosage of 5 lb./acre was recorded. Three weeks after spray application at the 4–8 true-leaf stage, weed control was also assessed on the basis of fresh weight per sq. ft., three replicate weights at each of five dosage levels being recorded.

Growth of crops was assessed by measuring fresh weight or height, 8 weeks after spraying in the conifers, and 3–4 weeks in the other crops. Weight of plants per 6 or 12 in. length of five replicate rows at 3 to 6 dosage levels was recorded, and the results expressed as mean fresh weight per plant. The non-random design of the experiments precluded statistical analysis of the data.

Results

Weed control

Sodium diphenylborinate induced both acute and chronic phytotoxicity and species differed markedly in susceptibility to each form. Acute symptoms of leaf scorch often appeared within an hour, whereas chronic effects were not discernible for a week or longer. Leaf blades thickened and tended to deepen in colour. Petioles and stems swelled, often to the point of cracking and sections of these revealed blackened and necrotic phloem tissue. Roots were thickened, necrotic, and devoid of root hairs. Depending on the dosage applied, age and species of plant, growth was either partly or completely inhibited. Death of younger seedlings appeared to be mainly the result of acute damage, whereas older plants succumbed more to chronic effects, and especially to collapse of stems due to internal necrosis.

Weed mortality and growth inhibition data are summarised in Tables Ia and Ib in which species are grouped according to their susceptibility to acute phytotoxicity.

Table I

Toxicity of sodium diphenylborinate to annual weeds

(a) High acute phytotoxicity

Weed	Dosage (lb./acre) indicated for 90% kill		Dosage (lb./acre) indicated for 90% reduction wt. weeds/ sq. ft.
	Stage of weed development		
	Cotyledon	4–8 true leaves	4–8 true leaves
Sinapis arvensis (charlock)	1·7	4·8	2·9
Sonchus oleraceus (sowthistle)	1·8	5·5	4·4
Senecio vulgaris (groundsel)	1·5	4·0	2·5
Spergula arvensis (spurry)	1·4	4·0	3·5
Papaver rhoeas (poppy)	<0·75	2·0	2·0
Capsella bursa-pastoris (shepherd's purse)	1·0	3·0	3·4

* Number of surviving weeds ranged from 52–98/sq. ft.

(b) Low acute phytotoxicity

Weed	Dosage for 90% kill, lb./acre	Kill at 5 lb./acre, %	Dosage for 90% reduction wt. weeds†/sq. ft., lb./acre
	Stage of weed development		
	Cotyledon	4–8 true leaves	4–8 true leaves
Galium aparine (cleavers)	4·0	50	3·0
Chenopodium album (fat hen)	4·8	71	1·5
Matricaria inodora (mayweed)	2·7	46	2·1
Polygonum persicaria (persicaria)	4·3	55	2·7

† Number of surviving weeds ranged from 30–84/sq. ft.

Charlock, sowthistle, groundsel, spurry, poppy and shepherd's purse were all highly susceptible in the cotyledon stage, and 90% kill was achieved by dosages of 0·75–1·8 lb./acre. A threefold increase in dosage was required to obtain an equivalent control of these weeds sprayed in the 4–8 true-leaf stage.

Cleavers, fat-hen, mayweed and persicaria were less susceptible and a dosage of 3·0–5·0 lb./acre and 5·0–7·5 lb./acre were required for 90% kill at the cotyledon and 4–8 true-leaf stages, respectively. It appeared that in this group of weeds increase in resistance with age was not so marked.

Whereas higher dosages of borinate were needed to kill cleavers, fat-hen, mayweed and persicaria than the other species, the dosages required for control, as indicated by fresh weight of surviving weeds, was similar for both groups and ranged from 1·5 to 4·4 lb./acre for 90% inhibition of growth.

Crop tolerance

Preliminary glasshouse tests had shown that seedlings of radish, lettuce, French and broad bean, tomato, sugar beet and carrot were killed or severely damaged by 1–2 lb./acre of the borinate. These crops were considered too sensitive and not therefore included in the field tests.

With the exception of the conifers, no crop mortality occurred in any of the sprayed plots, and the predominant form of phytotoxicity was growth inhibition.

Of the crops investigated, cereals (see Table II) were the most resistant, and appeared to tolerate 6·0–7·0 lb./acre of the borinate both before and after tillering. There were no large differences between the varieties tested. Leaf scorch was negligible in all cases.

Table II

Effect of sodium diphenylborinate on growth of cereals sprayed at two stages of development

Crop and variety	Fresh weight per plant, g. Control	Crop sprayed when 4–7 in. high, Dosage, lb./acre 1·3	1·7	2·2	3·3	4·6	6·4	Crop height, cm. Control	Crop sprayed when 8–18 in. high, Dosage, lb./acre 1·5	2·0	3·0	4·0	5·0	7·0
Wheat														
Koga II	2·2	2·2	4·5	3·3	2·9	2·4	2·4	51·1	65·7	62·3	61·5	55·3	49·0	46·0
Atle	3·0	3·1	3·1	4·8	3·4	2·7	3·2	57·5	69·5	61·8	71·0	70·1	60·0	65·6
Atson	3·9	3·6	2·9	3·7	5·5	4·3	3·7	59·3	76·7	72·0	81·7	70·4	66·4	65·1
Sveno	3·0	1·5	3·9	4·0	—	3·5	4·6	64·3	84·4	79·8	82·4	74·2	66·5	61·4
Oats														
Sun II	5·9	8·3	12·2	6·3	5·4	8·1	9·3	56·8	42·1	41·2	44·9	42·7	49·1	43·4
Blenda	6·9	9·7	5·6	5·2	5·9	5·8	3·1	57·4	53·7	36·4	40·4	56·3	51·3	41·1
Eagle	7·6	6·5	8·8	7·4	8·0	8·0	9·6	62·5	43·9	49·6	38·7	38·5	56·5	50·2
Supreme	8·9	7·5	8·7	5·9	7·6	8·8	9·4	58·7	59·6	43·4	59·1	56·2	55·1	53·5
Barley														
P. Archer	9·1	10·0	11·6	10·4	9·0	12·6	10·4	75·5	74·2	75·4	76·8	73·5	72·1	73·3
Proctor	9·2	12·3	11·3	10·1	8·2	7·1	8·2	88·3	78·9	76·5	78·5	74·4	82·4	79·7
Carlsberg	11·3	11·0	11·9	14·7	10·9	13·9	12·2	88·1	81·1	81·8	79·4	78·9	83·1	84·8
Rika	11·4	8·8	12·7	10·4	6·7	8·2	10·7	70·2	80·5	82·2	85·9	69·5	68·2	85·1

Onions (var. Bedfordshire Champion) tolerated 3·75 lb./acre sprayed when 2–3 in. or 6 in. high without growth inhibition (see Table III) or leaf scorch. Linseed (var. Redwing) was equally tolerant sprayed when 3–5 in. high (see Table IV).

Table III

Effect of sodium diphenylborinate on growth of onions sprayed at two stages in comparison with H_2SO_4

Height of crop, in.	Fresh weight per plant, g. Control	Borinate, lb./acre (in 25 gal.) 2·0	2·5	3·0	3·75	Sulphuric acid lb./acre (in 50 gal.) 25·0
2–3	4·1	4·0	5·3	3·2	4·9	5·0
6	21·5	21·0	28·5	29·0	32·1	21·6

Table IV

Relative toxicity of sodium diphenylborinate and MCPA to seedling linseed sprayed when 3–5 in. high

Fresh weight per plant, g.

Control	Borinate lb./acre (in 25 gal.) 2·0	2·5	3·0	3·75	MCPA lb./acre (in 25 gal.) 0·50	0·625	0·75	1·0
11·3	12·7	14·6	13·5	15·1	11·5	10·5	11·9	11·6

The other crops tested, namely clovers, grasses, peas and certain conifers, were in general less tolerant of the borinate. Moreover, the data obtained were difficult to interpret, because in several instances growth response to increasing dosage was not linear. It appeared that factors additional to phytotoxicity were involved.

Of the clovers, lucerne was the most tolerant (3·75 lb./acre) followed by trefoil and alsike (2·5–3·0 lb./acre). Broad-leaved and late-flowering red clovers tolerated 2·0 lb./acre. S.100 white clover was the most sensitive of the species tested (see Table V).

All the grasses tolerated 2·5 lb./acre of borinate except Italian rye grass, the growth of which was reduced by 20% at this dosage level.

Of the eight pea varieties (see Table VI), Meteor, Sharpes Canner and Zelka were the most resistant and dosages up to 7·5 lb./acre had little effect on their growth. Lincoln, Charles I and Thomas Laxton were all sensitive, and 1·5 lb./acre of borinate reduced their growth by 10%, 20% and 30% respectively. Little Marvel and Alderman were intermediate in tolerance, and dosages up to 5·5 lb./acre of the borinate on these varieties were not more toxic than 1 lb./acre of dinoseb.

When the borinate was sprayed on conifer seedlings (see Table VI) seemingly anomalous results were obtained. It was noted that the growth of several of the sprayed species was appreciably more vigorous compared with that of the untreated seedlings. Counts made two months after spraying indicated a higher seedling density on the plots which had received

Table V

Effect of sodium diphenylborinate on growth of seedling grasses and clovers

Crop and variety	Stage of growth	Control	Fresh weight per plant, g. Dosage (in 25 gal./acre) 1·0	2·0	2·5	3·0	3·75
	No. of leaves						
English broad-leaved red clover	3–4	11·5	7·2	8·4	4·4	11·4	6·3
Cornish late-flowering red clover	3–4	13·7	14·9	17·2	8·7	8·9	7·5
S.100 white clover	3–5	17·3	9·3	16·4	13·6	10·3	7·4
French alsike	3–4	19·6	41·3	13·6	27·2	22·3	15·4
English trefoil	5–7	14·5	9·6	12·8	14·5	12·3	10·4
Canadian Grimm lucerne	5–7	18·3	11·2	17·1	13·6	21·0	19·2
S.23 rye grass	3–4 in.	8·0	7·5	7·8	9·7	4·7	5·9
Italian rye grass	7–9 in.	12·8	10·9	10·4	8·9	5·7	10·5
S.37 cocksfoot	3–4 in.	6·3	5·5	7·3	8·6	5·5	4·1
S.48 timothy	3–4 in.	5·5	4·0	5·4	6·1	4·0	5·8
S.59 red fescue	2–3 in.	1·3	1·0	0·9	1·4	0·9	1·1

Table VI

Effect of sodium diphenylborinate on growth of peas, in comparison with dinoseb

Variety	Height when sprayed, in.	Control	Fresh weight per plant, g. Dosage, lb./acre: Dinoseb (in 50 gal.) 1·0	Borinate (in 25 gal.) 1·5	2·25	5·5	7·5
Meteor	5–6	19·1	18·6	19·0	20·8	20·0	18·2
Little Marvel	5–6	36·9	26·8	30·1	41·2	28·4	23·0
Lincoln	4–8	20·9	21·5	18·0	18·3	17·9	8·4
Thomas Laxton	3–5	21·4	22·9	15·8	17·5	15·3	18·3
Sharpes Canner	4–5	22·5	25·2	20·0	22·1	28·4	25·3
Charles I	2–3	20·3	24·3	16·4	16·4	15·4	17·6
Alderman	3–4	31·0	28·0	25·2	25·5	26·5	17·8
Zelka	5–6	33·1	31·6	28·1	30·4	32·3	32·3

Table VII

Effect of sodium diphenylborinate on survival and growth of conifer seedlings

Species	Stage of growth, in.	Fresh weight per plant, mg. Control	Dosage (in 25 gal.), lb./acre 1·25	2·0	3·0	No. seedlings/sq. ft. 1·25	2·0	3·0	Control
Scots pine	1½	760	640	680	770	11	29	21	10
Lodge pole pine	1	210	470	400	290	13	7	21	9
Japanese larch	1	650	670	300	570	6	4	12	8
Thuja	cotyledon	150	120	170	160	10	10	25	14
Sitka spruce	½	44	50	100	120	6	2	9	9

borinate at the 3·0 lb./acre level, in the case of both pines, larch and thuja. One possible explanation was suggested by the observation that there was a higher incidence of seedling mortality on the controls attributable to 'damping off' disease than on some of the sprayed plots. It seemed that the borinate might have fungicidal properties. This was subsequently confirmed for several organisms including *Pythium* spp. The superimposed fungicidal effects of the borinate, although of considerable interest *per se*, precluded any definite conclusions on the toxicity of the compound to the conifer seedlings, but it would seem that they may be classed as tolerant rather than sensitive.

Discussion

The results obtained suggested that sodium diphenylborinate possesses selectivity and is highly phytotoxic to susceptible species at relatively low dosage. The boron content of the compound (5%) is lower than that of existing inorganic borate herbicides, and in contrast with the latter, its use would be unlikely to result in the accumulation of toxic boron residues in the soil. Thus assuming one-half of the borinate reached the soil, an application of 5 lb./acre would increase the boron content by 0·25 lb./acre. It is improbable that this amount would constitute a residue problem, in view of the ease with which the element is leached from soil and the amount taken up by crops. The latter is of the order of 0·5 lb./acre per annum for a heavy boron feeder such as sugar beet.

Crop residues were not determined, but it is known that the borinate and its decomposition products have a low mammalian toxicity.

A possible mode of action has been suggested by the results obtained with the various groups of compounds synthesised, and will be discussed in a future paper. Certain features of the present experiments appear relevant to the selective action of sodium diphenylborinate, in particular the two forms of phytotoxicity induced. The acute form, typically leaf scorch, occurred predominantly in the more sensitive weeds, and to no appreciable extent in crops which tolerated the herbicide, a majority of which possessed a relatively waxy leaf cuticle. The latter might be expected to impede the penetration of borinate. This simple explanation of selectivity is, however, inadequate, for some of the crops also tolerated the herbicide applied to their roots when grown in nutrient solution. It is considered therefore that at least part of the mechanism of selectivity must be of a physiological nature.

The morphological changes associated with the chronic form of toxicity induced by the borinate are significant in their close resemblance to boron-deficiency symptoms, and it is perhaps noteworthy that the cereals, which showed the highest tolerance of the herbicide, are recorded as having a very low requirement of boron.[7]

The association of acute and chronic phytotoxicity which characterise sodium diphenylborinate is probably explained by its hydrolysis and oxidation to phenol and phenylboronic acid, which taked place readily *in vitro*. The toxicity of phenylboronic acid to weed seeds was reported by Bergal & Caujolle.[8] As a post-emergence herbicide we found it to be less active than phenylborinic acid, but with broadly similar selectivity. Further, whereas both acids induced comparable chronic effects, the boronic acid lacked acute phytotoxicity. It is suggested, therefore, that the decomposition of sodium diphenylborinate occurs either on or in plant leaves, with the formation of phenol which causes acute symptoms and phenylboronic acid which induces chronic phytotoxicity.

The absence of appreciable acute damage in tolerant crops and the more tolerant weeds, and its predominance in the susceptible species, suggests that only the latter can readily oxidise the borinate. Alternatively, if the borinate is not selectively oxidised within plants, then the waxiness of the leaf cuticle, by influencing the speed of penetration of the herbicide, may also determine whether its decomposition occurs predominantly inside or on the surface of the leaf. Phenol produced externally would not be expected to cause appreciable scorch in weeds and crops with waxy leaves, but would result in damage if formed within plant tissues.

The phytotoxicity of phenol, a non-translocated substance, would decrease rapidly as the age and size of plants increased, but this factor would be less critical for phenylboronic acid which is systemic. This may explain why the increase in resistance with age was greater in those weeds which sustained acute damage, than in the species affected mainly by chronic symptoms.

References

1 Peligot, E., *C.R. Acad. Sci. Paris*, 1876, **83**, 686
2 Warrington, K., *Ann. Bot., Lond.*, 1923, **37**, 629
3 Robbins, W. W., Crafts, A. S., & Raynor, R. N., 'Weed Control', 1942, p. 283 (New York: McGraw Hill)
4 Lingle, J. C., & Carolus, R. L., *Proc. Amer. Soc. hort. Sci.*, 1958, **71**, 507
5 Gauch, H. G., & Dugger, W. M., *Plant Physiol.*, 1953, **28**, 457
6 Fryer, J. D., *Proc. 3rd Brit. Weed Control Conf.*, *1956*, p. 585
7 Wallace, T., 'Mineral Deficiencies in Plants', 1951, 2nd Edn, p. 74 (London: H.M.S.O.)
8 Bergal, G., & Caujolle, F., *C.R. Acad. Sci. Paris*, 1949, **228**, 1249

Discussion

Dr. M. A. Phillips.—What is the mammalian toxicity of sodium diphenylborinate?

Mr. Barnsley.—The toxicity is 400 mg./kg. (LD_{50}, oral, rats).

Dr. Phillips.—Has the effect of introduction of chlorine atoms into the phenyl nuclei been considered?

Mr. Barnsley.—Yes. This resulted in loss of selectivity.

THE HERBICIDAL PROPERTIES OF 1:1′-ETHYLENE-2:2′-DIPYRIDYLIUM DIBROMIDE

by

J. STUBBS

(*Imperial Chemical Industries, Ltd., Jealott's Hill Research Station*)

An account is given of the herbicidal activity of 1:1′-ethylene-2:2′-dipyridylium dibromide. This new quaternary ammonium compound is active against a wide range of annual plants although it shows some selectivity, grasses in general being more tolerant than broad-leaved species. Good top kill of perennials is obtained but in most cases this is followed by regeneration from the base.

The chemical acts systemically, being rapidly absorbed and translocated so that, although water soluble, it is in effect 'rainfast'. It is instantly adsorbed and inactivated by soil and consequently provides a unique example of a systemic herbicide which has no effect as a soil treatment and no residual activity.

Potential outlets lie mainly in the field of destruction of potato haulms, crop desiccation and non-selective weedkilling, but it may find some application as a selective herbicide.

Introduction

Early in 1955 a series of quaternary ammonium compounds was being evaluated as herbicides at Jealott's Hill Research Station. One of these, 1:1′-ethylene-2:2′-dipyridylium dibromide (**I** in this paper) proved to be outstanding.[1,2] Greenhouse and field tests with the compound are described below.

Experimental

(1) *Greenhouse herbicidal tests*

Pre- and post-emergence applications were made on wheat, sugar beet, red clover, white mustard, *Calendula* sp. and *Galium aparine*. Aqueous solutions of the chemical, both alone and with added wetter (0·3% v/v 'Agral' LN) were applied through a paint spray gun at the rate of 100 gal./ or 20 gal./acre. Foliage sprays with added wetter gave complete kill of all test species down to ½ lb./acre. Even at ⅛ lb./acre, test plants other than *Galium aparine* were seriously damaged. The action was very rapid, localised wilting developing within a few hours and general wilting and collapse of susceptible plants followed in a few days. At sub-lethal dosages, regeneration from the apices took place but developing leaves were at first chlorotic. Similar results were obtained when the chemical was applied alone except that wheat and clover were less affected. The volume of spray had no effect on the herbicidal action. Pre-emergence applications, even at 10 lb./acre, were inactive.

In later tests other crop plants, including peas, lucerne and kale, were unaffected by pre-emergence treatment but killed by foliage sprays at 2 and seriously scorched at ½ lb./acre. Foliage sprays at ¼–½ lb./acre killed seedling *Stellaria media, Senecio vulgaris, Matricaria* sp., *Veronica* sp. and *Salsola pestifer*.

(2) *Uptake and translocation tests*

Movement of the compound **I** was traced by blackening in broad beans and by wilting in oats. With broad beans, entry through cut and intact leaves immersed in an 0·05% aqueous solution was observed. Translocation throughout the shoot followed and death took place within 48 h. Rate of entry was determined by painting single leaves with 0·05% solution, and then washing the treated leaves at intervals of from 1 min. to 4 h. Some damage developed after 1-min. contact and the entire treated area was affected after 5-min. exposure. When the cut ends of oat leaves were immersed in 0·05% solution the whole plants wilted within 24 h. and death followed in 2–3 days. Entry also took place through intact leaves but the effect was then more localised.

Uptake by roots was investigated in water culture. Within a few hours of the addition of 0·05% **I** to the culture solution, blackening of the shoot of broad bean and wilting of the oat leaves developed and death followed in 24–48 h.

Soil drenches of up to 0·2% **I** had no effect on broad bean plants nor were broad bean or oat seedlings affected when transplanted into soil containing 0·1% w/w of the herbicide. Subsequent experiments showed that this was due to adsorption of the chemical by the soil particles. Samples of both heavy clay and light sandy soil were shaken up in 0·1% aqueous solutions of **I** and the filtrate sprayed on seedlings of *Stellaria media*. No damage developed. Colorimetric testing of the filtrate with caustic soda failed to give the characteristic red coloration normally produced by **I**.

(3) *Field evaluation*

Observational field trials on arable crops, weedy fallow, waste ground and brushwood sites were laid down in early summer, 1955. Spray application in these and later trials was done by hand using a pneumatic sprayer fitted with standard ceramic nozzles. The results are summarised below:

(i) Most common annual broad-leaved species were killed by **I** at or below 2 lb./acre. Linseed proved to be somewhat resistant.
(ii) Higher rates were required to give complete kill of annual grasses, including cereals.
(iii) Good top kill of most perennial species, including brushwood, was readily obtained but this was usually followed by basal regeneration.
(iv) Low-volume (20 gal./acre) applications were generally as effective as high-volume (100 gal./acre).
(v) Addition of wetter increased the activity against grasses but gave rather variable results on broad-leaved species.

The following practical applications were then examined in more detail. (Spray volume, unless otherwise stated, was 20 gal./acre.)

Potato haulm destruction.—Fourteen trials on early and maincrop varieties were conducted in 1955–57. Four-row-wide, 1/400-acre plots, separated by guard rows, were arranged in two randomised blocks. Application was at $\frac{1}{4}$–2 lb./acre, alone or with added wetter (0·5% v/v 'Agral' LN). Sulphuric acid (15% v/v B.O.V.) at 100 gal./acre and sodium arsenite at 10 lb./acre in 25 gal. of water/acre were included as standard treatments.

Haulm destruction in all trials with **I** at 1–2 lb./acre was fully comparable with that given by the standard treatments. **I** was slower in action than sulphuric acid but in general gave rather faster kill than sodium arsenite. Added wetter had little effect in the 2-lb. treatments but tended to improve the efficiency of lower rates. Rain falling shortly after application had no effect on the activity of the new chemical. The storage properties of the tubers were not affected by the use of **I** as a haulm destroyer, sprouting and subsequent growth were normal.

Kill of common annual weeds including *Chenopodium album, Polygonum persicaria, Urtica urens, Stellaria media* and *Solanum nigrum* was uniformly good at 1–2 lb./acre. Effective control of the tops of perennial weeds such as *Convolvulus arvensis, Cirsium arvense, Picris hieracioides* and *Mentha* sp. was also obtained.

Crop desiccation.—In a preliminary trial in 1956, as a desiccant of red clover seed crops, **I** at 1 lb./acre gave results comparable with sulphuric acid (15% v/v B.O.V.) at 100 gal./acre. Wetter improved the performance of **I** at $\frac{1}{4}$ lb./acre but not at higher rates.

Three more trials were conducted in 1956–57 with 1/800- or 1/400-acre plots arranged in two randomised blocks. In these trials $\frac{1}{2}$–2 lb./acre **I** gave desiccation approaching that produced by sulphuric acid. Wetter (0·5% v/v 'Agral' LN) in some cases improved its efficiency. Seed germination was unaffected by the desiccants.

Weed control in cereals.—Thirteen trials were conducted in 1956, and 13 in 1957, on spring- and autumn-sown wheat, oats and barley, using 1/400-acre plots arranged in four replicate blocks. Rates of **I** were (all lb./acre):

1956 $\frac{1}{4}$ with wetter; $\frac{1}{4}$, $\frac{1}{2}$, 1 without wetter
1957 $\frac{1}{2}$, 1, $1\frac{1}{2}$ without wetter

In both seasons one series of trials was done on weed-free stands of spring wheat, oats and barley in which applications at the 2–3-leaf stage, early tillering, and just prior to heading, were compared. At the remaining weedy sites the timing of application followed usual practice. Crop damage was assessed visually. Yields were estimated by harvesting 3 sq. yd. from each plot. Weed counts were made at intervals on ten 1-ft.-sq. quadrats in each plot.

In 1956 all rates caused localised foliar scorch, followed in some instances by temporary chlorosis of the developing leaves. Damage was most marked on barley and least on oats.

On weed-free sites spraying at the earliest stage significantly reduced the yield of barley but did not affect wheat or oats. Later applications significantly depressed grain yields of all three cereals. Straw yields generally followed similar trends but to a lesser degree. In all crops the addition of 'Agral' LN to the $\frac{1}{4}$-lb. rate of **I** significantly reduced the yield below that of the plots treated with **I** alone. No significant effects on yield were recorded in two weed trials on winter oats and one on winter wheat. Yields of spring wheat and oats were reduced, however, at two centres where late application was made at 100 and 40 gal./acre respectively. No yields were recorded in the one trial on weedy barley but crop depression was clearly evident.

Results in 1957 showed similar trends but chlorosis was more marked and recovery from the initial setback was much slower. Consequently the effects on crop yield were more marked.

One trial on maize was conducted in 1956. Damage ranged from slight at $\frac{1}{4}$ to very severe at 2 lb./acre. No yields were taken.

Effective control of most broad-leaved annual weeds in these trials was obtained with **I** at 1–1$\frac{1}{2}$ lb./acre. Susceptible species included *Galium aparine, Stellaria media, Senecio vulgaris, Matricaria* sp., *Veronica* sp., *Polygonum aviculare, P. convolvulus, P. persicaria, Sinapis arvensis, Brassica alba, Raphanus raphanistrum, Lamium hybridum, Chenopodium polyspermum, C. album, Atriplex* sp., *Lapsana communis, Anagallis arvensis* and *Urtica urens.* Resistance to **I** at 1 lb./acre was shown by *Papaver rhoeas, Chrysanthemum segetum, Lithospermum arvense, Scandix pecten-veneris* and *Aphanes arvensis.* As elsewhere, good top kill of perennial weeds was obtained but they subsequently regenerated.

Weed control in linseed.—**I** at $\frac{1}{4}$–2 lb./acre caused scorch and growth inhibition of linseed in 1956, damage being very marked at 2 lb. Measurements made 16 days after treatment showed considerable height reductions on the plots sprayed with **I** at $\frac{1}{2}$–2 lb./acre. A heavy weed infestation subsequently reduced the growth on the control plots. This competition was effectively eliminated by **I** at 1–2 lb./acre and on those plots the linseed became taller and sturdier than on the controls and those treated with the lower rates of **I**.

Non-selective weed control.—Many trials were conducted during 1955–58 on weedy fallow and waste ground. Excellent control of mature broad-leaved annual species was obtained by 2 lb. or less/acre. Other susceptible species included *Viola tricolor, Sonchus oleraceus* and *Scrophularia nodosa.* Good top kill of many perennial broad-leaved species was also obtained. *Plantago major, P. lanceolata, Heracleum sphondylium, Aegopodium podagraria, Achillea millefolium, Glechoma hederacea, Stachys sylvatica, Lamium album* and *Urtica dioica* were all susceptible. Regrowth from the base subsequently took place with these species but *Ranunculus repens* was killed by 5 lb./acre.

Grasses were generally more resistant than broad-leaved species. Much better control, however, was obtained by adding wetter to the spray. *Poa annua* was controlled by **I** plus wetter at 2–3 lb. but with *Alopecurus myosuroides* some regrowth took place even at 10 lb./acre. Established perennial grasses were never effectively controlled. Good top kill of *Agropyron repens, Dactylis glomerata, Arrhenatherum elatius, Poa nemoralis, Festuca* spp., *Agrostis* spp. and *Holcus lanatus* was given at 2–5 lb./acre but the plants subsequently recovered. Kill of seedling *Lolium multiflorum* and *Festuca pratensis* and severe damage to young *Dactylis glomerata* and *Phleum pratense* was obtained at 5 lb./acre.

Brushwood control.—Activity against *Rubus* spp., *Rosa* spp., *Crataegus monogyna, Sambucus nigra, Ulmus* spp., *Corylus avellana* and *Ulex europaeus* was investigated in small-scale trials during 1955–57. Summer spray treatments at 2–5 lb./acre caused rapid desiccation of foliage and some kill of younger shoots of all the test species. Regeneration from the base or from lower laterals followed later in almost all cases.

Discussion

The herbicidal properties of 1:1′-ethylene-2:2′-dipyridylium dibromide (**I**) are unique in several respects. It resembles contact weedkillers in speed of action yet it has been shown to be systemic. Unlike most contact herbicides it is immediately adsorbed by soil and completely inactivated. It shows no residual activity whatsoever. Although it is readily water-soluble it is rainfast in practice because of its rapid absorption into plant tissues. Herbicidal activity is largely independent of volume of application.

Sprayed on foliage the new chemical effectively controls many broad-leaved annual species at 2 lb./acre or less. Annual grasses are more resistant but some at least can be killed at increased dosages. Top growth of many perennials, including brushwood, is also readily killed or seriously damaged by similar treatments, although subsequent basal regeneration largely offsets the initial effect.

The inactivity of **I** on underground organs, whilst a limiting factor in weed control, is of value in relation to potato haulm destruction. Thus low-volume foliage sprays kill the aerial portions of the plant but have no effect on the tubers.

Pre-harvest desiccation of seed crops is another potential outlet, for which the quick action of the chemical and its rainfast properties make it particularly suitable. Preliminary results with red clover seed crops are very promising.

As a non-selective weedkiller the main limitation of the new herbicide is its failure to kill perennial species. On the other hand its speed of action together with total absence of persistence are desirable properties in certain applications.

Its use as a selective post-emergence herbicide in cereals is limited by the risk of crop damage. Similar considerations apply in the case of linseed.

More research is needed before the full potentialities of this new herbicide can be defined. Results available, however, clearly indicate its value for potato haulm destruction, crop desiccation and general weedkilling.

Acknowledgments

The author expresses thanks to his colleagues who have been associated with this work, in particular to Messrs. R. J. Fielden, R. F. Homer and R. L. Jones who were responsible for the chemical synthesis, and to Messrs. R. C. Brian, L. G. Spencer and H. C. McIlvenny for their assistance with the biological evaluation.

References

[1] Fielden, R. J., Homer, R. F., & Jones, R. L., B.P. 785,732

[2] Brian, R. C., Homer, R. F., Stubbs, J., & Jones, R. L., *Nature, Lond.*, 1958, **181**, 446

POTATO HAULM DESTRUCTION AND PRE-HARVEST WEED CONTROL WITH CHEMICALS

by

A. J. BUTLER

(*Plant Protection Ltd., Fernhurst Research Station*)

During 1957 1:1′-ethylene-2:2′-dipyridylium dibromide was compared with sodium arsenite and pentachlorophenol (PCP) in vaporising oil, in two trials on early, and eight on maincrop, potatoes.

In the maincrop trials 2 lb./acre proved equal to sodium arsenite (10 lb./acre As_2O_3) and very similar to PCP at 3 lb./acre. The results suggested that where haulm is not vigorous lower rates may be satisfactory. On early potatoes, at rates of $\frac{1}{2}$–2 lb./acre, haulm destruction was less satisfactory. On seed potatoes $1\frac{1}{2}$ lb./acre gave a satisfactory haulm destruction. Increasing the volume of water from 20 to 40 gal./acre did not affect haulm destruction.

This chemical gave excellent pre-harvest control of the main weeds of maincrop potatoes at $1\frac{1}{2}$ lb./acre. Control of established *Stellaria media* (chickweed) was considerably better at 40 than at 20 gal./acre. In early potatoes $\frac{1}{2}$ lb./acre gave satisfactory weed control.

The addition of a wetter improved the action of the chemical in the trials on earlies, but not in the maincrop or seed potato trials except on *Agropyron repens* (couch grass).

Evidence was obtained that the absorption of 1:1′-ethylene-2:2′-dipyridylium dibromide is considerably quicker than that of sodium arsenite.

Introduction

The primary reasons for the removal of potato haulm and weed growth are to facilitate harvesting, especially where mechanical harvesters are used, to reduce the chances of blight spreading from foliage to tubers and to reduce the spread of virus diseases in seed potatoes. Again, in seed potatoes haulm destruction is carried out to limit the size of the tubers. In maincrop potatoes pre-harvest spraying is also carried out to kill weeds which cause trouble at harvest. For early potatoes a speedy haulm destruction is needed to allow the grower to take advantage of favourable market prices.

In this country sodium arsenite is widely used for haulm destruction. Although it is cheap and effective against both haulm and most broad-leaved weeds, it has the disadvantage of being a toxic chemical. Furthermore, it is very slowly absorbed and its action is severely limited if rain falls shortly after spraying.

Sulphuric acid is, however, still the most widely used chemical, but the difficulties in handling it have led to its application mainly by contractors, which makes it a relatively expensive treatment. It takes less than a week to achieve complete kill, is relatively unaffected by weather conditions and gives good weed control, except perhaps on established *Stellaria media* (chickweed), which is the most important weed of maincrop potatoes.

Although PCP, DNOC and various tar oil derivatives have been tried, sodium chlorate is the only other chemical used to any extent commercially, mainly in Scotland. There is no completely satisfactory chemical available for haulm destruction, and the replacement of sodium arsenite by a non-toxic chemical of equal or superior performance would be an important step forward. Against this background the discovery that 1:1′-ethylene-2:2′-dipyridylium dibromide* might be suitable for this purpose was obviously of great importance and trials were planned in 1957 and 1958 to test this chemical under field conditions.

Experimental methods and results

Assessments were made throughout by visual gradings.

(1) *Early potatoes*

Two trials were laid down on Arran Pilot potatoes in Devonshire in June 1957. A four-replicate randomised block lay-out was used with plot size 6 yd. × 2 yd. (1/400 acre). The chemicals were applied at 20 gal./acre with the Oxford Precision Sprayer using Allman's No. 00 jets and a pressure of 30 lb. p.s.i. The following rates were compared:

I at ½ lb./acre with 'Agral' LN at 0·5% v/v concentration
I at 1 and 2 lb./acre
Sodium arsenite at 10 lb./acre (As_2O_3)
PCP at 1½, 3 and 6 lb./acre diluted with vaporising oil.

The results for haulm destruction and weed control are shown in Tables I and II respectively.

Table I

Haulm destruction in early potato trials, %

Weather conditions at spraying	Hours after spraying	I, lb./acre ½+0·5% 'Agral' LN	1	2	PCP, lb./acre 1½	3	6	Sodium arsenite 10 lb./acre as As_2O_3	Sig. diff., 5%
Hot and dry	30	21	21	41	54	74	90	13	12
	50	32	37	62	60	82	90	17	18
	70	40	47	80	67	80	95	17	13
	120	44	73	90	69	82	95	36	24
Warm and damp	30	67	69	85	49	59	79	36	8
	50	78	86	95	62	76	86	70	9
	70	83	87	93	58	75	87	78	12
	120	85	90	95	62	77	86	85	11

I, even at ½ lb./acre with wetter, was as effective as sodium arsenite and at 2 lb./acre was as good as PCP at 6 lb./acre for haulm destruction, although not giving such a quick kill in the first trial. It was very noticeable that both **I** and sodium arsenite were much more effective when sprayed under warm damp conditions, but the action of PCP seemed to be relatively unaffected.

In both trials, **I** and sodium arsenite gave a satisfactory dry stem kill, while PCP tended to leave the stem rather soggy. Slight basal regrowth was noticed after about 6 days on plots sprayed with **I** and PCP.

* 1:1′-Ethylene-2:2′-dipyridylium dibromide is hereafter referred to as **I** for convenience.

Table II

Weed control in early potato trials, %

Site	Weed	I, lb./acre $\frac{1}{2}$+0·5% 'Agral' LN	I, lb./acre 1	I, lb./acre 2	PCP, lb./acre $1\frac{1}{2}$	PCP, lb./acre 3	PCP, lb./acre 6	Sodium arsenite 10 lb./acre as As_2O_3	Sig. diff. 5%
1	*Polygonum aviculare*	50	15	35	57	67	72	10	17
2	,, ,,	80	40	47	32	45	57	17	20
1	*Stellaria media*	90	85	92	62	62	90	32	18
2	,, ,,	95	92	97	42	57	72	32	24
1	*Rumex* spp.	72	74	82	49	59	74	16	38
2	*Chenopodium album*	87	62	57	45	65	65	22	21

The weed control assessments were taken about 36 hours after spraying. **I** at $\frac{1}{2}$ lb./acre with wetter gave very satisfactory weed control except on *Polygonum aviculare* (knotgrass) on one site. Sodium arsenite is known to be slow in its effect so a later grading would possibly have shown better control from this chemical.

(2) *Maincrop potatoes*

Eight trials on Majestic potatoes (four for haulm destruction and four for weed control) were laid down in the Spalding area of Lincolnshire in 1957. A four-replicate randomised block lay-out was used with plot size 20 yd. × $3\frac{1}{2}$ yd. (1/70 acre). The chemicals were applied with a Ransomes' 'Cropguard' adapted to carry Robbicans. Low-volume (20 gal.) applications were made with Ransomes' No. 00 jets and a pressure of 35 lb. p.s.i. Medium-volume applications required No. 9 jets and a pressure of 30 lb. p.s.i.

The following rates were compared in 20 gal. of water/acre:

I at $\frac{1}{2}$, 1, $1\frac{1}{2}$ and 2 lb./acre
I at $\frac{1}{2}$, 1, $1\frac{1}{2}$ and 2 lb./acre+'Agral' LN at 0·5% v/v concentration
Sodium arsenite at 10 lb./acre (as As_2O_3)

In two haulm destruction trials PCP was applied at $1\frac{1}{2}$, 3 and 6 lb./acre diluted with vaporising oil to 20 gal. In one of these trials **I** at 2 lb./acre with wetter was omitted. In no trial was the haulm particularly vigorous.

The standard treatments above were also used on two weed-control sites. On the other two sites, where a dense mat of established *Stellaria media* (chickweed) was sprayed, the rate of sodium arsenite was increased to 15 lb./acre as As_2O_3 (as in commercial practice) and the rates of **I** were increased to $1\frac{1}{2}$, 2 and 3 lb./acre. All these treatments were compared in 20 and 40 gal. of water/acre.

Results

Haulm destruction (Table III).—All treatments gave over 80% leaf kill after 1 week. For stem kill **I** at 2 lb./acre was equal to sodium arsenite and very similar to PCP diluted with vaporising oil, for speed of kill and efficiency of stem breakdown. All three chemicals gave a dry kill, unlike the results of the early potato trials. **I** at 1 and $1\frac{1}{2}$ lb./acre was inferior to sodium arsenite, but not markedly so in these trials, where the haulm was not very vigorous. In one trial where the stem was about one-third dead at spraying, **I** at $\frac{1}{2}$ lb./acre gave a satisfactory kill. No consistent advantage was seen from the addition of wetter to **I**.

Weed control.—Full weed-control tables cannot be included in this report. **I** at 2 lb./acre was markedly similar in effect to sodium arsenite at 10 lb./acre for control of broad-leaved weeds and gave considerably better control of *Agropyron repens* (couch grass). No weed control data for PCP were obtained. **I** at $1\frac{1}{2}$ lb./acre gave a commercially acceptable level of control of the following weeds: *Polygonum convolvulus* (black bindweed), *Chenopodium album* (fat hen), *Polygonum persicaria* (redshank), *Urtica urens* (annual nettle), *Sonchus oleraceus* (annual sowthistle) and *Stellaria media* (chickweed); 2 lb./acre was needed to give an acceptable control of *Galium aparine* (cleavers).

Again no advantage was seen from the addition of wetter to **I** except for control of *Agropyron repens* where 15–20% improvements were observed.

Where *Stellaria media* was in the early stages of development **I** at $1\frac{1}{2}$ lb./acre in 20 gal./acre gave an excellent kill. Two trials were laid down, however, where this weed had become densely established and **I** at $1\frac{1}{2}$ lb./acre gave a level of control that would just be commercially

Table III

Haulm destruction in maincrop potatoes

Leaf and stem kill, %

Site No.		3			4		5	6			
Sprayed on		27th August			27th August		3rd Sept.	5th September			
Type of kill		Leaf	Stem		Leaf	Stem	Stem	Leaf		Stem	
Days after spraying		6	13	16	6	13	8	7	13	15	22
I, lb./acre											
0·5	(1)	80·0	86·3	96·3	82·5	95·0	96·3	93·8	53·8	66·3	86·3
0·5+'Agral'	(2)	77·5	83·8	95·0	91·3	96·3	90·0	91·3	57·5	70·0	92·5
1·0	(3)	95·0	93·8	97·5	95·0	95·0	95·0	98·8	65·0	76·3	90·0
1·0+'Agral'	(4)	86·3	91·3	97·5	98·8	98·8	98·8	97·5	68·8	75·0	90·0
1·5*	(5)	96·3	91·3	100·0	100·0	100·0	97·5	97·5	66·3	72·5	90·0
1·5+'Agral'	(6)	98·8	93·8	98·8	98·8	87·5	97·5	98·8	71·3	83·8	97·5
2·0	(7)	96·3	98·8	100·0	98·8	96·3	100·0	100·0	73·8	78·8	96·3
2·0+'Agral'	(8)	—	—	—	97·5	98·8	95·0	100·0	78·8	85·0	98·8
PCP, lb./acre											
3	(9)	95·0	95·0	98·8	91·3	97·5	—	—	—	—	—
4½	(10)	85·0	83·8	100·0	98·8	90·0	—	—	—	—	—
6	(11)	93·8	100·0	100·0	93·8	96·3	—	—	—	—	—
Sodium arsenite, 10 lb. as As_2O_3/acre	(12)	96·3	96·3	100·0	98·8	93·8	100·0	100·0	78·8	81·3	96·3
Significant difference, at 5%		9·7	9·7	N.S.	7·6	N.S.	N.S.	N.S.	13·6	9·4	2·5
Significant differences between treatments		1, 2, 4, 10 <12	1, 2, 10 <12	—	1 < 12	—	—	—	1, 2, 3 <12	1, 2 <12	1, 2, 3, 4, 5 <12

* Leaves all killed by blight and stem about ⅓ dead at time of spraying N.S.=not significant

acceptable only when applied at medium volume (40 gal./acre) (Table IV). The improved performance of both **I** and sodium arsenite at medium volume in these two trials was considerable.

In one of these trials heavy rain fell 4 hours after spraying and the results from sodium arsenite were extremely poor, whereas the effect of **I** was unimpaired.

(3) *Seed crop potatoes*

Four trials were laid down in Scotland, one on Arran Pilot, one on Redskin and two on Majestic variety. A four-replicate randomised block lay-out was used with plot size 12 yd. × 2 yd. The chemicals were applied with an Oxford Precision Sprayer at 20 and 40 gal./acre at a pressure of 35 lb. p.s.i.

Table IV

Chickweed control

Percentage kill and later regrowth gradings

		Site No. 9						Site No. 10				
Days after spraying		5	8	12	15	22	31	5	8	11	18	25
I, lb./acre												
1½	LV	36·3	45·0	47·5	62·5	50·0 V	55·0 V	43·8	57·8	63·8	68·8 V	70·0 M/V
1½	MV	56·3	70·0	83·8	88·8	92·5 S	77·5 M	48·8	67·5	77·5	91·2 S	93·3 S
2	LV	47·5	55·0	68·8	76·3	72·5 M	68·8 V	36·3	53·8	70·0	8·12 M	85·0 M
2	MV	55·0	73·8	83·8	91·3	92·5 S	83·8 M	55·0	80·0	88·8	95·0 S	100·0 S
3	LV	43·8	55·0	67·5	78·8	42·5 M	66·5 V	56·3	75·0	81·3	86·7 S	93·3 S/M
3	MV	56·3	76·3	95·0	96·3	95·0 S	88·8 S	63·8	86·3	95·0	100·0*	100·0*
Sodium arsenite, lb. As_2O_3/acre												
15	LV	45·0	62·5	78·8	82·5	87·5 M	75·0 M	8·8	15·0	23·8	53·8 V	40·0 V
15	MV	56·3	76·3	92·5	98·8	100·0*	88·8 S	12·5	36·3	53·8	72·5 V	75·0 M/V
Treatments significantly better then sodium arsenite MV					None		None			All **I**		**I** at 3 lb./acre LV; 1½–2, 3 lb./acre MV
Treatments not significantly different from sodium arsenite MV					**I** at 2, 3 lb./acre MV		**I** at 1½, 2, 3 lb./acre MV			None		**I** at 1½, 2 lb./acre LV
MV compared with LV					MV significantly better		MV significantly better			MV significantly better		MV significantly better
I treatments at MV 3 vs. 1½ lb./acre					N.S.		N.S.			3 significantly better		N.S.
2 vs. 1½ lb./acre					N.S.		N.S.			N.S.		N.S.

Notes.—(1) Heavy rain fell 5 h. after spraying at site 10: hence poor results with arsenite.
(2) LV=20 gal./acre; MV=40 gal./acre.
(3) Capital letters indicate regrowth gradings: V=vigorous; M=moderate; S=slight. * no regrowth

The following treatments were used on the Arran Pilot trial:

I at 1, $1\frac{1}{2}$ and 2 lb./acre with and without 0·5% v/v 'Agral' LN
Sodium arsenite at 10 lb./acre (as As_2O_3)

On the other three trials the rates of application were:

I at $1\frac{1}{2}$, 2 and $2\frac{1}{2}$ lb./acre with and without 0·5% v/v 'Agral' LN
Sodium arsenite at 10 lb./acre (as As_2O_3)

Results

Haulm destruction (Table V).—All treatments with chemical **I** gave over 60% leaf kill within 2 days of spraying and were superior to sodium arsenite in speed of action. After 14 days the stem kill obtained with **I** was superior to that obtained with sodium arsenite. The addition of wetter did not materially increase the efficiency of **I**, nor did application at 40 gal./acre have any advantage over 20 gal./acre.

Table V

Haulm destruction in seed potatoes

Percentage leaf kill (2 days after spraying) and stem kill (14 days after spraying)

	Arran Pilot		Redskin		Majestic		Majestic	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Chemical **I**, *lb./acre, applied in 20 gal./acre*								
1	66	99	—	—	—	—	—	—
1 +'Agral'	69	99	—	—	—	—	—	—
$1\frac{1}{2}$	70	99	70·0	97·25	61·0	94·5	77·0	98·0
$1\frac{1}{2}$+'Agral'	67	99	75·0	97·5	66·0	96·75	80·0	98·0
2	76	99	71·0	97·0	65·0	95·75	77·0	98·0
2 +'Agral'	65	99	75·0	97·25	70·0	96·25	75·0	98·0
$2\frac{1}{2}$	—	—	75·0	97·25	67·5	96·25	83·0	98·0
$2\frac{1}{2}$+'Agral'	—	—	75·0	98·25	72·5	97·0	81·0	98·0
Sodium arsenite, lb./acre as As_2O_3, applied in 20 gal./acre								
10	45	99	62·5	94·75	17·5	97·45	16·0	90·0
Chemical **I**, *lb./acre, applied in 40 gal./acre*								
1	71	99	—	—	—	—	—	—
1 +'Agral'	67	99	—	—	—	—	—	—
$1\frac{1}{2}$	69	99	75·0	96·5	66·0	95·0	79·0	98·0
$1\frac{1}{2}$+'Agral'	76	99	74·0	97·5	72·5	96·5	84·0	98·0
2	74	99	76·0	97·25	71·0	96·5	83·0	98·0
2 +'Agral'	75	99	77·5	97·25	72·5	96·5	89·0	98·0
$2\frac{1}{2}$	—	—	80·0	97·25	72·5	96·75	84·0	98·0
$2\frac{1}{2}$+'Agral'	—	—	81·0	97·25	74·0	96·75	89·0	98·0
Sodium arsenite, lb./acre as As_2O_3, applied in 40 gal./acre								
10	48	95	61·0	96·5	17·5	95·0	14·0	91·0
Significant difference at 5%	8	N.S.	5·25	1·1	6·1	1·0	4·6	3·1

Discussion

Chemical **I** at 2 lb./acre has been proved to be as effective as, or superior to, sodium arsenite for potato haulm destruction both in main and seed crop potatoes for speed of kill and efficiency. On early potatoes it is effective, but it is probably too slow in action.

For pre-harvest weed control **I** at 2 lb./acre was markedly similar in effect to sodium arsenite at 10 lb./acre As_2O_3 on broad-leaved weeds. With the addition of wetter, **I** at 2 lb./acre gave a very good kill of the aerial growth of couch grass in the main crop trials. The addition of wetter did not increase the efficiency of **I** for haulm destruction nor did application in 40 gal. of water/acre compared with application in 20 gal. of water/acre. On chickweed, however, application in 40 gal. of water/acre did improve the control.

Chemical **I** is rapidly taken up by the plant and this is reflected in the very speedy leaf kill. This is an important advantage, for rain falling soon after application does not reduce the efficiency of **I**. This was demonstrated in one main crop trial where rain fell 5 hours after spraying without affecting the action obtained by **I**.

I is therefore as efficient as sodium arsenite for potato haulm destruction and has the added advantage of being quickly absorbed, easy to handle and non-toxic.

Discussion on the two preceding papers

Mr. R. G. Hughes (N.A.A.S.).—The emphasis in Mr. Butler's paper is on the speed of action, which is a good thing in potato haulm destruction. In view of what Mr. Stubbs said about regrowth following spraying, in particular in perennial weeds, I would like to enquire whether a delay in harvesting following application of spray would allow for regrowth of a difficult weed such as fat hen.

Mr. Stubbs.—No regrowth has been observed.

Dr. M. A. Phillips.—In view of the special properties of ethylenedipyridylium dibromide, can the authors give any indication of its stability towards rain.

Mr. J. F. Ormrod.—I can add a little to the question of rainfast qualities. On spraying a clover desiccation trial, heavy rain fell as the last treatment was being applied, and continued for half an hour. DNC oil emulsion had been included in the trial as a control, and this was rendered completely ineffective, but the new chemical was effective at all rates of application, giving complete desiccation of the white clover.

Dr. M. A. Phillips.—Since this compound has a somewhat complicated structure, could the authors indicate whether this compound was competitive in cost.

Mr. Stubbs.—My firm will be considering this point in the near future.

Mr. E. B. Scragg (North of Scotland College of Agriculture).—We had a small trial in Aberdeen with ethylenedipyridylium dibromide on potatoes, the treated and untreated tubers being sent to the M.A.F.F. experimental factory at Aberdeen for organoleptic tests. Four out of five experts could detect the treated tubers. It is rather beside the point that three members said that they preferred the treated potatoes. One member recorded a slight burning after-taste. This single test may not have much significance, but serves to warn us of one aspect of haulm killing which must not be ignored.

Dr. van der Zweep (I.B.S.).—We have investigated this compound in our herbage seed work in comparison with DNC and mixed DNC–sodium arsenite sprays commonly employed for controlling weeds in grass seed crops in autumn. Heavy damage to the grass was followed by regrowth. The influence will be assessed next year. All plants, except *Galium aparine*, were well controlled by $\frac{1}{2}$–1 lb. of ethylenedipyridylium dibromide/acre. In several Dutch soil types, mixing with the soil in concentrations of up to 50 p.p.m. resulted in no or slight influence on the growth of the test crop (oats).

At the Research Station for ornamental plants at Boskoop, branches of many dicotyledonous and coniferous shrubs and trees were sprayed with 4% ethylenedipyridylium dibromide and 1·6% chloro-IPC. *Cotoneaster salicifolia, Myrica pennsylvanica* and several conifers showed a considerable resistance to this spray. Did the authors observe any resistance in plants?

Mr. Stubbs.—It is difficult to say whether there is a physiological resistance. Penetration and translocation are involved.

NEW HERBICIDE FOR AQUATIC WEED CONTROL

by

J. VAN OVERBEEK

(*Shell Development Co., U.S.A.*)

F.98 aquatic herbicide (essential ingredient acrolein) satisfactorily and economically controlled submerged weeds in irrigation canals, even up to 15–20 miles from the point of application. Retreatment was necessary only after about 8 weeks. In less than one week the full water-carrying capacity of the canals had been restored. The treated water is not harmful to crops. Water snails are also effectively controlled by the chemical.

Introduction

Open canals in irrigation systems have two major drawbacks: (1) there are aquatic weeds which, when left uncontrolled, soon render the irrigation system inoperative; (2) especially in tropical countries, there are water snails which carry animal and human diseases.

According to Crafts[1] submerged weeds cause more trouble from the standpoint of reduced waterflow in irrigation ditches than the ditch bank weeds. Millions of dollars are spent annually for the control of aquatic weeds in the western United States. Mechanical means for control of these submersed weeds have been tried out, but with rising labour costs, these methods are becoming less and less attractive. Among chemical methods, copper sulphate was found effective on algae but is not found generally effective on the higher forms of aquatic vegetation. Aromatic solvents such as crude xylenes have given effective control of submerged aquatic weeds but these solvents can be used economically only in the smaller canals. Large amounts of solvent and emulsifier are required and even when as much as 10 gal. of solvent are applied per cubic foot second (cfs.) in the canal, such an application is effective only for distances up to 5 miles without 'booster' applications.[2]

Experimental results and discussion

A method has been developed involving the use of a technical product, F.98 aquatic herbicide, the active ingredient of which is acrolein, which will control submerged aquatic weeds economically even in large canals of 300 cfs. and over. Submerged weeds have been controlled as far as 15–20 miles below the point of application of only 1–1·5 gal. of F.98 per cfs. of water flow introduced over a period of 30–45 min. The following examples will illustrate the beneficial effect of acrolein on the water-carrying capacity of irrigation systems.

The average maximum capacity of a canal near Bakersfield, California, was 311 cfs. during the two weeks preceding treatment. On 4th July, 1957, 150 gal. of F.98 aquatic herbicide were introduced into the canal. It was then found that during the period between 7th July and 10th July the maximum capacity was 552 cfs., so that the maximum capacity of the canal had increased by 78%. A little later in the same year the same canal was treated, but the effectiveness of F.98 aquatic herbicide treatment was compared with that of a standard mechanical cleaning by chaining. The week before chaining, the maximum capacity of the canal was 282 cfs. Between 22nd August and 24th August the canal was chained and during the week after chaining the maximum capacity of the canal had increased to 344 cfs., a gain of 22%. On 1st September, 100 gal. of F.98 were introduced into the canal and in the two weeks following this treatment the average maximum capacity was 479 cfs., a gain of an additional 48% over the 22% gain obtained by chaining. Clearly F.98 aquatic herbicide treatment is far more effective than chaining in restoring the canal to full capacity.

In the spring of 1958 the same main canal was treated again. Chaining this time proved to be entirely without effect, but again F.98 aquatic herbicide treatment was highly effective, as the following figures will show. Ten days before treatment the average maximum capacity was 253 cfs. Then, on 3rd May, a total of 280 gal. of F.98 was introduced in two locations in the 20-mile-long canal. The daily measurement made between 6th May and 10th May showed that the maximum capacity was 462 cfs., an increase in capacity of 83%.

The major weed in this canal was *Potamogeton crispus*, but the chemical controlled all other submerged vegetation as well. After treatment the dead vegetation disintegrated and hence did not clog gates, weirs and pumps as happens after chaining. When deposited on the land, such masses of organic matter could be beneficial. Treated water used for irrigation did not harm crops.

F.98 aquatic herbicide is a potent irritant and lachrymator but in the hands of a skilled operator with proper application equipment, can be applied safely and without irritation or discomfort. F.98 aquatic herbicide readily forms a true solution in water, and travels down the canal acting as a chemical drag chain. The location of the F.98 wave in the canal can be detected easily with a drop of potassium permanganate in a test tube or with 2,4-dinitrophenylhydrazine reagent.

Control of snails

F.98 aquatic herbicide has been found highly effective against aquatic snails in the waters treated. Against the pond snail, *Lymnaea bulimoides*, and also against a local planorbid snail, it was found at least as effective as sodium pentachlorophenate. The latter is commonly used in the tropics for the control of bilharzia-carrying snails.[3]

Mode of action

F.98 aquatic herbicide is a potent sulphydryl reagent and has been observed to destroy isolated enzyme systems. For instance, against urease it is nearly four times as toxic on a molar basis as ethylmaleimide, a common -SH reagent. Turgor in cells of the leaves of water plants (*Elodea densa*) was maintained for a few hours after a dip in 1000 p.p.m. of F.98, even though microscopical examination showed the cell interior to be destroyed. This observation leads to the conclusion that F.98 aquatic herbicide destroys the biochemical system of a cell, unlike aromatic solvents which act primarily on the plasma membrane.

Acknowledgment

The author is much indebted to Mr. Allen Watts, Manager of the Canal Department of the Kern County Land Company, for his co-operation. The maximum canal capacities mentioned in the text were computed by his department.

References

[1] Crafts, A. S., *Calif. Agric. Ext. Serv.*, Circ. 158, October 1949

[2] Bruns, V. F., Hodgson, J. M., Arle, H. F., & Timmons, F. L., U.S. Dept. Agric., Circ. 971, October 1955

[3] Tredre, R. F., *Chem. & Ind.*, 1957, pp. 700, 1138

AERIAL SPRAYING TECHNIQUES DEVELOPED IN NEW ZEALAND FOR HELICOPTERS

by

E. C. S. LITTLE

(*Department of Agriculture, University of Oxford*)

With spray rates of 3·6 lb. of 2,4,5-T ester in 40–60 gal. of water/acre, using coarse droplets from ¼-in. jets, spraying by helicopter killed gorse successfully in four overlapping swaths.

Slow, low-flying helicopters using aqueous sprays can compete with fixed-wing aeroplanes using oil as a diluent on 2,4-D-susceptible weeds on hills, and also with ground equipment on wet or rough country.

Sodium chlorate applied by helicopter shows promise in releasing seedling pines from weed competition, and sodium arsenite sprayed through special 'solid' jets from helicopters can be used to cut tracks through scrub.

Introduction

New Zealand has large areas of hill country suitable for pastoral farming, but which are either occupied by scrub weeds preventing grass sowing, or have established pastures invaded by weeds such as thistles or ragwort. After the aerial application of fertilisers had been successfully developed, attempts were made to use the same aeroplanes for weed spraying but with limited success. Fixed-wing planes have to fly at a minimum of 70 m.p.h. and on hilly country this forces high flying for safety. With increasing height above the target there is less accuracy, more loss of spraying by evaporation and greater risk of drift. This and other disadvantages of fixed-wing planes created a need for a slow-flying vertical-take-off machine. In 1955 a helicopter was introduced and it became necessary to work out the best way to use this novel means of spray application, particularly for scrub weed control. The problem presented difficulties because experimental work hitherto indicated that high volumes of spray at high pressures were essential. Such rates would be uneconomic from aircraft, and there was no experience from elsewhere to draw on. In 1956 a useful assessment of the spray distributions at medium volume rates from aircraft was made by the New Zealand Department of Agriculture.[1]

In 1956 the problems of weed control in forests seemed suitable targets for aerial application and some work was done to find suitable methods of treatment. The so-called 'total' weedkillers were tried in comparison with 'hormone' weedkillers.

Experimental

Scrub weeds on hills

Gorse, *Ulex europeaus*, introduced to New Zealand as stock food, has flourished and now occupies large areas of hill country (well over 100,000 acres). It is susceptible to 2,4,5-T ester, the usual treatment with ground equipment being 3–4 lb. acid equiv./acre in 400–600 gal. of water at high pressures (200–600 p.s.i.). The cost of this application on steep country is prohibitive, even by ground equipment, and to bring the rate of application down to economic limits for aircraft demands reducing the volume of spray to about a tenth (i.e., 40–60 gal.).

The Bell and Hiller (Fig. 1) helicopters used in New Zealand were fitted with booms 25 ft. long carrying 40 jets. With spraying from a height of about 10 ft. at 25 m.p.h. the swath width is about 60 ft. with reasonably even distribution (highest in the centre). The droplet pattern was studied by impregnating long sheets of newsprint with dry dye crystals (magenta) using a special, simply constructed box containing felt rollers which rubs the dye in under pressure. When a water drop falls on to paper prepared in this way it dissolves the minute crystals on to which it falls, colouring the paper, and showing the droplet shape and relative size clearly.

Magenta fades rapidly in sunlight, which is a useful property in view of the inevitable unwanted contamination which follows its use.

FIG. 1.—*Hiller helicopter spraying gorse in New Zealand with 2,4,5-T butyl ester at 3·6 lb. acid equiv. in 60 gal. of water/acre. Application made in four passes over the target, each at 15 gal./acre*

Droplet patterns delivered by helicopters show that the drops at the margins of the swath are propelled sideways while those in the centre travel directly downwards. This feature can be made use of to aid the penetration of scrub targets (which may be growing densely up to 12 ft. high).

It was decided that costs permitted four flights over the target. The following pattern gave good coverage (which is essential, especially for gorse, if satisfactory control is to be achieved). The first pass is made 30 ft. inside the margin of the target; the second pass flies over the same track but in the reverse direction; the third pass is 30 ft. further into the target, and the fourth flies over the same track as the third but in the reverse direction; and so on. Each part of the target is thus subjected to both downwards and horizontal spray each coming from two directions. This eliminates shadowing effects which can occur if the flights are all made in the same direction. A spray twice round the perimeter completes the job.

Unevenness of topography and the amount of wind may force the pilot to modify this ideal pattern, but it has been shown to give remarkably good results when properly carried out.

Losses by evaporation are high especially in low humidity, even when flying low. It would in theory be desirable for the pilot to adjust his spray rates to suit the humidity conditions but this is generally impracticable. It was thus necessary to provide against the highest evaporation conditions by delivering large drops. It was found that 40 hollow cone jets with $\frac{1}{4}$-in. orifices at 20–30 lb. pressure were satisfactory and gave a delivery rate of 12–15 gal./acre per pass at 25 m.p.h. As the carrying capacity of a Bell or Hiller is 50–60 gal., one load will spray one acre. With efficient refilling arrangements 12–15 acres/hour were practicable depending on the distance to the target.

Complete kills of *Cytisus* under a variety of climatic conditions are possible by this technique, but *Ulex* is more capricious and considerable work is in progress and remains to be done to find out why in some cases good kills are obtained and in others many plants survive the treatment. A target may take on, after a few weeks, the typical orange-brown appearance of 2,4,5-T treatment with every indication of complete coverage, yet in some areas most of the plants may subsequently recover, while other targets treated similarly show a satisfactory kill. Whether the age of the plants, climatic conditions (humidity, temperature, light, etc.), soil types, the stage of growth or some other factors appreciably affect success are not known. Plants which have been heavily grazed by sheep are known to be harder to kill. Young plants or plants regrowing vigorously after cutting were believed to be the most susceptible, but these observations from ground spraying trials did not appear to be confirmed under helicopter spraying.

Trials by helicopter were laid down using different concentrations of 2,4,5-T and different amounts of water and wetting agent and applied at different times of the year. No final conclusions are yet possible without further work, but it seems at this stage that applications in December and January, i.e., early to mid-summer, under good growing conditions give the best results. The problem is complicated by the long time (about a year) which must elapse before the results can be judged and the difficulties and expense of finding suitable sized areas in steep country and making applications with sufficient replications to give worthwhile data. Consideration is being given to fitting a variable dosage sprayer to a helicopter in an attempt to deal with one variable, i.e., whether concentration can have a worthwhile effect or whether it is necessary to seek a better chemical than 2,4,5-T to get consistent completely successful control of gorse.

Pasture weeds

(a) *On hills.*—Thistles (*Silybum* sp. and *Carduus* sp.) invade established pastures in dense stands. Fortunately they are susceptible to 2,4-D, and fixed-wing planes using 4 gal. of oil as diluent can obtain good control. Oil, however, is both expensive and presents a fire hazard to the aircraft and it reduces the selectivity of 2,4-D to clover.

The slow, low-flying helicopter has enabled water to be used as a diluent instead and this economy has made it possible for helicopters to compete with fixed-wing planes and improve on their results by greater accuracy of application.

MCPA is equally as effective as 2,4-D but contractors prefer 2,4-D ester as it appears to be more 'rain-fast' than salts of MCPA.

Coarse droplets are used from $20 \times 3/16$-in. hollow cone jets at 50 p.s.i. or $10 \times \frac{1}{4}$-in. jets at 30 p.s.i. giving 4–5 gal./acre at 25 m.p.h. Under easier flying conditions helicopters may work at 30–35 m.p.h. for economy, using more jets.

Young thistles of both species are readily killed by $\frac{1}{2}$ lb. of 2,4-D/acre but some resistance is shown by mature plants.

(b) *On level country.*—Much level pasture land should be sprayed for weed control in early spring, but frequently because the ground is very wet this is not practicable with ground equipment. Tests with helicopters have shown that efficient spraying can be done on fields of all sizes without, of course, any damage to the ground surface. This technique is particularly useful when applying phenoxybutyric weedkillers to new pastures in the spring.

Willows in New Zealand are a serious problem. Tests so far carried out show that helicopter techniques used for gorse spraying, but with 2,4-D ester, are not very effective. Trials with very fine sprays down to aerosols are contemplated, as only in this way is it considered likely that coverage of the dense mass of willow foliage characteristic of a heavy infestation can be obtained. Evaporation problems are less serious when working over water.

Successful spraying of weeds in irrigation channels by helicopter has been achieved.

Forest weeds

(a) *Regenerating forests.*—New Zealand has large forests of exotic pine trees. After being felled, many native species of shrubs and ferns compete with regenerating seedlings. Hand-cutting is difficult and expensive, especially on steep country cumbered with branches and stumps. Trials with total weedkillers were made, applied by helicopter, using concentrated solutions on the principle that the competing plants, having mostly broad leaves, would accept a greater proportion of the spray than the seedling pines, thus achieving selective control. Sodium chlorate/calcium chloride mixture ('Atlacide') proved the most satisfactory. The seedling pines were scorched, but apical buds were not killed, so that the young trees were able to grow away from the severely checked competitors. The rates tested were 56 and 112 lb./acre in water respectively. The approximate costs for each treatment were £5 and £10 per acre, half in each case being the cost of the chemical. The higher rate gave the best results but the lower, in one trial, gave indications that it would be adequate and was, of course, more attractive economically.

Sodium arsenite solution (at 56 lb. and 28 lb. As_2O_3 equivalent) was more effective against the weeds but was too severe on the pines even at the lower concentration.

A pentachlorophenol/creosote preparation was ineffective at 6 and 3 gal./acre.

2,4,5-T butyl ester at 3·6 and 1·8 lb. acid equiv./acre was effective against some species but unsatisfactory against others, especially ferns. It also distorted seedling pines.

All the chemicals were sprayed with similar amounts of water, i.e., 60 gal./acre for the higher amount and 30 gal. for the lower.

(b) *Cutting tracks.*—Cutting tracks through scrub for access or tree planting is expensive, slow and difficult. The effectiveness of sodium arsenite against a wide range of plant species makes this chemical suitable for aerial application. Reasonable precautions can take care of the poisonous hazards.

Special jets, 1 ft. long, were specially designed so as to give solid jets of liquid as free from 'break' as possible. At 25 m.p.h. and 15 ft. above the target each jet delivering 5 gal./min. at 40 p.s.i. gave a swath only 2–3 ft. wide.

One gal. of concentrated sodium arsenite solution (5·6 lb. As_2O_3/gal.) at 25 m.p.h. made 150 yd. of track. This cost about 0·8d. a yard. Flying costs were about 0·3d. per yard at 25 m.p.h. So one track would cost about 1·1d. per yard or about £8 per mile. Multiple tracks sprayed simultaneously would be proportionately cheaper as regards flying costs.

In one trial on light soil with considerable rainfall, the tracks (indicated by killed and defoliated plants) persisted for several months.

This method could be used to prepare planting lines or access paths, to grid trees for thinning purposes, or to prepare an area for burning.

Conclusion

The helicopter is already providing a valuable tool for many weedkilling tasks. When these aircraft become cheaper, more reliable, and specially designed and fitted with suitable equipment they will become an essential adjunct to weedkilling operations.

Some of the points discussed briefly here have been dealt with more fully in previous papers.[2]

References

1 Lynch, P. B., Matthews, L. J., & Thompson, F. B., *N.Z. J. Sci. Tech.*, 1956, **37A**, 505

2 Little, E. C. S., *Proc. N.Z. 8th Weed Control Conf., 1955*; *Proc. 19th Sheep Farming Conf. Massey College N.Z., 1956*; *J. R. Aero. Soc.*, 1958, **62** No. 570