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THE CONTROL OF STRIGA HERMONTHICA IN PEASANT FARMING

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Summary Northern Nigerian peasant farmers grow mixed food crops usually containing sorghum (*Sorghum vulgare*) which is the staple food grain of the area. Low yields limit the cash income of farmers. Improved methods of weed control must be cheap. Shortage of surface water prevents widespread use of knapsack sprayers.

The effect of these limitations on the control of striga (*Striga hermonthica*) parasitising sorghum in mixed crops is discussed. Weekly hand pulling is required to prevent striga seed production. This is not attempted by farmers. 'Spot-sprayed' ametryne, atrazine, linuron and MCPA completely controlled striga at doses below 0.5 kg a.i./ha. Large percentage sorghum yield increases were also obtained in sole crop.

Ametryne applied at village observations in a 0.4 mg a.i./ml solution with an intermittent 'spot-sprayer' controlled striga at a total dosage of about 20 g/ha.

Sorghum (*Sorghum vulgare*) is the staple cereal crop for a population of over 30 million subsistence farmers in northern Nigeria. Almost every sorghum crop in this area is infested with the parasitic weed 'striga' (*Striga hermonthica* Senth). Striga seed remains dormant in the soil until stimulated to germinate by an exudate from the root of a susceptible host crop. The seedling attaches itself to the host root and subsequently develops an aerial stem which flowers and bears seed.

Research to develop weed control methods for African peasant farmers has been in progress at Samaru since 1967. In this paper the general principles of this type of agricultural development are discussed in relation to the particular problem of striga control.

The characteristics of the peasant farmer

Though northern Nigeria contains peoples in all stages of development, those most ready to adopt any sort of improved agricultural practice usually have the following common characteristics. The production of a range of food crops for home consumption and local sale is their main occupation. These are invariably grown in a mixture of two or more crops. Norman (1970) showed that mixed cropping gave a greater return to the farmer than sole cropping at present levels of crop yields. Mixed millet and sorghum is also more profitable than the equivalent areas of sole crops even at very high levels of management and yield (Andrew, 1972). Mixed cropping may be expected to persist until systems of sole cropping become considerably more profitable. Improved weed control methods must therefore be compatible with mixed cropping. Cash crops such as cotton (*Gossypium hirsutum*) are grown in some areas but the cash income of the farmer remains low. The gross annual income per farming family in the Zaria area was reported to be £N100, Norman (1972). In the absence of subsidies or agricultural credit the cash investment in any improved method must therefore be very limited. Though paid labour may be employed, there is no general class of landless labourers. Richer farmers employ their poorer neighbours. As a result, labour is scarce and expensive during the period of maximum activity on the farms in June and July. The first weeding of the food crops has to be done at this time mainly be family labour. Delay results in serious yield reductions and failure to weed usually results in failure to yield at all. Any improved method of weed control must therefore not increase the labour demand in June and July.

Farmers use very little mechanical equipment. Cattle powered cultivations are used in certain areas but the vast majority of farmers cultivate their crops exclusively by hand. Knapsack sprayers are recommended for the insecticidal spraying of cotton but the shortage of surface water even during the peak of the rains limits their large scale adoption by farmers. The shortage of water is even more severe at the beginning of the season when herbicides would need to be applied for general weed control. Granular formulations are therefore likely to be used for applying herbicides to the soil and a granular fertilizer carrying a small percentage of a soil active herbicide is a possibility.

The problems of striga control in mixed crops

Trap cropping (Andrews and Wilson-Jones, 1948) or catch cropping (Last, 1960a) have been recommended for striga control but cannot be adapted to mixed cropping.

A negative correllation between striga infestation and apparent soil fertility has been reported by Porteres (1948), Wilson-Jones (1953a) and Last (1960a, 1960b, and 1961) but Butler (1953) reported that striga emergence increased when FYM was applied to a low yielding area of sorghum at Samaru. All these reports with the possible exception of Porteres (1948) referred to sole crop cereals. The effect of 80 kg of fertilizer N/ha broadcast in a mixed stand of sorghum, cowpeas and groundnuts (Arachis hypogaea) was examined by Ogborn (1970a). There were 13,400 sorghum stands/ha and at this density sorghum grain yield and dry matter were significantly increased and the striga was slightly depressed. In three out of five experiments cowpeas and groundnuts were a crop failure as a result of the increased competition from the sorghum and were depressed in the remaining two experiments. The effect of placing (instead of broadcasting) the same rate of nitrogen fertilizer has not yet been examined, but it has been repeatedly observed that the recommended dosage of 26 kg N/cropped ha increased both sorghum vigour and striga emergence in mixed crops. Very high levels of fertilizer nitrogen may well have a direct effect delaying or reducing striga emergence, but this has not yet been observed or reported in mixed crops. The limited evidence therefore indicates that application of fertilizer nitrogen is not an efficient means of controlling striga in mixed crops though it may alleviate the adverse effects on yield.

The only current recommendation to farmers is to 'handpull the striga before it produces seed'. It is necessary to handpull every week because striga can flower two weeks after emergence (Wilson-Jones, 1953b) and produce viable seed from plants pulled and left lying on the ground (Andrews, 1945).

Striga generally starts to emerge after the end of July in the northern savannah zones. Handpulling therefore needs to be done after the period of high labour demand and does not conflict with other handweeding operations but in practice farmers do not attempt to carry out the recommended control method.

Table 1 shows that intensive handpulling very strongly stimulates striga emergence. About five seasons are needed to begin to exhaust the striga seed reserve in the soil.

Table 1

Effect of weekly handpulling striga on sorghum grain yield (kg/ha) and striga emergence (000/ha)

Site	Samaru		Yandev		Yandev	
Date	1968		1954		1957	
Sorghum variety	Short Kaura		Fara fara		Fara fara	
Duration of handpulling	1 year		3 years		5 years	
	Grain	Striga	Grain	Striga	Grain	Striga
Handpulling	680	1,879	841	277	620	10.6
None	250	200	506	64	510	24.2
S.E. mean	±213	±40.5	±281[a]	±99.5[a]	± 26	±3.93[a]
Level of significance	ns	**	ns	ns	***	*
Soil applied herbicide	960	70	-	-	-	-
Source	Ogborn (1970)		Watson (1958)			

[a]Errors calculated from the original records at Samaru, not previously published.

Table 1 also shows that intensive handweeding is unprofitable. The removal of 1.9 million striga plants (weighing 3.5 t) restored only 430 kg out of a total loss of potential yield which certainly exceeded 710 kg/ha.

In practice the best farmers use a single handweeding timed to destroy most of the potential striga seed crops at the price of a considerable loss of grain.

Probably the greatest total loss of yield occurs on the large area of lightly infested land. Nigerian farmers near Samaru regard an infestation of one or two striga plants/m^2 (10-20,000/ha during the growth of the crop as normal and tolerable. The total Nigerian crop was estimated to be 2.8 million long tons in 1968 (NADC, 1971). If only half the area has a light infestation this will still be causing a total loss of about 5% of the total potential crop. The need to prevent this enormous loss of human food makes it desirable to develop a method of destroying the comparatively small reserve of seed in these lightly infested areas. This should be done if possible without interrupting the normal system of (mixed) cropping. There is therefore need for a method of controlling emerged striga on lightly infested land which can prevent the production of striga seed and which the average peasant farmer will be willing to apply. As was stressed earlier in this paper the immediate cost of the method would have to be low.

An alternative control method using herbicides

Robinson *et al.* (1967) and Shaw *et al.* (1962) reported the successful control of *S. asiatica* in maize by repeated foliar applications of 2,4-D to the emerged parasite. 2,4-D is not very suitable for use by African farmers because of the hazard to sensitive crops from drift and seed contamination in store. A search for other foliar active herbicides at Samaru from 1967 onwards showed that out of 68 formulations tested, 18 were selective in sorghum and possessed definite foliar activity against striga at low dosages. Table 2 shows that in the early stages of the screening work it became apparent that large and certainly profitable yield increases could be obtained from weekly spot spraying without the enormous increases in striga emergence which were obtained when the striga was handpulled weekly.

Table 2

Effect of 'spot' spraying of striga in sole crop sorghum

Herbicide	Dosage applied kg a.i./ha		Effect on striga em. % of control value		Yield increase, % of untreated control yield	
	1968	1969	1968	1969	1968	1969
ametryne	.22	.20	+88%	+104%	+80%	+77%*
atrazine	.26	.29	+63%	+ 2%	+59%	-15%
linuron	.45	.29	+ 9%	+ 95%	+75%	+31%
MCPA	.19	.45	-13%	+168%	+17%	+96%*
Weekly handpulling	-	-	-	+2,268%*	-	+32%
S.E. mean	±.031	tr	tr	tr	±33%	tr
untreated control yield in kg/ha					640	1530
Striga emergence 000/ha			22	56		
Sorghum variety					'FFxCK'	Short Kaura

Data in table was adapted from Ogborn (1970a). 'tr' indicates that the data was transformed before analysis. No single standard error applies to the retransformed means. * indicates a significant difference from 'Untreated control' yield (P=0.05)

Several of the herbicides were also reported to be tolerated by a number of the crops usually grown in mixture with sorghum. It appeared that a control method which completely prevented striga seed production could be developed for crop mixtures. Another valuable characteristic of this method was that it could be used in the dry season when soil applied herbicides would be practically inactive. Finally and most important, the method could potentially eradicate striga in mixed crops if used for several seasons in the same area.

Village observations

As it was already clear that a possible method could be worked out for village communities, two pilot observations near the Samaru and Kano stations of I.A.R. were started in 1969. Eleven were established in village communities in 1970 and of these eight were continued in 1971. There are 26 observations in 1972.

Spot sprayers. In 1969 and 1970 the village observations were issued with a low-pressure knapsack sprayer fitted with a narrow angle floodjet. This had the disadvantage that it was very easy for an inexperienced operator (who was not paying for the herbicide) to grossly overdose the striga. Several small intermittent type (water-pistol) sprayers were tested and a satisfactory model was obtained in 1971. This has an adjustable jet with a maximum range of 3 m when adjusted to spray very coarse droplets and can also produce a 'mist' when very finely adjusted. The ideal adjustment for spraying striga gives a range of about 1 m with a spread of about 25 cm. The droplet size produced is too large to drift seriously except in a very high wind but still gives a very satisfactory cover to the average size striga plant. It delivers almost exactly 1 ml/stroke with very little variation between sprayers.

The batch of 400 sprayers imported by airfreight in 1971 cost less than 5 shillings (Nigerian) for each sprayer including the cost of a 500 ml plastic bottle.

The availability of this type of sprayer not only made it possible for an individual farmer to buy his own sprayer but also solved the problem of overdosing. This type of sprayer is referred to as the 'pistolgrip' in the subsequent discussions. This sprayer is so cheap that it can be thrown away in the event of failure without grossly inflating the cost of striga control.

The herbicides used in the observations. At the end of 1968 the most effective herbicide in sole crop sorghum appeared to be ametryne. This herbicide was tolerated by groundnuts and cowpeas in an experimental series in 1968 at total sprayed doses up to 0.2 kg a.i./ha and was therefore chosen for use in the village observations from 1969 to 1971.

It was observed that the activity decreased considerably during the dry period between the end of the rains and sorghum harvest. This had little effect on the quantitative control of the parasite. In most sites the striga was controlled sufficiently well to give a noticeable increase in crop vigour but a few plants managed to survive and set seed. Fluorodifen killed rapidly at a low dosage in both 1969 and 1970 under humid conditions but was almost inactive at low humidities. As this herbicide was reported to be better tolerated by cowpeas than ametryne it was issued in 1971 to a number of centres where cowpeas are an important crop.

Information which has now accumulated as a result of two more years of detailed testing indicates that linuron is probably as reliable as ametryne, though rather slower acting. Linuron has the advantage that it is recommended for selective weed control in both groundnuts and cowpeas (Kasasian, 1971).

The general procedure for village observations. Except in 1969, these observations have been under the supervision of the field staff of the various Ministries of Natural Resources of the northern states of Nigeria.

The intended sequence of development is that in the first season a 0.1 ha demonstration plot is marked out on an already planted area of mixed crops. The plot is sprayed every week under the supervision of the extension staff who in fact tend to do the spraying themselves. The instructions stress the importance of encouraging the farmers to spray their own crops. In second and subsequent seasons it is intended that the farmers should take over the spraying operations on an increased area. The final form of an approved method will be based upon the experience gained in these pilot scale observations.

So far the observations have given little information about the organization of striga control at village level, but have produced much information about the practical aspects of the method itself which could not easily have been obtained in formal experiments.

Results from village observations. In an investigation of this type it is difficult to report precise quantitative results. The most important 'result' is the qualitative rejection or acceptance of the method by the farmers for whom it is intended. In all eight observations in 1971 the reported level of striga control was good enough to satisfy the local extension staff and in five villages the farmers were reported to be at least favourable (see Table 3).

The other most striking feature of these reports is the very low amount of herbicide needed to obtain control. The dosage is calculated from the amount of herbicide reported to be used and the reported area over which control had been obtained. Both of these values are unlikely to be precise but do enable an estimate of the dimensions of the operation to be made. At village HA a total of 10.5 g of fluorodifen was applied to 2.1 ha. Of this total 9.3 g were applied in a concentration of 0.4 mg/ml. During this period the control was reported to be complete. The last two volumes of solution made up were at 0.8 and 1.6 mg/ml respectively and did

Table 3

Reports from village observations in 1971

Village	Herbicide	Concentration in sprayed solution mg a.i./ml	Area treated ha	Herbicide used g a.i./ha	Farmer reaction	Striga control	Crop mixture	Remarks
D	ametryne	0.4	0.2	20	Favourable	'Complete'	Millet and sorghum	Bigger sprayer requested
GK	fluorodifen	?	0.4	?	?	'Good'	Sorghum, cowpeas and groundnuts	
GG	fluorodifen	0.4-0.6	0.2	12	Enthusiastic	'Complete'	?	4 more observations requested for 1972 in this area
HA	fluorodifen	0.4-1.6	2.1	5	Favourable	'Complete'	Sorghum, cowpeas, groundnuts and cassava[a]	3rd year observation
HK	ametryne	0.4-1.6	0.2	6	Wary	'Complete'	Sorghum and cowpeas	Cowpeas damaged here in 1970
R	ametryne	0.4-0.6	?	?	?	'Complete' until October	?	Sprayer 'failed' in October
W	ametryne	0.4	0.3	9	Favourable	'Complete'	Sorghum, okra[a] cowpeas and groundnuts	
Y	ametryne	0.4	0.4	8	Favourable	'Complete'	Sorghum and upland rice	Rice was also attacked by striga

[a]Cassava = <u>Manihot esculenta</u>, okra = <u>Hibiscus esculentus</u>

Four more proposed observations were not performed in 1971 not give complete control. The total volume of solution applied during the 'complete control' period was therefore 23.25 l. spread over a period of 8 weeks. The striga emergence cannot be measured directly but on the assumption that at least half of the sprayed striga plants died each week a minimum total emergence of 7,400/ha would have been controlled. By the same type of calculation it can be shown that the striga population remaining to be controlled in the dry season would not have exceeded 480/ha. The area was divided between five different farmers who all sprayed their own crops.

The other unsatisfactory nature of the observation reports is that 'complete' control is probably not complete at all. Striga hermonthica is an inconspicuous plant until it flowers and is easy to miss in a stand of mixed crops. At present farmers are conditioned to accept quantitative control of sufficient striga to ensure that they will obtain an acceptable crop. It will undoubtedly be more difficult to persuade them to undertake the extra effort needed to ensure that no plants survive to set seed. This is an extension problem for the future. At present the two years of observations indicate that the farmers are prepared to accept this method of control and that it will be very cheap.

Ametryne damage. The number of reported cases of damage was 7 in 1970 and 2 in 1971. The great improvement in herbicide utilisation in 1971 brought about by the introduction of the pistolgrip sprayer was accompanied by continued favourable acceptance from the farmers. In 1971 in fact the reports spoke of 'slight leaf scorch, which disappeared after three days' in damaged groundnuts at village 'W' and 'slight damage to the leaves of cowpeas next to the striga plants' at village 'GK'. Two weeks after the damage at 'GK' the cowpeas were reported to be 'vigorous'.

Operational aspects of the control method. The proposed method would replace the present single handweeding with a weekly visit to control a small number of emerged striga before flowering.

Ogborn (1971) showed that in an average year at Samaru, the heavy rainfall in August and early September prevented a massive emergence of striga until the last week of September. Nearly all the striga then emerged in the following three weeks. The major striga control effort would therefore be required at the end of September and the beginning of October in order to control the striga while still immature.

At first sight it may seem surprising that control of striga so late in the life of the crop should produce large percentage yield increases. The probable reason is that the traditional long season sorghum cultivars are day-length sensitive and do not form their grain until September. The control of emerged striga in September and October therefore coincides with grain production and may be expected to stimulate yield.

The pistolgrip sprayer now in use enables an operator to 'shoot' an individual striga plant with a volume of 1 ml of herbicide solution at ranges of up to 2 m. At emerged striga populations of up to 30,000/ha one operator can treat a strip of about 2 m wide at a slow walking speed. An emerged population of this order in any one week can be equivalent to a total emergence during the life of a sorghum crop of at least 100,000/ha. At this level of infestation the use of a soil applied herbicide begins to be practicable (in sole crop sorghum), (Ogborn, 1970b).

With the sparse cereal stands of the order of 2,000/ha usually found in crop mixtures the emerged striga stand does not normally exceed 20,000/ha even though this can cause the loss of a high proportion of the potential grain yield.

Costs. The dosages applied in the mixed crops in 1971 were very low. Fluorodifen costs about 100 Nigerian shillings per kilo of active ingredient. The cost of herbicide for controlling an estimated 7,400 striga/ha at village 'HA' was therefore

6 Nigerian pence for 5 g of active ingredient. Allowing 100% depreciation for the sprayer (which is actually still in working order) increases the maximum cash input to 3/- Nigerian/ha.

Unlike the fixed cost of an effective soil application of herbicides (Ogborn, 1970a) the cost of foliar herbicide application is proportional to the severity of the striga attack and to the potential yield increase.

Profits. The average 'farm gate' price of sorghum grain is certainly not less than 6d/kilo (Buntjer, 1972) so that an increase in yield of 6 kg/ha would be enough to pay for the running costs of this method of control at 'HA' in 1971.

The major 'profit' of the method is that the farmer may be encouraged to attempt to eradicate striga in his land by a comparatively light physical effort. Before this development, it was not physically possible without abandoning mixed cropping and cereal growing for many years. This would not be economically feasible for the farming community. Henceforward, each farmer can expect both higher cereal yields and less effort with each succeeding year of striga control.

Possible applications in other crops. Striga certainly attacks and causes losses in millet, maize and upland rice. Farmers also claim that it attacks irrigated wheat and sesame in Nigeria. *Striga gesneroides* seriously damages cowpeas in the drier zones of the country.

Conclusions

The control of emerged *Striga hermonthica* is possible by directed foliar applications of dosages of about 0.5 g a.i. of herbicide/1000 striga plants.

Complete control of striga in crop mixtures containing sorghum was reported when less than 20 g a.i. total dosage/ha was spot-sprayed with an intermittent type pistolgrip sprayer.

It is therefore now technically possible for Nigerian peasant farmers to control striga in mixed crops by this method.

It should therefore be possible to organise the virtual eradication of striga by persistent communal effort at village level.

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EXTENSION WORK WITH HERBICIDES IN THE SMALL SCALE TROPICAL FARM SITUATION

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Herbicides were discovered and developed in the more temperate developed countries and many have shown useful activity in a number of crop situations that exist in the small cultivator sector of tropical agriculture. But the economic and social patterns that contributed to the growth of herbicide use in developed agriculture were far removed from the patterns that generally exist in tropical and sub-tropical agriculture of developing countries excepting the plantation industries.

A quick look back at the developments that led up to the general use of herbicides in the UK shows that even in the fairly advanced conditions of the 1930's, British farmers could adequately control weeds without resort to chemical means - sulphuric acid (brown oil of vitriol) being the main herbicide of the period.

As recently as the 1946 edition of 'Crops and Cropping' (H I Moore) it could be written that "...... where steerage hoes can be used for inter-row hoeing .... a careful driver and a steady light legged horse can eliminate 95% of weeds in wheat", - adding that hand hoeing and pulling was required for the control of thistle and docks. The post 1945 fall in the numbers of regular hired agricultural workers, the growth in the use of fertiliser and the availability of cheap, reliable tractors were probably the main contributors to the rapid growth in the use of the newly discovered hormone herbicides. The farmer could not buy a 'steady light legged tractor', did not have the staff or desire to keep horses and found that the appetite of weeds for plant nutrients was equal to that of the crops. He therefore used herbicides for these reasons, not because of the presence of weeds per se.

More recent developments, particularly in the field of soil-acting and non-residual contact herbicides have confirmed the value of weed killers as substitutes for manual and mechanical labour, and by eliminating the need for inter-row hoeing their use has removed the major constraint to increasing plant density.

There are a number of situations in tropical and sub-tropical agriculture, even in the small cultivator sector, where we can identify the same motivations to using herbicides as have operated in more developed agriculture, for example the adoption of mechanisation and the thinning out of the rural work force by urban attractions and opportunities. The extension worker in such circumstances can draw on existing knowledge and experience in promoting the optimum relationship between herbicides and the local agro-economic pattern of crop production.

Practical examples can be drawn from our Company's experience in this field of work. Herbicide use in the coffee, banana, sugar cane, oil palm and rubber plantation industries of the tropics is quite sophisticated, and extension of herbicide use to the smallholding sector of these industries has been rapid. The adoption of herbicide techniques has been hastened by the fact that the smallholder is generating a steady cash income, needs to utilise his labour to best advantage, and often benefits from subsidy schemes backed by strong extension advice from both government and commercial agencies. The practical example of his big commercial brother is a major factor in the adoption of new techniques.

Other examples of the rapid acceptance of herbicides by the smallholder are found in the papya crop of Mexico, and among the pepper and vegetable growers of Malaysia, Indonesia and Brazil: again cash income is being generated, and specialised cultivators are concerned.

In the more general subsistence agriculture of the tropics, however, the pattern of resource use associated with crop production in the small farm is totally different; the use of labour is intensive and there is little opportunity to accumulate capital. Added difficulties arise from the heterogeneity of practices and attitudes that characterises even small tracts of country. Experience and knowledge of extension methods in developed agriculture is therefore of doubtful relevance in determining when and how herbicides may be fitted into the agro-economic and social pattern of crop production. Even when practicable uses have been established, there remain problems of convincing the cultivator of the value of new herbicide techniques. It is not simply a case of 'herbicides kill weeds, therefore use herbicides instead of hand weeding or bullock hoeing'. The risks associated with subsistence and near-subsistence farming demand that any new techniques must have striking advantages before the cultivator will be persuaded to adopt.

This is why the introduction of new high yielding and fertiliser responsive varieties of wheat, rice and to a lesser extent coarse grains has been the main agent of change initiating 'The Green Revolution' in tropical agriculture. The 1969 Provisional Indicative World Plan for Agricultural Development estimated that 10M hectares of these high yielding varieties had been sown in Asia in 1968 and that the area would increase at an average rate of 12% per annum to about 74M hectares by 1985, with fertiliser consumption increasing at roughly the same average rate. In India in 1970-71, 14.5M hectares of high yielding varieties were expected to be sown, representing about 16% of the total cereal area of the country. But figures such as these hide the rapidity with which particular regions have adopted those new varieties and the associated increased fertiliser consumption. In India for example, well over 70% of the area of wheat in the Punjab consists of high yielding varieties. Conversely they hidethe larger areas where such developments are still in their infancy and highlight the magnitude of the problems of introducing new inputs to the cultivator sector of tropical agriculture.

The pioneers of recent developments in plant breeding would be the first to admit that the introduction of a new high yielding variety is probably the easiest of all introductions that can be made to the small cultivator sector.

The need for the associated input of fertiliser is probably a little more difficult to adopt but nevertheless can be clearly demonstrated in the field. Both introductions are not far removed from the part and parcel of the existing experiences of small cultivators.

Many agronomists and extension workers would classify herbicides in the same category on the basis that their use also is relevant to the cultivator's experience in that he has always practiced weed control, albeit by hand labour, and then, without logic jump to the conclusion that herbicides should be an integral part of what is often loosely and misguidingly called the "package of practices".

Is this conclusion correct? Let us examine a number of circumstances which the extension worker will meet in his work of promoting new and better techniques aimed at improving the lot of the small cultivator.

Although there are one or two exceptions, it is rare for herbicides to initiate a change in the small cultivator sector of tropical agriculture. Their use follows other developments. When the prime and only agent of change is the introduction of a high yielding variety plus more fertiliser, it can be argued that weed control can be satisfactorily obtained by continuing with hand weeding even if the three extra days per hectare suggested by IRRI investigations are required. Results of herbicide experiments in rice for example, often show that similar yields are obtained with hand weeding as with chemical control and that "one handweeding, properly timed (21 DAT) may be adequate to reduce the weed population sufficient to obtain high yields of IR8", (IRRI Annual Report 1967).

But there is evidence from Dr H H Lange's work on seven crops in Colombia that, when herbicides are applied earlier than when hand weeding is physically possible an average yield increment of about 20% over hand weeding is possible - the range in his work being 13% to 24% according to crop. If these results can be repeated elsewhere and if the cost/benefit ratio is satisfactory, the extension worker has a case for introducing herbicides as an integral part of the package of practice. They provide a means of optimising the effect of the other new inputs of high yielding varieties and fertilisers.

Workers at IRRI have suggested that there is more economic justification for the use of herbicides in the rice crop if the chemical performs part of the tillage requirements in addition to its function as a simple herbicide (Moomaw et al 1968). Of particular interest to Plant Protection Limited in this respect has been the development of minimum cultivation techniques based on the use of paraquat; the chemical's wide spectrum of activity, rapid herbicidal effect and lack of residual activity in the soil, could help the small farmer to break through the traditional limitations on his productivity imposed by vigorous weed growth, difficult soil and weather conditions and the absence of mechanical aids. Work has indeed shown that the use of paraquat permits timeliness of sowing and facilitates multi-cropping and when combined with MCPA or 2,4-D post planting, eliminates much of the weed problems of the wet paddy farmer. (Mittra & Pieris 1968; Moomaw et al 1968; Seth et al 1971).

In Japan this use of paraquat to clear paddy fields of weeds prior to seed bed preparation has been widely established. This rapid acceptance stemmed from the fact that although the Japanese farm is small, the farmer, backed by a good extension service is sophisticated and has every incentive to maximise production from his land. The practice of part time employment in manufacturing industry is common. This provides an additional cash income and makes it necessary for the farmer to make the most efficient use of his labour on the farm. The typical tropical farmer is not in this happy situation. Nevertheless, a number of situations have been identified in subsistence type farming where paraquat techniques have proved valuable, particularly in rice production.

In Ceylon, where the work first started, a useful degree of success has been achieved. Here, in the Wet Zone, the farmer is in a particularly difficult situation, dealing with water logged paddies that are often infested with _Salvinia auriculata_ and where mechanical equipment is no help. Prompted by observations in a government sponsored _Salvinia_ eradication programme (Dias, 1966) a pre-cultivation spray with paraquat has been found to abbreviate the job of land preparation to such an extent that double cropping is now possible, where before it was limited by lack of time. Several thousands of acres of crops are now regularly prepared for seeding using this new technique.

Similarly in parts of Western Malaysia and Philippines, where the productivity of farmers has been limited by particularly difficult weed and soil conditions, and in south India where the time interval between harvesting the Kurvai and planting the Thaladi crop is short, the chemically assisted cultivation techniques are proving to be of considerable value to small cultivators.

The facility that these herbicide techniques provide to small farmers to practice multi-cropping, while reducing the peak labour requirements at sowing or planting does tend to increase the annual demand for labour. When two, if not three crops can be grown in a year the whole process of production, storage and distribution of the increased output together with the increase in associated activities provides new opportunities for employment.

The adoption of herbicides in small scale tropical farming (principally 2,4-D and MCPA in rice) now extends to many millions of acres but these represent only the more amenable areas. The task of extending the process to the far wider less amenable areas of paddy and other crops will require a considerable effort by official and commercial workers. Our experience in developing the use of paraquat has high-lighted the need for a large number of field development units with sufficient resources to carry out the detailed work required to establish techniques that are suitable for local agricultural and social conditions. Precise techniques developed in one area often require modification if they are to be applicable in another. The extension worker then has to face the problems associated with the sheer weight of numbers of cultivators that have to be contacted and instructed in the new techniques. The number of decisions in favour of adopting required per 100 acres treated or per 100 Kg of product, are nearly a hundredfold more numerous than in say the UK. The size of the problem can also be measured when one tries to apply the 'one extension officer per 1,500 farmers' norm of western agriculture to say, India with its 79M cultivators, the majority of whom have less than 5 acres.

In 1969, The Alkali and Chemical Corporation of India Limited established a product and marketing development project in four blocks in Sambalpur in the State of Orissa, India in order to obtain a more precise measure of the effort required to introduce paraquat minimum tillage, and post-planting 2,4-D techniques in rice production. Since 1962/63 when it became one of the fifteen IADP Districts, Sambalpur had been subjected to an intensive extension effort which resulted in a ten-fold increase in the consumption of nitrogen, a successful introduction of high-yielding varieties of rice for the Rabi season and a rapid expansion in seed treatment. But in the four blocks selected by ACCI Ltd herbicides were not used. In the first year (1969) therefore ACCI Ltd directed all its efforts to a programme of detailed field experiments carried out by two graduates. In 1970 they were joined by two graduate marketing staff. These four supported by ten 'Kamdars' were only able to contact a maximum of 1,500 cultivators per crop season out of the over 4,000 cultivators farming in the four blocks. Only 51 cultivators adopted the paraquat technique in the 1970/71 Rabi crop and 65 in the 1971 Kharif crop. About twice the number adopted the use of 2,4-D.

Apart from the huge effort and cost, and the low level of response (this was anticipated) the main lessons learned in these two years were:-

(a) The adoption of both paraquat and 2,4-D was related more to the proximity and accessibility of a viable distributor than to the proximity of a demonstration site.

* Kharif - Monsoon period
Rabi - Post Monsoon period

(b) The extension effort is more effective when confined to areas accessible to 'all weather roads'. In the second year the area of operation ceased to conform with administrative boundaries and instead concentrated on areas that were within one mile of 'all weather roads' and allowed the 'ripple effect' to operate into the hinterland.

(c) The majority of adopters were in the larger farm size group (10 acres +) and the majority of repeat purchases came from this size group.

The choice of extension techniques must of course allow for the different conditions that exist in the areas and countries concerned. In Malaya we have found the use of demonstration vans to be appropriate while in Indonesia, the absence of local distributors made it necessary to provide a system of centralised distribution points equipped with advisory aids. The 'Kamdar system' used in India and Ceylon has been of particular value. The Kamdar, generally a locally recruited matriculate, having gained experience of the products as a field assistant in the trial programme, is well equipped to introduce the products to the cultivator. The system must be flexible enough to allow the 'Kamdari' to operate individually as small spraying contractors in their spare time or to be employed ultimately by local distributors of crop protection chemicals.

Our experience has shown time and time again the vital role that the distribution system plays in support of extension work. But in the small cultivator sector, distributors of crop protection chemicals suffer serious constraints. The length of the distribution chain from manufacturer to the village retailer, the need for small packs at acceptable low prices to the user result in small distributor margins. These margins are generally associated with such a small volume of business that rarely can the distributor accumulate sufficient income to invest in early extension work - indeed, in some areas, not at all. The problem is often aggravated when Government agencies establish parallel distribution systems to provide cultivators with some of the products at subsidised prices or during pest epidemics.

But even when the extension worker has resolved these problems of scale and support he will be left with a dilemma which arises from the heterogeneity of the society within which he may well be working.

In recommending herbicides and other inputs on the basis of cost/benefit ratios to the larger cultivator, he might be compromising the position of the small farmer who derives some income from members of the family who hire their labour for hand weeding. And the question will arise "whose lot am I supposed to be improving?" This dilemma is high-lighted by Francine R Rankel's book "India's Green Revolution" when whe refers to the Thanjavur project and concludes "it is clear that the majority of cultivators in Thanjavur as in West Godavari Valley experienced a relative deterioration in their economic position as a result of the introduction of ADT27 (a high yielding variety of rice) once the gains of the small minority of landowners - the 9% of all cultivators having holdings of above 10 acres - are taken into account." The use of herbicides is still in its infancy in Thanjavur.

Perhaps there is room for thought here that should we ever aim to free the tropical peasant farmer from his load of perpetual weeding, so passionately described by Le Roy Holm (1969) we shall need to balance our technical developments with developments in the socio-economic field.

Commercial and Government extension activity in the field of herbicides must therefore be accompanied by policies aimed at upgrading the small cultivators' environment as a whole so that effort freed from manual toil can be satisfactorily and productively used in other fields.

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PRESENT AND FUTURE WEED PROBLEMS IN BEET, POTATO, AND ARABLE LEGUMES

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We are considering in this session a variety of crops grown under a wide range of conditions. There is a tendency for potatoes and legumes for processing to become concentrated on the most fertile and easily worked soils under intensive arable systems, while at the other extreme field beans are normally grown under low labour systems in a rotation dominated by cereals; often on soils with more difficult physical characteristics.

Though the predominant weed species and hence the detailed control methods may differ greatly between such farming systems (North 1970) the overriding problem facing any farmer is the same. This is that the farmer carries a serious and increasing burden of costs, and therefore partial crop failures due to weed infestation involves a financial penalty that cannot be tolerated.

Herbicides are unfortunately not invariably giving us a completely reliable standard of weed control and often there are enough weeds escaping herbicide treatments for most row crops to require some hand or machine work to deal with them. But in the years to come it would appear that the men will either not be available for this work, or else prove too expensive to employ as an insurance against herbicide failure.

If we look back, only a quarter of a century, to the time before herbicides were available farmers accepted weed in cereals, but kept the cash roots weed free, as cleaning crops for the whole rotation.

In the future, in the context of a virtually total reliance on herbicides, we may face a reversal of this philosophy. Cereals, where herbicides are extremely efficient, could become the 'cleaning crops', and farmers may have to tolerate a degree of weed survival in the sugar beet, potatoes, and arable legumes.

If consistent control of a virtual 100% of the weeds in these crops remains beyond our grasp for the immediate future then we should have much more information available on the fundamental aspects of what population of weeds can be tolerated in a crop, which species are competitive and at what stage of development. The work at Nottingham University (Scott & Moisey 1972) is a valuable contribution to our knowledge but needs repeating on other crops and weed species.

A great deal of research is directed towards killing as many weeds as possible at a cost, we hope, the farmer can afford. No doubt this pragmatic approach generally results in the removal of sufficient weed competition to outweigh any harmful effects due to possible herbicide toxicity, but we do not always bother to confirm that this is in fact so.

In some intensive cropping systems weed infestations are declining and the weed spectrum is changing (Fryer & Chancellor 1970). Before we insist on the destruction of the last half per cent of the weed population I suggest that we ought to be in a position where we could face the future from a much firmer baseline of knowledge about various topics:- weed competition, the possible adverse effects of herbicides and combinations of herbicides on the crop: possible disease herbicide interactions, and the relationships between weeds and attacks by soil pests (Dunning 1971).

The attitude of the farmer to weeds may in itself create problems. As an example a paper in the 9th Conference (Edwards & Cattle 1968) reported how farmers in South Lincolnshire were applying a residual herbicide in potatoes post-emergence and were well satisfied with the kill of weeds. Trials, however, indicated that yields were as a result reduced by up to 20% (3.6 tons per acre). This treatment was neither approved by the Ministry of Agriculture nor recommended by the manufacturer but it does illustrate how an illogical hatred of weeds can prove very expensive to the farmer. A less extreme but more widespread problem of a herbicide adversely affecting yields is the effect of simazine depressing the yield of field beans (Johnston & Briggs 1971). In many instances one suspects that beans are not drilled at an adequate depth, and that the use of unsuitable cereal drills is really at the root of the problem rather than a lack of selectivity in the herbicide.

Weed competition is, of course, not the only consideration; weeds seriously interfere with harvest. Bitter practical experience has shown us which species are a problem. Chenopodium album and Polygonum aviculare in sugar beet and potatoes block the machine harvesters; the seed heads of Circium arvense and fruits of Solanum nigrum can be serious contaminants of vining peas.

Superficially we have here a reason for demanding a 100% control from our early herbicide applications, but however effective pre-emergence treatments are initially we are normally faced with some late flushes of annual weed germination, and the growth of perennials, particularly in sugar beet and potatoes which now tend to be drilled or planted earlier in the spring.

If we were sure that weed development later in the crop's development was not producing a serious competitive effect then an answer could lie in the use of chemical desiccants for potatoes and dried peas and beans. A mechanical weed chopper has been used successfully for removing tall weeds in sugar beet (Bradford 1972) but though this improves the appearance of the crop one wonders if it would be possible to exploit the height differential between Chenopodium album and sugar beet in order to apply herbicide selectively to the weed.

As the labour situation becomes even more critical we may need to divert more effort and ingenuity towards developing weed control measures that can be used to clean up after partial herbicide failures.

Weed survival is sometimes a problem where pre-emergence residual materials have been used. We can now match these very well to the soil type, though soils with high organic matter still present difficulties. Unfortunately we seem unable to match dose rates to seasonal variations in rainfall, and have to risk some crop damage in wet years or, more commonly, indifferent herbicide action in dry springs. This is often the case with sugar beet and potatoes; and the processors' demands for an extended drilling season for vining peas and dwarf peas accentuates the difficulty even more, because crops drilled in England after mid April often receive insufficient rain for residual herbicides to be effective. Incorporation techniques for pre-emergence residual herbicides in sugar beet may help us in dry years but by no means provide a complete answer with all materials. If adequate rainfall follows there is a reduced margin of crop safety, and indeed weed control may prove inferior to surface applications; presumably because of a dilution effect in the extreme surface layer.

In what other ways can the reliability of residuals be improved? Certainly materials with much increased selectivity would be the most straightforward answer, if these could be produced at the right price. High enough doses could then be applied to insure against unsatisfactory weather conditions. Changes in the method of formulation of existing materials might be a possibility; interest in granules has increased recently for wild oat control in cereals, but apart from possible use in field beans have had little impact on the crops we are discussing. The use of surface mulches might be worth considering for sugar beet if the cost could be justified.

In the United Kingdom there has been interest in another approach in the case of sugar beet. With no single herbicide application giving complete and consistent control then the combination of reduced rates of pre-emergence residuals followed by a post-emergence herbicide seems logical, and has indeed given very good results (Norfolk Agricultural Station 1972). The risk of herbicide damage to the crop is reduced particularly when soil types within the field show great variation.

This planned approach is preferable to the present situation where farmers often delay post-emergence sprays for too long in the vain hope that weeds will eventually die from pre-emergence treatments. The problem associated with this approach is probably not so much technical as commercial, in that advice must be given on the combined use of chemicals produced by different organisations. This difficulty must be overcome, because the number of herbicide treatments crops receive are in any case on the increase. This brings us to the more detailed weed problems in these crops.

In the less intensive cropping systems the weeds of cereal crops predominate, and most serious of these are the grasses and Avena fatua, Alopecurus myosuroides and Agropyron repens. In practice most of the field beans and a large proportion of the sugar beet have to be grown in the presence of these grass weeds, but they are also a problem in potatoes and peas.

The necessity for using materials such as TCA di-allate and EPTC for grass weed control not only involve the farmer in extra labour and expense but, perhaps more serious, they necessitate an extra incorporation treatment when this may be undesirable for producing optimum seedbed conditions.

There is a trend towards using fewer pre-sowing cultivation treatments for many spring crops, and conditions for crop germination and growth are generally improved because the soil is less consolidated. Unfortunately over-wintered plants of Stelleria media and A. myosuroides may survive seedbed preparation, and there is much more need for the planned use of contact herbicides in these situations.

Broad leaved weeds such as Polygonum aviculare and some Veronica species create difficulties due to a measure of resistance to most herbicides used on the arable farm, but perhaps more of a problem are those weeds a proportion of which tend to germinate late in the spring - Chenopdium album and Solanum nigrum.

Perennial weeds such as Circium arvense and Tussilago farfara are only of very localised importance but if they should increase they could create real difficulties because they are relatively unaffected by most herbicides used in beet potatoes and legumes and are not always controlled by herbicides in cereals.

Unless herbicides can deal with these twin problems of perennials and late germinating annuals we may well see tractor hoes and potato row cultivators with us for many years to come.

In discussing the problems we must not loose sight of the general picture of the overriding success rate of herbicides in these crops. They have made possible a true revolution in growing methods. If, as seems likely, the pace of introducing new herbicides may slow we should turn increasing attention to a more logical and integrated use of what herbicides are already here in the profitable production of crops, rather than an all out assault on weeds. These two methods of approach are not necessarily compatible.

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HERBICIDE EVALUATION IN PEAS AND FRENCH BEANS 1971-72

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Summary On peas more effective weed control at normal doses was obtained with cyanazine and mixtures of trietazine/simazine and terbutryne/terbuthylazine than with the standard prometryne. On light soils, however, the selectivity of the former two treatments was less than prometryne.

Application of cyanazine at the 4 - 5 leaf stage caused damage in one trial at the low dose of 0.75 lb. The contact herbicide, bentazon, was more selective than dinoseb amine in peas, and French beans also showed good tolerance to this product.

Results with methabenzthiazuron and credazine are also included.

INTRODUCTION

Following the good results obtained with cyanazine (DW 3418) and methabenzthiazuron in 1970 trials (Cassidy 1970) investigations were continued with these herbicides in 1971-72. Other promising treatments were also included in these trials to determine if they were suitable alternatives to the standard pea herbicides, prometryne and dinoseb amine. The limitations of the standard herbicides have been described by King (1970).

Although the mixture of monolinuron + dinoseb acetate gives general satisfactory results in French beans, there are some common weed species which show resistance or partial resistance to this pre-emergence treatment. Veronica spp., Fumaria officinalis and Polygonum aviculare are examples. Lack of persistence is another problem with this mixture and late germinating weeds can often cause difficulty at harvesting. Because of these drawbacks preliminary trials were carried out with bentazon (BAS 3510H) to determine if it could be applied safely post-emergence and be used either as an alternative or as a supplement to the monolinuron + dinoseb acetate mixture.

MATERIALS AND METHODS

Trials were sited at Kinsealy and on growers crops in the Carlow and Cork areas. In all trials a randomised block design was used with four replications and a plot size of 20 - 30 yd^2. Treatments were applied with a pressure retaining knapsack at a volume of 40 gal/ac. Plant and weed counts were recorded and trials in the Carlow area were harvested using a small plot viner to obtain yield data. Visual assessments of treatment effect on crop and weeds were also made.

Weed counts were made within an area of a square foot quadrat thrown at random 4 - 6 times in each plot and plant stand was determined from counts made within eight 3 ft lengths of row per plot. The terbutryne/terbuthylazine formulation used in trials on peas was a mixture containing 35% terbutryne + 15% terbuthylazine.

In this paper doses of the mixture are referred to in terms of total active ingredient (a.i.) based on 70% terbutryne + 30% terbuthylazine. Similarly the monolinuron/dinoseb acetate mixture contained 12.5% monolinuron + 37.5% dinoseb acetate and is expressed as total a.i. based on 25% monolinuron + 75% dinoseb acetate. The trietazine/simazine formulation is given as lb product/ac.

RESULTS

Peas - pre-emergence trials - 1971 Sites A and B

Methabenzthiazuron and cyanazine at normal, one-and-a-half and twice normal doses were compared to prometryne at 1.25 lb at 2 sites in the Cork area. (Sites A and B). Both crops were sown in early March and treatments were applied under damp soil conditions 18 days later about 1 week prior to crop emergence. Site A was a light gravelly loam and the soil was of a slightly heavier texture at Site B. The predominant weed species in order of prevalence were *Spergula arvensis*, *Poa annua*, *Mentha arvensis*, *Viola arvensis* and *F. officinalis* at Site A and *P. aviculare*, *Chenopodium album*, *P. annua* and *Ranunculus arvensis* at Site B. The *P. aviculare* population was particularly high at 61 seedlings per ft^2 in untreated plots. Weed counts were recorded seven weeks after application of treatments. Results are given in Table 1.

Table 1

Effect of treatments on crop and weeds, Sites A & B 1971

Treatments	Dose lb/ac	Plant Stand as % of standard[1] A	B	Assessments[2] (mean of both sites) Crop	Weeds	% weed kill Site A Sp.a.	P.a.	M.a.	Site B V.a.	P.av.	Ch.a.
Prometryne	1.25	100	100	9.1	8.3	98	86	28	59	97	99
Methabenz-thiazuron	1.5	89	96	9.2	7.6	97	85	46	69	88	84
"	2.25	90	94	9.2	8.5	100	92	55	75	91	91
"	3.0	92	99	9.1	8.6	100	94	55	80	95	94
Cyanazine	1.5	96	94	9.2	8.6	100	96	65	73	93	99
"	2.25	99	99	9.3	9.1	100	100	77	82	91	98
"	3.0	91	96	8.8	9.7	100	99	85	88	96	99
Control (untreated)		97	92	9.4	0.0	0	0	0	0	0	0
S.E. as % of gen. mean		11.3	9.1								
Weeds/ft^2 in control plots						32	18	8	5	61	7

[1] Standard = prometryne

[2] Rating scale = Crop : 0 (complete kill) - 10 (no damage)
Weeds : 0 (dense cover of weeds) - 10 (no weeds)

Sp.a. = *Spergula arvensis*. P.a. = *Poa annua*. M.a. = *Mentha arvensis*,
V.a. = *Viola arvensis*. P.av. = *Polygonum aviculare*. Ch.a. = *Chenopodium album*.

Selectivity of treatments was high at both sites. Some slight check to crop vigour was noticeable in plots treated with cyanazine at 3.0 lb but plant counts showed that stand was not significantly affected.

At Site B, all treatments gave satisfactory weed control and there was little difference in degree of control between the low and high doses of cyanazine and methabenzthiazuron.

At Site A, however, there were significant differences in the effectiveness of treatments. S. arvensis and P. annua were well controlled by all treatments but only cyanazine gave any reasonable control of M. arvensis. Prometryne was slightly less effective than the other herbicides in controlling V. arvensis.

Sites C & D

At these sites the twice normal dose of cyanazine and methabenzthiazuron was not tested but chlorbromuron and mixtures of trietazine + simazine and terbutryne + terbuthylazine were included.

Crops were drilled in late April and treatments were applied 1 and 6 days after drilling at Site C and D respectively.

There was a good range of weeds at both sites. The most prevalent were P. annua, P. aviculare, Veronica spp., Stellaria media, Papaver dubium, Sonchus arvensis and Anagallis arvensis at Site C and S. media, Veronica spp., P. aviculare, P. annua, Spergula arvensis and V. arvensis at Site D. Treatments and results are given in Table 2.

Table 2

Effect of treatments on crop and weeds, Sites C & D 1971

Treatment	Dose lb/ac	Yield as % of standard[1] C	Yield as % of standard[1] D	Pea stand as % of standard[1] C	Pea stand as % of standard[1] D	Assessments[2] (mean of both sites) Crop	Assessments[2] (mean of both sites) Weeds	% weed kill Site C P.av.	% weed kill Site C P.d.	% weed kill Site D S.m.	% weed kill Site D V.s.	% weed kill Site D S.a.	% weed kill Site D V.a.
Prometryne	1.25	100	100	100	100	9.0	7.8	89	100	89	78	83	50
Methabenz-thiazuron	1.5	108	113	103	112	9.0	8.7	88	100	99	97	100	98
"	2.25	108	108	107	104	8.8	9.2	96	100	100	99	99	98
Cyanazine	1.5	92	109	103	109	9.1	9.5	98	100	100	100	100	100
"	2.25	99	108	108	101	8.9	9.7	100	100	100	100	100	100
*Trietazine + simazine	2.5	106	114	105	108	9.3	9.4	100	100	99	95	100	83
"	3.75	101	114	112	102	9.3	9.4	100	100	99	96	100	88
Terbutryne + terbuthylazine	1.0	106	111	107	103	9.2	9.3	100	100	99	95	100	94
Chlorbrom-uron	1.0	104	116	110	115	9.3	8.4	95	100	99	49	100	65
Control (untreated)		87	98	108	106	9.2	0.0	0	0	0	0	0	0
S.E. as % of gen. mean		6.7	15.1	6.6	4.8								
Weeds/ft[2] in control plots								13	4	19	10	6	3

[1]Standard = prometryne

* lb product/ac

[2]Rating scale as in Table 1

P.av. = P. aviculare. P.d. = Papaver dubium. S.m. = Stellaria media. V.s. =
V.s. = Veronica spp. Sp.a. = Spergula arvensis. V.a. = Viola arvensis

Plant counts, visual assessments and yield data recorded at the two sites (coarse sandy loams) showed that no significant crop damage occurred with any treatment.

At Site C, control of all species was good with each treatment, but cyanazine and the mixtures of trietazine + simazine and terbutryne + terbuthylazine were slightly more effective at normal doses than prometryne or the other herbicides.

At Site D, prometryne was not nearly as effective as at Site C even against the same species. A finer seedbed at Site C could account for the difference in control. Cyanazine and the two mixtures which were the best treatments at Site C were the most effective at Site D as well.

F. officinalis, Veronica spp. and V. arvensis showed partial resistance to chlorbromuron at 1.0 lb/ac. The latter species was also poorly controlled by prometryne.

Peas - post-emergence trial - 1971 Kinsealy

Cyanazine at 1.0 and 1.5 lb, bentazon at 1.75 and 2.25 lb/ac were compared to dinoseb amine at 1.85 lb/ac for application at the 1 - 2 and 4 - 5 leaf stage of peas.

Weed growth was very sparse in the trial area and no useful data on the comparative effectiveness of the different treatments could be obtained. At the earliest stage of application cyanazine at 1.5 lb and to a lesser extent bentazon at 2.25 lb/ac caused crop scorch and a moderate check to crop vigour. Both herbicides even at the lowest doses were slightly less selective than dinoseb at this stage of growth. The later application caused much less injury and differences in selectivity between treatments were difficult to detect.

Peas - pre-emergence trials - 1972 Sites E & F Carlow

Evaluation of the 1971 pre-emergence treatments (except for chlorbromuron) was continued in 1972 at Site E (clay 20.4%,o.m. 3.8%)and Site F (clay 9.5%,o.m. 2.8%)in the Carlow area. Normal and twice normal doses were compared. Peas were drilled at both sites in late April and treatments were applied the day following sowing under moderately dry soil conditions. TCA at 15.0 lb/ac for Agropyron spp. control was applied 8 and 6 weeks prior to sowing at Sites E and F respectively.

P. annua, Polygonum persicaria, C. album, Veronica spp. and S. media were the main weeds in order of prevalence at Site E. A wide range of species in relatively large numbers occurred at Site F. The main ones were P. annua, Spergula arvensis, Veronica spp., V. arvensis, Brassica rapa ssp campestris, P.persicaria and S. media. Treatments and results are given in Table 3.

Yield, plant counts and visual assessments showed that severe reduction in stand and vigour occurred, particularly at Site F, with the double doses of cyanazine and the mixture of trietazine and simazine. Surviving plants in plots thus treated were still very much retarded two months after spraying when plant counts and final assessments were being recorded. The mixture of terbutryne and terbuthylazine was less damaging than either of these treatments but at Site F the higher dose caused a slight reduction in stand and yield. Methabenzthiazuron also reduced crop vigour at both sites and there was little difference between the normal and twice normal doses in the degree of damage they caused. Prometryne 2.5 lb also reduced stand and yield but was not as severe as cyanazine or trietazine/simazine at twice normal doses.

Excellent weed control was given by cyanazine and the mixtures of trietazine/simazine and terbutryne/terbuthylazine and these at normal doses were more effective than the standard, prometryne, particularly for control of P. persicaria and V. arvensis. Methabenzthiazuron at 1.5 lb failed to control P. persicaria and also did not give adequate control of C. album or V. arvensis.

Table 3

Effect of treatments on crop and weeds, Sites E & F 1972

Treatments	Dose lb/ac	Yield[1] E	Yield[1] F	Stand[1] F	Assessments[2] Site E Crop	Site E Weed	Site F Crop	Site F Weed	% weed kill Site E P.a.	Site E P.p.	Site F Sp.a.	Site F V.a.	Site F B.r.
Prometryne	1.25	100	100	100	4	8	3	4	62	36	100	62	98
"	2.5	85	86	88	3	4	5	3	98	58	99	92	100
Cyanazine	1.5	103	80	95	3	4	3	2	95	64	100	94	100
"	3.0	104	83	76	5	2	8	3	100	95	100	100	100
*Trietazine + simazine	2.5	89	112	106	5	4	5	2	98	66	100	96	100
"	5.0	87	63	83	7	3	8	2	100	99	100	100	100
Terbutryne + terbuthylazine	1.0	93	121	101	5	4	3	2	88	60	100	94	100
"	2.0	106	87	86	4	3	6	2	100	84	100	99	100
Methabenz-thiazuron	1.5	101	75	86	4	7	5	3	92	0	100	76	100
"	3.0	94	77	93	6	4	5	3	99	75	100	94	100
Control (untreated)		96	87	100	4	9	3	9	0	0	0	0	0
S.E. as % of gen. mean		7.9	27.3	15.1									
Weeds/ft^2 in control plots									21	9	7	5	4

[1] as % of standard = prometryne at 1.25 lb/ac [2] E.W.R.C. scale 1 - 9 * lb product/ac

P.a. = Poa annua. P.p. = Polygonum persicaria. Sp.a. = Spergula arvensis
V.a. = Viola arvensis. B.r. = Brassica rapa ssp. campestris

Peas - post-emergence trials - 1972 Sites G & H

Bentazon and cyanazine were further tested in 1972 at two sites (G & H) in the Cork area for post-emergence application in peas. Crops were 4 - 6 in. high and at the 4 - 5 true leaf stage when treatments were applied. Weather was dry, cloudy and mild at both sites at time of application, but the lower leaves of the crop and weeds were damp following rain a few hours previously. Conditions for a period of 3 - 4 weeks prior to spraying had been continually dull and wet with below average temperatures. Weeds varied in development depending on species but generally most had 2 - 6 true leaves.

There was a high weed population at Site G where the major species were, in order of prevalence, P. persicaria, Spergula arvensis, A. arvensis, P. annua, S.media, Polygonum convolvulus and Galeopsis tetrahit. At Site H, P. aviculare, S. media Veronica spp. and Sinapis arvensis were the principal species.

Treatments and results are given in Table 4.

Plant counts and assessments taken three and six weeks after application of treatments showed that bentazon was highly selective at both sites. Less crop scorch occurred with this herbicide even at a dose of 3.0 lb/ac than with dinoseb amine at 1.85 lb. Cyanazine on the other hand was severely damaging particularly at Site H (clay 20.6%, o.m. 2.7%) where even the lowest dose of 0.75 lb caused considerable scorch and reduction in plant stand. At Site G (clay 17.9%, o.m. 3.2%) however, much less damage occurred with cyanazine at 0.75 lb but at 1.50 lb crop damage was equally severe to that obtained at Site H.

Bentazon gave effective control of P. persicaria and Spergula arvensis but was very poor against P. annua, Veronica sop., S. media and P. aviculare. The latter species was resistant to all treatments.

Cyanazine at 0.75 and 1.5 lb gave excellent control of Veronica spp and S. media but the higher dose was needed to control P. annua, Spergula arvensis and A. arvensis. Overall, dinoseb amine at 1.85 lb was slightly less effective than cyanazine 0. 75 lb but somewhat more effective than bentazon at 1.75 lb/ac.

Table 4

Effect of treatments on crop and weeds, Sites G & H 1972

Treatments	Dose lb/ac	Stand as % of standard[1] G	Stand as % of standard[1] H	Assessments[2] Site G Crop	Assessments[2] Site G Weeds	Assessments[2] Site H Crop	Assessments[2] Site H Weeds	% weed kill Site G P.p.	% weed kill Site G Sp.a.	% weed kill Site G P.a.	% weed kill Site H S.m.	% weed kill Site H P.av.	% weed kill Site H V.s.
Bentazon	1.75	96	110	3	7	2	8	92	70	6	8	0	0
"	3.5	92	98	3	6	2	8	95	92	0	0	0	0
Cyanazine	0.75	118	72	4	5	7	7	3	64	65	90	0	88
"	1.5	73	76	8	3	8	7	80	97	100	92	0	93
Dinoseb amine	1.85	100	100	5	6	4	8	81	25	26	49	0	68
Control(untreated)		98	106	1	9	1	9	0	0	0	0	0	0
S.E. as % of gen. mean		14.0	18.0										
Weeds/ft^2 in control plots								27	23	8	8	10	4

[1]Standard = Dinoseb amine at 1.85 lb/ac   [2] E.W.R.C. scale 1 - 9

P.p. = P. persicaria. Sp.a. = Spergula arvensis. P.a. = Poa annua.
P.av. = P. aviculare. S.m. = Stellaria media. V.s. Veronica spp.

French beans - post-emergence trials - 1971-72

Bentazon at 1.75 and 2.25 lb was applied at the early 1 - 2 trifoliate leaf stage to the cultivar Processor in a trial at Kinsealy in 1971. Simazine at 1.0 lb was also included and applied at the same time. The trial area received a pre-emergence application of the standard monolinuron/dinoseb acetate mixture and few weeds were present when treatments were applied. Assessments, plant counts and yield data showed that bentazon was very selective at a dose of 1.75 lb. At the higher dose some initial scorch to the simple leaves occurred but plants quickly recovered and yield was not significantly reduced. Simazine caused considerable crop damage.

In 1972 bentazon was further evaluated at Kinsealy for post-emergence application in French beans (cultivar Meteor). It was applied at 3 doses : 1.5, 2.25 and 3.0 lb/ac. Credazine at 1.25 lb was included and no pre-emergence treatment was given. Both treated and untreated plots were handweeded when weed counts were recorded one month after crop emergence. Treatments and results are given in Table 5.

With bentazon only scorch of the simple leaves occurred and this effect was more severe at the high doses. No trace of injury was evident on the first trifoliate leaf even though it was present when treatments were applied. The crop grew away quickly from this damage and after 3 weeks no reduction in vigour was evident. Credazine caused severe check and two weeks after application plants were only half the size of those sprayed with bentazon.

Excellent control of Capsella bursa-pastoris was obtained with bentazon at all doses, but a dose of 2.25 lb was necessary to give complete control of F. officinalis.

No effect on P. annua was obtained even at 3.5 lb. Credazine gave very poor control of all species.

Table 5

Effect of post-emergence treatments on crop and weeds - French beans - 1972

Treatments	Dose lb/ac	Yield as % of control	Stand as % of control	Assessments[1] Crop	Weeds	% weed kill P.a.	C.bp.	F.o.
Bentazon	1.50	211	125	3	6	0	99	73
"	2.25	158	105	4	6	0	87	92
"	3.0	175	101	4	6	0	96	97
Credazine	1.25	31	91	6	9	13	22	0
Control (untreated)		100	100	4	9	0	0	0
S.E. as % of gen. mean		29.1	19.2					
Weeds/ft^2 in control plots						4	5	2

[1] E.W.R.C. scale 1 - 9

P.a. = Poa annua. C.bp. = Capsella bursa-pastoris. F.o. = Fumaria officinalis

French beans - pre-emergence - 1972

Credazine at 1.25 and 2.0 lb applied pre-emergence, EPTC at 4.0 lb and trifluralin at 2.0 lb applied pre-sowing and a programme of trifluralin at 0.5 lb pre-sowing plus monolinuron/dinoseb acetate at 3.0 lb pre-emergence were compared with the standard monolinuron/dinoseb acetate mixture in a trial at Kinsealy.

Credazine gave good control of Senecio vulgaris and Veronica spp., fair control of C. bursa-pastoris and poor control of F. officinalis. Trifluralin and EPTC failed to control C. bursa-pastoris but were effective against Veronica spp and F. officinalis. Both S. vulgaris and C. bursa-pastoris were well controlled by the monolinuron/dinoseb mixture but Veronica spp was resistant. Best all round weed control was obtained with the trifluralin plus monlinuron/dinoseb programme.

DISCUSSION

The results of the 1971/72 trials show that there are a number of effective treatments now available for pre-emergence application in peas in addition to the standard prometryne.

In this series, cyanazine confirmed the promise of earlier investigations (Cassidy 1970, King 1970) and showed that at a dose of 1.5 lb it is a safe, effective pre-emergence treatment. Although no damage resulted from one-and-a-half or twice normal doses in the 1971 trials the results obtained in 1972 on light soils in the Carlow area indicate that on such soils the safety factor with this herbicide is less than 2. Consequently its use on soils with organic matter levels below 3% appear to be hazardous. Similar remarks apply to the trietazine/simazine mixture which also significantly reduced stand and yield at double the normal dose in 1972. The other mixture tested, terbutryne + terbuthylazine, showed better selectivity than the previous two and was more akin to prometryne in this respect.

More effective weed control was obtained in these trials with cyanazine and the two mixtures than with prometryne particularly of such species as P. persicaria, M. arvensis and V. arvensis.

Methabenzthiazuron was in general slightly less selective than prometryne but showed similar activity against weeds.

Although cyanazine caused little damage in 1971 when applied at the 4 - 5 leaf stage the serious injury which occurred in 1970 (Cassidy 1970) and again in 1972 with this herbicide suggests that its use as a post-emergence herbicide involves a certain amount of risk, particularly in dull wet seasons as was experienced in 1972. These conditions inhibit wax development and greater amounts of herbicides are retained and adsorbed by the pea foliage thus leading to injury. The relatively low organic matter levels of the 1972 sites probably also contributed to the degree of damage obtained.

Bentazon proved the most selective contact herbicide in peas but its effectiveness is less than dinoseb particularly against S. media and Veronica spp.

In French beans, bentazon also showed a high level of crop selectivity when applied as a post-emergence treatment at the early trifoliate leaf stage. In the two trials carried out with this herbicide no injury has occurred to the trifoliate leaves but scorch, severe at a dose of 3.0 lb, has affected the simple leaves on both occasions. These preliminary results would suggest that bentazon is a useful addition to the limited range of herbicides available for application in French beans. Used in conjunction with the monolinuron/dinoseb acetate mixture it could solve the problem of late germinating weeds in bean crops. In these trials it was particularly effective against P. persicaria, a species which is often a problem after the residual effect of monolinuron/dinoseb acetate has disappeared. Credazine showed good selectivity as a pre-emergence treatment but more experience is needed on lighter soils and on a wider weed spectrum to determine if it is a worthwhile alternative to the standard.

Acknowledgements

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WEED CONTROL IN NURSERY STOCK PRODUCTION

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Notcutts Nurseries cover some 240 acres of East Anglia. The soil ranges from a sandy loam overlying gravel to boulder clay with a pH of 5.5 to 8.5 and often varies widely within one field. For all weed, pest and disease control I am responsible with a staff of four men over a period of 9 months of the year.

Herbicides are used on most of the nursery and weed control is based on simazine applied in spring and autumn to give a total of 1½ lb/ac annually. In a normal year planting takes place from the end of February to the end of April. Simazine is applied from a few days to three weeks after planting. If there is any delay, land is lightly cultivated before spraying. At this time the tilth on some soils may be rather cloddy so to avoid spray shadows, the boom is fitted with nozzles projecting the spray to front and rear.

Although trials with atrazine at 1½ lb/ac in spring 1969 caused damage to species of Berberis, Callicarpa, Cotoneaster, Diervilla, Euonymus, Ligustrum, Philadelphus, Syringa, Viburnum and death of Tamarix, the risk to many species of trees seemed slight and it was decided to adopt it for species which had been undamaged. Atrazine has therefore been used for two seasons on trees and hedging species at the same rate as simazine and until 1972 little damage had occurred. However, during 1972 several trees showed damage as will be commented on later. Atrazine has a great attraction, as with some contact action timing is less critical then simazine.

In practice the rates are varied according to crop type and weed competition. Due to lack of control by simazine of certain weeds, the main problems are annuals, Urtica urens, Sinapis arvensis, Sonchus arvensis, Polygonum spp. Sherardia arvensis, Galium aparine and Veronica spp. Perennials include Cirsium arvense, Equisetum arvense, Rorippa sylvestris, Agropyron repens, Convolvulus arvense, Tussilago farfara, Carex spp. and Heracleum sphondylium.

Other residual herbicides in use are lenacil for herbaceous plants, terbacil on roses where A. repens (couch) is a problem and propachlor on wallflowers. During the summer directed sprays of paraquat, diquat or 2,4-D are used as additional annual weed control.

Perennial weed control in crop situations is by spot treatment with dichlobenil in late winter followed by directed sprays of 2,4-D, MCPA or aminotriazole during the growing season. Pre-cropping treatment is with aminotriazole, often with the addition of 2,4-D or MCPA.

Each year more 2,4-D is used and less paraquat as we prefer a small amount of distortion from this to the scorch associated with paraquat drift. With paraquat there has been difficulty in obtaining a suitable spray pattern.

We believe our good results with simazine at 1½ lb/ac per annum is due to a low rainfall of 23 in. and low organic level of the soil. In spite of this many simazine sensitive plants have been treated with success. Surface rooting species and those with variegated foliage tend to be more susceptible and do not receive simazine during the first year after planting.

Both operator error and weather conditions can lead to damage, as spring 1972 when lilac, a surface rooted plant, was stunted and even killed following heavy rain. The margin between weed control and crop safety is narrow and a few weeds present serve as indicators.

In the last 10 years, equipment has improved and a bed system of planting has been adopted to facilitate spraying. Application is by a sprayer mounted on a high clearance tractor and able to spray by boom or by lances where access is not possible. Knapsack sprayers are also extensively used.

Future planting will enable greater use to be made of tractor spraying but it is not expected that the hoe will be entirely replaced and on a nursery of this type some floating labour is required to cope with peaks of work throughout the season.

The use of herbicides has contributed to checking rising costs. Chemical weed control costs about £25 per acre and hand work as much as £100. The nursery industry must be ready to experiment on its own account as we must accept that chemicals and equipment will only be developed with a larger market in mind.

Our contribution is in the use of atrazine for nursery stock and the results are listed in table 1.

Table 1

Application of atrazine to trees and hedging plants

	Rate lbs /ac	Age in years: Stocks and 1 year	2	3	4	5	6	Season: Spring 1970	Autumn 1970	Spring 1971	Autumn 1971	Spring 1972	Damage	Remarks
Acer spp.	1-0.75	*	*	*	*	*	*	*	*	*	*	*		No damage to older trees. Damage to young Acer negundo and A. rubra.
Aesculus parviflora	0.75	*	*	*	*	*	*	*		*	*	*	No	
Ailanthus glandulosa	0.75	*	*	*	*	*	*		*	*	*	*	Yes	Leaf scorch up to 6yr.
Alnus spp.	0.75	*	*	*	*	*	*		*	*	*	*	Yes	Alnus incana 'Aurea' leaf scorch at 4-5 yr.
Amelanchier canadensis	0.75		*	*							*	*	No	
Berberis spp.	0.75	*	*									*	No	
Betula spp.	0.75	*	*	*	*	*	*			*	*	*	Yes	Some deaths 2-4 yr.
Caragana spp.	0.75	*										*	Yes	Leaf chlorosis
Carpinus spp.	1-0.75	*	*	*	*	*	*	*	*	*	*	*	No	
Castanea sativa	0.75			*	*	*			*		*	*	No	
Catalpa spp.	1-0.75	*	*	*	*	*	*		*	*	*	*	Yes	Leaf scorch on Catalpa 'Aurea'
Cercidiphylum spp.	0.75		*	*						*		*	No	
Chaenomeles spp.	0.75	*									*		No	
Corylus spp.	0.75	*										*	No	
Cotoneaster spp.	0.75	*	*	*	*	*			*		*	*	No	
Crataegus spp.	0.75	*	*	*	*	*			*		*	*	No	
Cytisus spp.				*								*	No	
Davidiana spp.	0.75	*									*		No	
Fagus sp.	1-0.75	*	*	*	*	*			*	*	*	*	No	
Fraxinus spp.	0.75		*	*	*	*			*		*	*	Yes	Fraxinus Argentea leaf scorch 4-5 yr.
Ginko biloba	0.75	*	*	*	*					*		*	No	
Gleditschia spp.	0.75	*	*	*						*		*	No	
Hippophae rhamnoides	0.75	*	*									*	No	
Koelreuteria paniculata	0.75	*	*	*	*						*	*	No	

Table 1 cont.

Application of atrazine to trees and hedging plants

	Rate lbs /ac	Age in years Stocks and 1 year	2	3	4	5	6	Season Spring 1970	Autumn 1970	Spring 1971	Autumn 1971	Spring 1972	Damage	Remarks
Laburnum spp.	0.75				*	*			*		*		No	
Liquidambar styraciflua	0.75	*	*	*						*	*	*	No	
Liriodendron spp.	0.75	*	*	*						*	*	*	No	
Lonicera spp.	0.75	*	*									*	No	
Magnolia spp.	0.75	*										*	Yes	Leaf chlorosis
Mahonia spp.	0.75	*	*									*	No	
Malus spp.	0.75	*	*	*	*	*	*	*	*	*	*	*	No	
Nothofagus spp.	0.75	*									*	*	No	
Ostrya spp.	0.75	*									*		Yes	Leaf chlorosis
Parrotia persica	0.75	*	*	*	*						*	*	No	
Paulownia imperialis	0.75	*										*	No	
Platanus spp.	0.75	*	*	*	*	*			*		*		No	
Populus spp.	1-0.75	*	*	*	*					*	*	*	No	
Prunus spp.	1-0.75	*	*	*	*	*	*	*	*		*	*	Yes	Several varieties showing marginal chlorosis. Prunus 'Sargentii'
Pterocarya fraxinifolia	0.75	*									*		No	
Pyrus salicifolia	0.75	*	*	*	*	*	*	*	*		*	*	No	
Quercus spp.	0.75	*	*	*	*	*	*	*	*		*	*	No	
Robinia spp.	0.75	*	*	*	*						*	*	No	
Salix spp.	1-0.75	*	*	*	*					*	*	*	No	
Sophora japonica	0.75	*										*	No	
Sorbus spp.	0.75	*	*	*	*		*				*	*	No	
Styrax japonica	0.75	*							*			*	No	
Taxus spp.	0.75	*	*									*	No	
Tilia spp.	0.75	*	*	*	*	*			*		*	*	No	
Ulmus spp.	0.75	*	*	*	*						*	*	No	
Mespilus germanica	0.75		*	*	*	*			*		*	*	No	

WEED CONTROL OF FIELD GROWN CROPS IN THE ORNAMENTAL PLANT NURSERY

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Summary After a brief introduction the principles of weed control in the nursery are discussed. Four important phases are recognised: i) land preparation; ii) pre-planting; iii) post-planting; iv) maintenance and 'follow-up', and features of these phases explained. A final section on the management approach towards weed control in the nursery emphasises the importance of nursery layout and integrated mechanization to achieve timeliness and flexibility in weed control techniques.

INTRODUCTION

The control of weeds has always played a significant part in ornamental plant nursery practice. The low density and long term plantings of diverse species creates conditions suitable for the generation of weed problems. We believe the introduction of residual herbicides into British nurseries was by H.G.Hillier who first used them at his Eastleigh branch in 1957, and marked the beginning of a profound change in methods of weed control.

PRINCIPLES OF WEED CONTROL IN THE NURSERY

Weed control in our nurseries falls into several phases which together make up the complete system. Dependent upon the circumstances of site, soil, weather conditions, crop and crop management, different phases will assume greatest importance. Normally, to ensure successful weed control all phases will need to be properly accomplised.

Phase 1 Land Preparation

The attention given to this phase will depend upon the prevailing weed population, the proposed cropping plan for the area and the subsequent management of the crop. Elimination of perennial weeds is the main objective. This aspect becomes vitally important where it is proposed to plant slow growing evergreens or other items which remain on the land for extended periods and are sold with a root ball. Trees lend themselves to 'follow-up' weed control by regular inter-row cultivation and/or spraying at the base with paraquat. Slow growing evergreens are not easily maintained in a weed free condition by 'follow-up' weed control systems.

Severe perennial weed infestations of deep rooted weeds such as *Convolvulus arvensis* (convolvulus) and *Cirsium arvense* (creeping thistle) present particular problems. Other species such as *Agroypyron repens* (couch), *Rumex* sp. (dock) and *Equisetum* sp. (marestail) are more easily controlled due to the introduction of various specific herbicides.

In an ideal situation an intrim period of one season should be allowed to apply hormone type selective weed killers (including asulam if *Rumex* sp. are a problem) as an attempt to weaken or eliminate broad-leaved weeds. In the autumn or early spring following this treatment, the land is rotavated or ploughed to encourage maximum regrowth of all underground buds of A. repens and other rhizomatous grasses and by the following early June the area is sprayed with aminotriazole to control A. repens and any broad-leaved weeds which may have survived previous treatments. Deep ploughing then follows in July or early August at which time farmyard manure may also be incorporated. By the September or October following this treatment surviving patches of A. repens or Agrostis stolonifera will begin to re-establish and may be treated with TCA which is incorporated into the soil by rotavation or cultivation. Final ploughing in November completes the operation and leaves the land in good condition for planting the following spraing.

Shorter schedules than this are obviously in frequent use and systems involving the autumn use of aminotriazole followed by summer fallowing, frequent cultivations and ending with muck spreading, sub-soiling and final ploughing are common. In this situation deep rooted weeds will not be controlled and will reappear either in the autumn of the first season after planting or in the second season after planting.

Phase 2 Pre-planting herbicide treatments

This phase is often omitted from the schedule, usually due to the lack of time. However, if the land is brought into planting tilth sufficiently early to allow annual weeds to germinate in quantity these may then be killed by paraquat or other contact herbicides before planting and a useful reduction in weed population may be achieved. This technique is of particular benefit where a heavy dressing of muck has been applied previously or where because of low crop tolerance (as in herbaceous plants) only small doses of residual herbicides may be used.

Phase 3 Selective post-planting herbicide treatments

The use of residual herbicides chosen for crop tolerance comprises this phase which has in recent years probably received greatest attention and interest from nurserymen. Crop tolerance is frequently achieved by selective herbicides with very low solubility which remain in the upper layers of the soil. Here they kill germinating weed seeds by poisoning the young plants through the root system, the roots of the crop being situated within deeper layers of the soil are unaffected. Certain chemicals such as chlorthiamid and dichlobenil achieve selectivity by a different mechanism and in some situations give outstanding weed control severely reducing the growth of deep rooted weeds such as Rumex sp. while still retaining crop tolerance.

Like most nurserymen we still rely heavily upon simazine which for the past 15 years has proved to be the most satisfactory and important of all herbicides used. Newer materials such as lenacil have proved good alternatives or supplements to simazine when used alone or in combination with it. Some established materials such as atrazine, diuron and neburon have been re-appraised and shown to be more useful than at first supposed. Chlorpropham in combination with other chemicals, usually fenuron, is frequently used as a winter herbicide, being applied in the late autumn To date no residual herbicides has yet been made available to nurserymen which will give acceptable weed control under all situations whilst retaining crop tolerance.

Failure to control perennial weeds before planting, a build-up of resistant weeds, or unsuitable weather conditions are among the factors which can lead to varying degrees of failure by residual herbicides.

Phase 4 Maintenance and 'follow-up' weed control.

Most residual herbicides available to date do not remain active for more than 6 months. A feature of maintenance schedules will be the regular application of residual herbicides of the simazine/lenacil type.

'Follow-up' weed control presents greater problems since this is required when residuals have failed to achieve good results. Techniques here range from hand pulling to inter-row steerage spraying. The most commonly use chemical in this situation is paraquat. Paraquat is used in nearly all situations provided adequate precautions are taken to ensure it does not make contact with delicate portions of the crop. Weeds in tree crops can be completely eliminated by the use of this chemical as it may be sprayed up to the base of the stem. With some species paraquat can cause stem damage to young trees (Malus, Acer spp. etc.). Damage may be reduced by spraying only between early May and mid-September, choosing a bright day and reducing the active ingredient to lowest positive effective rates. Paraquat spraying in low growing crops can only be achieved with safety using carefully directed sprays and/or adequate systems of guarding the crop. Replacing hoe blades by spray jets on the conventional steerage hoe has produced a steerage spraying machine which considerably increases output over hand spraying systems. For maximum safety flood jet type nozzles surrounded by a lightweight rubber or metal guard are normally used. With correct adjustment and skilful use, most weeds can be killed and a little handspraying between the plants in the row should be all that is necessary to give complete weed control.

Occasionally spectacular tachniques may be used in 'follow-up' weed control, for instance towards the end of summer some of the leathery leaved evergreens and conifers are very tolerant to the hormone type herbicides such as MCPA or 2,4-D. If these plants become infested with broad-leaved weeds such as Convolvulus arvensis or Cirsium arvense it is possible to apply an overall spray of the above chemicals to give some measure of control. Obviously there is scope for further experimentation on this aspect as other crop tolerances may be found.

MANAGEMENT APPROACH TOWARDS WEED CONTROL IN THE NURSERY

To date no foolproof system of weed control in ornamental plant nurseries has been devised and no chemical has been made available which will cope with all problems. Successful weed control at present depends on good management as much or more than on good chemicals. Nurseries should be planned and equiped so that appropriate action against a given weed problem can be taken quickly and efficiently.

By growing the crops on a system adapted for use by agricultural tractors full advantage can be taken of the work output of these machines. The use of multiple row bed systems is suitable for low growing crops which may be straddled by standard or high clearance tractors. For crops such as trees, rows should be wide enough apart to permit a tractor (possible narrow Vineyard type) to pass between them. Once the basic layout is correct standard agricultural or horticultural spraying equipment may often be used with little or no modification although purpose built machines usually further enhance results and output.

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GARDEN MAINTENANCE WITH HERBICIDES

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Summary A herbicide programme based largely on overall applications of simazine supplemented by spot treatment with other herbicides has been used to maintain a 3 ac garden in a substantially weed free condition for four years. The garden contained a wide range of ornamental shrubs, trees, herbaceous plants and bulbs. Cultivation of the soil was discontinued and the labour required to maintain the garden was greatly reduced.

It is suggested that where experience on the use of herbicides has been obtained and where occasional temporary chemical injury to plants is acceptable, herbicide programmes could be used much more widely than at present to reduce the maintenance cost of amenity plantings. The technique widely practised by Parks Departments and Local Authorities of forking or cultivating sprayed areas each year is questioned.

INTRODUCTION

The use of herbicides in soft fruits and nursery stocks is now well established but their use in garden maintenance has not yet been fully exploited. With increasing scarcity and high cost of labour, means of reducing garden maintenance are urgently required by home owners. Many are interested in the possibility of using herbicides for weed control but are apprehensive about the risk of plant injury either directly or as a result of a build up of chemicals in the soil.

The following is an account of how herbicides have been used extensively in a large garden to reduce labour input to a minimum.

The garden, situated on the coast at Baily, north County Dublin, is approximately 4 ac in area, one ac of which falls steeply to the sea and is uncultivated. The remainder is divided into a series of small gardens surrounded by hedges for wind protection. In 1969 these small gardens contained shrubs, herbaceous borders, rock garden, rose beds, borders for annuals, bulbs and bedding plants, a soft fruit garden and an orchard. The gardens had been made gradually from about 1870. At one period four gardeners were employed but this number had been reduced gradually until in 1969 one gardener was employed full-time with part-time help.

Before 1969 the garden had been planted up with many hundreds of species of hardy and tender plants. The programme of planting and replacement has been continuous and a range of newly planted and well established plants are present. Among the most widely planted genera are:-

Trees - Pinus, Cupressus, Prunus, Salix, Syringa, Cotoneaster, Eucalyptus.

Shrubs - Floribunda and species roses, Rhododendron, Azalea, Fuchsia, Escallonia, Hebe, Olearia.

Herbaceous plants - Aster, Astilbe, Phlox, Chrysanthemum, Hosta, Kniphofia, Montbretia, Eryngium, Paeonia.

Rock plants - Saxifraga, Dianthus, Helianthemum, Sedum, Cyclamen, Erica, Calluna.

Bulbs - Narcissus, Tulipa, Crocus, Galanthus, Muscari.

Since 1969 many more trees and shrubs were planted. These included both hardy genera, e.g. Betula, Rhododendron, Azalea and Erica and tender genera, e.g. Clianthus, Crinodendron, Callistemon and approximately 30 species of Eucalyptus

The soil is a loam derived from Cambrian shale and quartzite. It contains in the 0 to 3 in. level approximately 25% clay and 4.5% organic matter.

In May 1969 a maintenance programme, based almost entirely on herbicides was introduced, so that with the exception of grass cutting the grounds could be maintained essentially in a weed free condition with only a few hours work each week.

A wide range of annual and perennial weeds were present at the start of the programme. The most prevalent of these were, Poa annua, Senecio vulgaris, Galium aparine, Atriplex patula, Stellaria media, Fumaria officinalis, Agropyron repens, Rubus fruticosus, Taraxacum officinale and Aegopodium podagraria.

METHOD AND MATERIALS

The following changes were made in methods of maintenance to reduce labour requirements and to facilitate spraying with herbicides.

(1) Annuals and bedding plants were eliminated and the areas freed were planted up with shrubs which are more resistant to herbicides.

(2) Several lawns were eliminated by spraying the grass with paraquat and planting up with shrubs, trees and ground cover plants directly into the killed sward. Five of the eight lawns present in 1969 were treated in this way.

(3) Hedges are gradually being reduced in number and replaced where shelter is required by informal plantings of trees and shrubs.

(4) The entire area was treated with a herbicide programme and wherever possible the soil was left undisturbed after planting. The herbicide programme was not planned in detail in advance but herbicides are selected as required to deal with the existing or anticipated weed problem.

Herbicides. The main herbicide in the programme for non-lawn areas was simazine. This was applied two or three times a year to control germinating annual weeds and once every two years on paths and roadways. Simazine was applied at 1.5 lb/ac to the rock garden, herbaceous border, and shrub borders in May and August, 1969, March, May and August, 1970, March and July, 1971 and March and July, 1972.

Other herbicides used as spot treatments as required were:-

paraquat (1 lb/ac) against all emerged weeds,
MCPA (2 lb/ac) against *Calystegia sepium Urtica dioica, Taraxicum officinale* and *Rumex* spp,
mecoprop (2.5 lb/ac) against *Galium aparine* and *Trifolium repens*,
2,4,5-T (2 lb/ac) against *Rubus fruticosus*,
dichlobenil (7.5 lb/ac) against *Aegopodium podagraria, Agropyron repens* and *Rumex* spp,
terbacil (2 lb/ac) against *Agropyron repens* and germinating weeds.

2,4,5-T was also used to kill the regrowth from stumps of cut down hedges and trees. These included *Cotoneaster, Griselinia, Fuchsia, Escallonia* and *Acer pseudoplatanus*.

Because of problems with some resistant weeds, terbacil was used at 2 lb/ac in 1971 and 1972 instead of simazine in areas containing shrubs known to be resistant to it, e.g. floribunda and species roses and escallonias. Only one application was made each year.

Glyphosate at 4 lb/ac was used experimentally in 1972 to control perennial weeds, especially *Agropyron repens*, a short time before planting *Eucalyptus gunnii*.

Spraying methods. An ICI "Gramoxone" knapsack sprayer with a flood jet nozzle was used for all herbicide applications. Overall application of auxin type sprays to lawns and of simazine were applied at 20 gal/ac and spot treatments of other non-granular herbicides at 50 to 100 gal/ac. Where a wettable powder was used the dose was measured out separately by volume for each sprayerful (4 gal) using a calibrated container. Application of soil-applied herbicides was timed to c ncide with a period of wet weather. Auxin-type herbicides were applied carefully as spot treatments under calm weather conditions using a low pressure (7.5 lb/in^2) to minimise wetting plant foliage.

Simazine was applied in bands 4.5 ft wide. Uniform application was hindered to some extent by the uneven topography of the rock garden and elsewhere by informal groupings of trees and shrubs. In these areas spraying in straight lines was facilitated by the use of two marker canes 4.5 ft long at each end of the area being sprayed. Before starting to spray each strip, the canes were moved along (using one also as a measuring stick) and placed in an upright position to serve as markers for the return journey.

Planting into herbicide-treated soil. Because of the extensive replanting programme, it was often necessary to plant shrubs into ground that had recently been treated with simazine and other soil-acting herbicides. Two methods were used for increasing plant resistance. In both methods the top inch of soil was removed before digging the hole as this is likely to contain most of the herbicide residue (Burschel 1961). The surface soil was placed to one side wherever possible as an unbroken crust. The hole was then dug to the required depth. In the first method the roots of the new plant were dipped in activated charcoal before planting and the soil replaced around the roots, a technique used to increase the tolerance of newly planted strawberry runners to simazine (Robinson 1965). After planting, the surface crust was replaced so that the herbicide residues in it could continue to suppress germinating weeds. When container or pot-grown shrubs were planted the root ball was dipped in activated charcoal if simazine had been applied within the previous two months of if the container or pot was less than 4 in. in diameter.

The second method was similar to the first except that instead of dipping plant roots in activated charcoal a small quantity of herbicide-free peat compost was placed around the root system of the shrub or tree during the planting operation.

RESULTS

The herbicide programme was highly successful. It was not possible to achieve complete control by chemicals but surviving weeds were few and in most cases were easily removed by hand. The principal weeds still remaining are Rubus fruticosus, Oxalis rubra, Sedum anglicum and patches of Agropyron repens. Some trouble was also caused by seedlings of Cotoneaster spp principally C. frigida. Berberis darwinii, Hypericum androsaemum and Aquilegia vulgaris.

Weed control was even more effective in those areas where terbacil was used instead of simazine. Terbacil gave good control of Sedum anglicum which was spreading rapidly in rose beds that had been treated in 1969 and 1970 with simazine. Glyphosate at 4 lb/ac gave good control of many perennial weeds, in particular Agropyron repens and caused no damage to Eucalyptus gunni planted 10 days after spraying.

In general, there was little need to hoe following spraying to control weeds. In the localised areas where hoeing was necessary a Dutch hoe was used shallowly in the top ½ in. of soil. There was no evidence that hoeing carried out in this way reduced the residual effect of simazine. As in the case of non-cultivated fruit plantations, the soil surface became cracked and crusted and covered with moss in damp periods (Robinson 1963). As with soft fruits, there was no evidence that the growth of any established ornamental plant was adversely affected by the absence of cultivation.

Despite the large number of genera and species treated, little herbicide damage was recorded. Fragaria vesca was, however, susceptible to simazine and was killed after two or three seasons. Phlox and Sparmannia africana showed symptoms of simazine damage each year but any check to growth was temporary and was soon outgrown. None of the other species treated showed any damage that could be attributed to simazine. Particular attention was paid to such genera as Syringia, Forsythia, Laburnum, Populus, Prunus, Senecio, and Spiraea which are reported to be more liable to damage by simazine than the majority of shrubs and trees (Woodford and Evans 1973). Growth of these plants was good and no symptoms occurred on the foliage.

The methods used for planting young trees and shrubs into simazine-treated soil were satisfactory and no injury was recorded. A substantial saving in the time required to manage the garden was achieved by planting up some of the original lawns with shrubs. Compared with regular grass cutting spraying shrubs with herbicides is much less labour intensive.

DISCUSSION

While the tolerance of woody plants to simazine is well known, the almost complete absence of noticeable damage on a wide range of rock, herbaceous and bulbous plants was unexpected. Simazine has been shown to reduce the bulb yield of narcissus (Anon. 1968) but in this garden there was no evidence of any adverse effect on flower size or flower numbers of narcissus or even of crocus and Galanthus which are normally planted more shallowly. The absence of noticeable damage in this case may have been due to the plants being well established before the start of the herbicide programme. It is possible, however, that bulb yield may have been reduced without affecting flower size or numbers and the long term effect of repeated applications will need to be watched carefully.

Damage to shrubs by auxin-type herbicides occurs often, usually as a result of drift when lawns are being treated with medium or high pressure sprayers. Nevertheless, current experience has shown that herbicides such as 2,4-D, MCPA and mecoprop can be used effectively around many shrubs provided the risk of damage is appreciated and suitable precautions are taken viz. the use of carefully directed applications using a low pressure sprayer under calm weather conditions. Occasional damage was seen in this garden but it was never serious and any harmful effect was slight and temporary. Damage with auxin-type herbicides was also minimised by spraying before the growth of perennial weeds was well advanced. This enabled spot treatment to be carried out selectively with little wetting of the plant foliage. These herbicides were also applied effectively in the autumn when growth of many ornamentals has stopped but when weeds are still active. Growth of most of the plants in the garden has been vigorous and the general impression is very satisfactory. Any damage was quickly masked by new growth of other parts of the plant or of adjacent plants.

The results obtained with glyphosate suggest that this chemical will have many uses as a herbicide for amenity areas. Because it has no apparent soil residual activity and is translocated it will enable shrubs to be planted shortly after spraying into areas infested with perennial weeds. When applied by means of a 'Roguing Glove' it should also provide a method of eradicating certain weeds that are intertwined with established shrubs.

The use of a single flood jet nozzle instead of a boom is particularly advantageous in mixed planting of trees and shrubs which would otherwise interfere with the uniform passage of the sprayer. The method used of measuring out doses of wettable powder by volume was less accurate than weighing each dose separately because of possible changes in density between batches of herbicide. This method, was, however, very rapid and proved satisfactory in practice. The use of a 4 gal container and a volume of 20 gal/ac enabled one fifth ac to be sprayed at one filling. The good results obtained with soil-acting herbicides using this relatively low volume were attributed partly to the careful timing of sprays to coincide with damp soil conditions.

The establishment of mosses e.g. Funaria hygrometrica and Polytricum commune on bare shaded surfaces was notable in some parts of the garden. The presence of moss on herbicide treated soil is regarded with favour by some gardeners and with disfavour by others who assume that it is a sign of bad husbandry. There is no evidence from long term, non-cultivation experiments in fruit to suggest that the growth of moss is harmful (Robinson 1963). It is noteworthy that one of the most highly regarded types of gardening in Japan is the moss garden (Iwatsuka et al 1961). There the soft beauty of variously coloured mosses in a small area is greatly prized as it gives an impression of being high in the mountains and creates an impression of tranquility. The development of a moss garden in Japan requires much skill and labour in its establishment and maintenance. The tolerance of many moss species to simazine and paraquat and the ease with which they grow in herbicide-treated areas in these islands suggest that this type of gardening could be more fully exploited particularly as mosses could be combined with rock and stone in damp and shady areas where higher plants are less successful. There is a need for horticulturists and others to make efforts to dispel the widely held fallacy that the presence of moss is evidence of bad husbandry and is detrimental to the growth of shrubs and trees.

The experience gained in managing this garden under a herbicide regime suggests that herbicides could be more widely used than at present for weed control in amenity areas. It seems likely that the decreasing availability of labour in the future will force many home owners to use herbicides for this purpose. The risk of overdosing in small areas is high and careful calibration of spraying equipment is necessary. It will also be necessary to adjust the dose used according to soil type. The advantage of using herbicides is considerable particularly when assessed over a period of years as spraying can be carried out rapidly once the necessary experience has been obtained. To facilitate weed control by herbicides, a garden should be planted up as far as possible with trees and shrubs; interplanting bedding plants and shrubs must be avoided.

The results obtained here and elsewhere (Ivens 1964) show that most woody ornamentals are resistant to simazine particularly when established for a few years. Slight leaf chlorosis occurs occasionally but it is not often serious and will usually be quickly masked by vigorous growth. The foliage symptoms caused by simazine even though temporary may be conspicuous. The subsequent vigorous growth, however, suggests that in many cases the herbicide is likely to be less damaging to shrubs than traditional cultivation although the check to growth and severed roots caused by cultivation cannot be easily detected. Obviously, there is greater potential for the use of herbicides in large scale plantings of shrubs as in parks or large gardens. However, as gardens tend to become smaller, there is scope for greater co-operation between neighbours and for activities in this field by Residents' Associations.

Many County Councils and Parks Departments are already using simazine and other herbicides on a routine basis. This is usually combined with routine forking to incorporate nutrients. The results obtained here suggest that, as in the case of soft fruit, such forking is unnecessary. Many ornamental plants are as shallow rooting as blackcurrants or gooseberries and it is likely that better growth would be obtained by eliminating all forms of cultivation. In some cases forking may be considered necessary for aesthetic reasons. In the short term a non-cultivated surface can look unpleasant but after a few months when natural structure forming processes begin to assert themselves, e.g. the activity of worms and other soil animals and the penetration of roots, the texture of the soil surface greatly improves. It seems likely that where aesthetics are of great importance and where a non-cultivated surface is not considered satisfactory, the use of a shallow mulch of peat would in many cases be preferable to forking.

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Discussion

Miss E. M. May. Will the manufacturers make materials mentioned available for gardeners ?

Dr. D. Robinson Several materials such as simazine and paraquat are available in small quantities. MCPA and 2,4-D can be damaging if misapplied but can do very good work as spot treatments.

A. Carter Your system for gardening is easy if it does not matter if plants live or die. Has Dr. Robinson stopped growing any plants.

Dr. D. Robinson Very few

J. B. Evison The appearance of ground between plants is unattractive. Moss grows freely.

Dr. D. Robinson Why keep moss down ? It is the most beautiful plant we can grow on this island, when in Japan they spend £'s growing it. Herbicides encourage the growth of moss and we could well make use of this to give attractive effects. Alternatively one could plant closer or cover with peat to improve the ground appearance.

Dr. J. G. Davison I would like to ask Mr Cox and Mr Humpheries if using weed killers to the extent they do, have they noticed any difference in the quality or distribution of the root which they subsequently lift to sell.

R. Cox I cannot really give any real evidence other than the look of the thing. We definitely feel that the root structure is better on most of the trees and shrubs because without rotavation as there used to be, taking away the surface root for a depth of 3 in. or so we get a good fiborous root and we are well satisfied with this. I think rotavation does great damage to plants.

B. Humpheries I would endorse that.

Dr E W Parnell I would like to ask Dr. Robinson about producing wonderful crops of Oxalis sp. during your methods of treating your garden to ensure that Oxalis does not develop as a weed problem.

Dr. D. Robinson Well I can give you good news for the future, the new material glyphosate, I understand does seem to be in my own garden extremely effective against Oxalis but I heard from the manufacturers yesterday that it will be late 1973 before this material is available. Now I have Oxalis in my own garden but it isn't really a problem. Everytime I go round the garden spot treating I hit it with whatever material I happen to have and I know it is a resistant weed, it is certainly resistant to MCPA, chlorthiamid and dichlobenil, but if you follow-up, if you use 2 or 3 different materials in rapid succession within a space of 6 months it will very quickly disappear.

J. W. Hancock I would briefly like to mention the problem of weeds apparently coming or not coming with peat. What sort of measures are taken to ensure that weeds are not shipped out with peat. Oxalis we have heard mentioned as possibly from peat and Cardamine hirsutum is a weed which some nurserymen have associated with the use of peat. I won't be sure its Irish peat.

Dr. D. Robinson Well I am not sure whether I am proficient to answer accurately that question. I do know of course the areas from which the peat is obtained and it is brown sterile peat bogs. Now there is very little chance of weeds coming in but I have heard rumours to the effect that there were one or two ditches where weed control was not as effective as it might have been. I think that this is a short term problem which might have occurred during the last 6 months or so but it will be attended too, certainly in the future. I do not think that it is likely to be a continuing problem.

Dr P Birch There is a chemical which effectively controls Oxalis that is trifluralin. It can be hoed into the soil at about 3 times the rate as used for controlling weeds in brassicas. It is extremely effective.

Dr. D. Robinson The other difficulty about an incorporated herbicide is I think that this is the one thing you want to avoid in the garden and that to avoid any form of soil disturbance in order to avoid damaging plant roots.

Dr. J. G. Davison Trifluralin is not available in small quantities.

E. Gunn Could I just ask Dr. Robinson the rate of simazine he used. I have done a very similar project to what he has done on a much smaller scale and I find that most plants, herbaceous which are normally considered susceptible, you can apply simazine at very low rates but apply more frequently, say twice or three times a year in my particular garden, two gardens in fact, an $\frac{1}{8}$ of a lb per acre but no damage at all. I start in the spring before there is any weeds at all, put it on, then again in about 3 weeks time, then again in about another month, frequently but very quick on a job on a small scale, spreading it but doing it frequently on sensitive plants. The rest of the garden is treated at normal rates.

Dr. D. Robinson Mr. Chairman, I think there is a lot to be said for putting simazine on in small quantities and often, but putting it on every 3 weeks seems just a little bit like hard work to me.

A. A. Tompsett Just for the observation to those whom moss is an anathema, lenacil would appear to give a very good control, I just thought this might be worth mentioning.

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POSTEMERGENCE CONTROL OF CREEPING SPEEDWELL WITH CHLORTHAL-METHYL

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Summary Numerous tests demonstrated that creeping speedwell (*Veronica filiformis*) can be effectively controlled with postemergence applications of chlorthal-methyl in turf areas. Activity was slow; usually 30 days were required before symptoms of phytotoxicity appeared. Some 85 to 90 percent control was consistently obtained with spray applications of 8 to 10 kg a.i./ha. Granular applications of chlorthal-methyl were markedly less effective than spray applications. Mowing within 1 to 3 days after applications reduced effectiveness. Applications made when creeping speedwell was not actively growing resulted in poor control.

INTRODUCTION

Creeping speedwell, (*Veronica filiformis*) is a perennial broadleaved weed infesting turf growing in Northern Europe, parts of Canada and the Northern United States. The creeping growth pattern of this weed competes strongly with desirable grasses and results in the formation of a dense mat. Hand weeding is a time-consuming and costly method of control. Usual selective preemergent and postemergent herbicide programs are unable to control this weed without inducing injury to desirable grasses.

Chlorthal-methyl provides preemergence control of many annual weeds in a variety of agronomic, ornamental and vegetable crops and turf. This herbicide exhibits little or no effect when applied postemergence to most plants. However, greenhouse screening tests during 1967 indicate chlorthal-methyl to be highly effective when sprayed on actively growing creeping speedwell plants. Results of subsequent field trials are summarized in this paper.

METHODS AND MATERIALS

1. Initial Field Evaluations

Tests were conducted during 1967 in Idaho, Ohio and Washington, U.S. on fairway turf areas containing Highland bentgrass (*Agrostis tenuis*) fineleaved fescues (*Festuca*), Kentucky bluegrass (*Poa pratensis*) and annual bluegrass (*Poa annua*) and known to be infested with creeping speedwell. Dosages of chlorthal-methyl ranged from 6 to 15 kg a.i./ha. Volumes of spray were 400 l/ha. or more. Plot size, determined by sizes of infested areas, ranged from 15 to 280 m^2. Dates of application ranged from early June to early August. Efficacy assessments were made 30 to 60 days after application and calculated on the basis of the degree of infestation at application time versus infestation at evaluation time.

2. Spray Versus Granule Applications

A test was conducted in Olympia, Washington, U.S. on established Kentucky bluegrass to compare the efficacy of spray versus granule applications. Dosages of 6, 12 and 15 kg a.i./ha. in 400 l. of spray and 12 kg a.i./ha. formulated as 5 percent granules were applied on 14 July 1967. All treatments were replicated 4 times using 9.3 m^2 plots. Evaluations were made 54 days after application by comparing infestations at application time and evaluation time.

3. Additional Field Trials

Tests were established in 1968 and 1970 in Holland and Ireland to further evaluate efficacy. Dosages of chlorthal-methyl ranged from 7.5 to 18.7 kg a.i./ha. Volumes of spray were 400 l./ha. or more. A comparison was made of the degree of infestation at the times of application versus evaluation.

4. Time of Application Study

A test to determine the effect of the time of application was initiated in Groningen, Holland on sports field turf containing Kentucky bluegrass (Poa pratensis), ryegrass (Lolium perenne), timothy (Phleum pratense) and red fescue (Festuca rubra). Experimental design was randomized blocks with 4 replications and plots of 10 m^2. Spray applications of 7.5, 9.4 and 11.2 kg a.i./ha. were made on 9 July, 3 August, 2 September and 5 October 1970. (Rainfall during this period was as follows: 9 July to 3 August - 74.3 mm; 4 August to 2 September - 49.9 mm; 3 September to 5 October - 147.6 mm; and 6 October to 3 December - 158.3 mm). Volumes of spray were 500 l./ha. Ratings of efficacy were made on 2 and 14 September; 2 and 27 October; 3 December 1970; 24 June and 12 August 1971. Efficacy was determined by comparing infestations at application time versus infestation at evaluation time.

RESULTS

1. Initial Field Results

The results presented in Table 1 demonstrate that 6-15 kg a.i./ha. of chlorthal-methyl effectively controls creeping speedwell. Mowing shortly after application, sharply reduced effectiveness.

Table 1

Control of creeping speedwell with postemergence spray application of chlorthal-methyl

Location	Application Date	Dosage kg ai/ha	Rating Date	Percent Control (1)
Washington, U.S.A.	1 June 1967	12	29 June 1967	99
Idaho, U.S.A.	5 June 1967	6	8 October 1967	99
Washington, U.S.A.	11 July 1967	12	15 September 1967	85
Ohio, U.S.A.	1 August 1967	9	24 September 1967	40 (2)
" "	"	12	"	50 (2)
" "	"	15	"	65 (2)

(1) Calculated on basis of infestation at application time versus infestation at evaluation time.

(2) Mowed shortly after application.

2. Spray Versus Granule Applications.
The results from the test (Table 2) comparing efficacy of spray versus granule

applications clearly show that 12 kg a.i./ha of chlorthal-methyl applied as granules was inferior to 9 kg a.i./ha. of spray.

Table 2

Spray versus granule application of chlorthal-methyl for control of creeping speedwell (1)

Dosage kg a.i./ha.	Application Method	Percent Control (2)
9	Spray	88
12	Spray	94
12	Granules	50
15	Spray	90

(1) Location - Washington, U.S.A.; Application date - 14 July 1967 and rating date - 6 September 1967.

(2) Calculated on basis of infestation at application time versus infestations at evaluation time.

3. Additional Field Trials

Tests established in 1968 and 1970 (Table 3) again demonstrated a high degree of efficacy of spray applications of chlorthal-methyl for controlling creeping speedwell.

Table 3

Control of creeping speedwell with spray applications of chlorthal-methyl

Location	Application Date	Dosage kg a.i./ha.	Rating Date	Percent Control (1)
Groningen, Holland	11 September 1968	7.5	1 May 1969	98
		13.5		100
		18.7		100
Dublin, Ireland	11 November 1970	7.5	19 April 1971	85
		11.25		90
		15.0		100
Ballygagin, Ireland	1 October 1970	10.0	5 May 1971	98

(1) Calculated on basis of infestation at application time versus infestation at evaluation time.

4. Time of Application

The results obtained from application of chlorthal-methyl at various times during the year are presented in Table 4. The degree of control improved as dosages increased from 7.5 to 11.2 kg a.i./ha. Best control was obtained when applications were made during the period from early August to early October when plants were actively growing and adequate moisture conditions prevailed.

Table 4

Control of creeping speedwell by spray application of chlorthal-methyl

Application Date	Dosage kg a.i./ha.	Percent Control (1)						
		2 Sept.	14 Sept.	2 Oct.	27 Oct.	3 Dec.	24 June	12 Aug.
		%	%	%	%	%	%	%
9 July	7.5	69	66	64	59	55	53	55
	9.4	84	85	80	78	74	66	63
	11.2	90	94	85	85	80	75	70
3 August, 1970	7.5	78	83	73	73	69	73	65
	9.4	80	96	86	84	73	78	78
	11.2	83	96	89	89	80	83	83
2 September 1970	7.5	-	-	69	64	63	65	65
	9.4	-	-	86	90	84	81	80
	11.2	-	-	90	93	91	89	90
5 October 1970	7.5	-	-	-	40	60	88	90
	9.4	-	-	-	40	58	94	94
	11.2	-	-	-	45	66	94	94

(1) Calculated on basis of infestation at application time versus infestation at evaluation time.

DISCUSSION

The results presented above demonstrate that 8 to 10 kg a.i./ha. of chlorthal-methyl effectively control established creeping speedwell when sprayed on actively growing plants. This type of control is quite unique because this herbicide has long been known for its preemergence activity against many annual grasses and broadleaved weeds and its lack of activity against most established plants.

Herbicidal selectivity of chlorthal-methyl to monocotyledenous species is dependent upon differences in locations of the shoot apical meristems in the developing seedlings and proper placement of the herbicide in the soil (Schauer 1970). Field inspections revealed that chlorthal-methyl does not interfer with germination of dodder (_Cuscuta_ spp.), but does prevent the establishment of the plant by stopping circummutation of the developing seedling (Schauer 1969). Localized applications of chlorthal-methyl to coleoptiles of sorghum were most effective when applied to the apical meristemic region (Nishimoto and Warren 1970).

Previous experience and the results of these studies indicate the necessity of having chlorthal-methyl in the shoot apical meristematic regions to effect control of established creeping speedwell. Spray applications deposit a sufficient quantity on the growing plant to ensure activity. Mowing shortly after treatment greatly reduces effectiveness. Chlorthal-methyl granules apparently do not readily adhere to the plants and thus the degree of control is markedly less than obtained with sprays. Perhaps the addition of suitable surfactants may improve the efficacy of spray applications.

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LEAF SURFACE FACTORS

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The activity of a foliage-applied herbicide is influenced by many factors including the efficiency of surface retention, cuticle penetration, translocation from the region of penetration, metabolism, adsorption at metabolically non-active sites together with its inherent effect on biochemical processes. There is abundant evidence in the literature (e.g. reviews by Hull, (1970) and Martin & Juniper, (1970)) that certain of these factors, viz retention and penetration are directly influenced by the nature of the cuticle, particularly the structure and composition of the surface wax. The other factors mentioned may indirectly affect herbicide penetration by influencing the concentration gradient across the cuticle.

1. The morphology of the cuticle

The surfaces of leaves, young stems and to a lesser extent, apical regions are covered by a skin called the cuticle which is composed of a non-cellular membrane formed of materials synthesised in the epidermal cells and subsequently extruded to the surface. There is evidence that even the sub-stomatal cavity is lined with a thin cuticle. (Martin and Juniper, 1970). The functions of the cuticle are to hold the cellular tissues compact and to minimise water loss from the tissues.

Sitte and Rennier (1963) proposed that the cuticle was composed of four layers, namely the outer wax, the cutin, pectin and an innermost region of cellulose which is actually the periclinal wall of the epidermal cells. The structure and composition of these layers has been reviewed by Hull (1970) and Martin & Juniper (1970).

The outer wax embedded within and sometimes extruded over the surface of the cuticle is an important component from the point of view of herbicide retention and penetration. It is composed of complex mixtures which generally contain long-chain hydrocarbons, alcohols, ketones, fatty and hydroxy-fatty acids and esters. Cyclic compounds such as terpenoids are also found.

Wax formation takes place at an early stage in leaf development, continues during expansion and declines in older leaves, presumably due to weathering. There is evidence from work with Beta vulgaris L. that the structure of the wax deposits may change with age. (Bystrom et al, 1968). Environmental factors causing slower growth result in leaves with a thickened layer of surface wax projections while high light intensities (900-5,000fc) produce a waxy bloom on pea leaves (Juniper, 1960). However, Juniper concluded that the variation in light intensity occurring in the field would be unlikely to affect the structure of surface wax.

The cutin is composed of a mixture of saturated aliphatic monocarboxylic, hydroxy-carboxylic and dicarboxylic acids linked by ester, peroxide and ether linkages to form a complex polymer. The pectin layer which separates the cutin and cellulose, is believed to be continuous with the middle lamella of the anticlinical walls of the epidermis, while the epidermal wall which merges into the pectin layer, is composed of cellulose microfibrils.

There is some evidence that cuticle thickness is influenced by environmental factors.

2. Spray retention

The wettability of a leaf surface is influenced by a number of factors including the hairiness and corrugation of the surface (Fogg, 1948a; Linskens, 1950; 1952; a & b), the topography of the epidermal walls and the chemical and physical nature of the wax (van Overbeek, 1956; Crafts & Foy, 1962; Ebeling, 1963). The importance of the wax *per se* is illustrated by the work of Fogg (1948a) who found that on removal of the wax from *Sinapis*, the contact angle fell from 96 to 29°. Similarly, Bukovac and Norris (1967) found that removal of the wax from the isolated pear leaf cuticles increased the adsorption and penetration of NAA.

Leaf wettability is apparently greatly influenced by the sculpturing of the surface wax, this, in turn, being dependent upon the manner in which the various materials have been secreted (Rao, 1963). These wax secretions have been classified according to whether they form a granular coating, projecting rodlets, flat platelets and scales, layers and crusts or liquid or soft wax coatings (Amelunxen, Morgenroth & Picksak, 1967).

Apparently the nature of the superficial wax plays a dominant role when it forms a rough surface with projecting rods or crystalline or semi-crystalline structure (e.g. Mueller, Carr & Loomis, 1954; Juniper & Bradley, 1958; Juniper, 1959 a & b; Thrower, Hallam & Thrower, 1965; Silva Fernandes, 1964; 1965). Using a range of species, the latter showed that while crystalline or semi-crystalline wax repelled water droplets, non-crystalline or smooth wax allowed the droplets to spread. Waxes with significant quantities of long-chain ketones and paraffins were the most difficult to wet, independent of the amount of wax present.

While the superficial wax structure of some species are relatively resistant to weathering, those of many others are delicate and even a fine spray of water can increase wettability. It is not surprising therefore that wind, wind blown soil and heavy rain can damage the surface of the pea plants, increasing their retention of dinoseb and reducing the selectivity between pea and weeds such as cleavers (*Galium aparine* L.) and knotgrass (*Polygonum aviculare* L.) (Dewey, Gregory and Pfeiffer, 1956). Atmospheric pollution may produce changes in the rate of wax rodlet extension (Bystrom *et al*, 1968) and certain soil-applied compounds including dalapon, monuron and TCA have been reported to inhibit surface wax production (Kolattukudy, 1968a).

3. Spray penetration

It is generally considered that the main route of entry of both water and lipid soluble materials is provided by the cuticle rather than by stomata or some other form of pore. Penetration is thought to take place by diffusion, the amount absorbed being dependent upon the duration of treatment, area of contact and the efficiency of surface wetting (Minarik & Weintraub, 1950). These authors suggest that since the cuticle is largely lipoidal, it is likely that non-polar molecules will penetrate more readily than polar. The former may move along pathways believed to be concerned with wax secretion, while polar compounds may traverse pectinaceous pathways (Martin & Juniper, 1970).

Several factors may influence the efficiency of movement of a penetrating compound, including the relative proportion of cutin and wax in the cuticle, the water and lipoid solubility of the compound, and the degree of dissociation of polar compounds (Martin & Juniper, 1970). There is evidence that a balanced lipoid/water solubility favours penetration and translocation and enables a compound to partition from the lipid into aqueous phase in which it will move within the plant (e.g. Kirkwood et al, 1972). Ester formulations generally penetrate more readily than salts (e.g. Morton, Davies & Merkle, 1968, Somerville, 1972); subsequent hydrolysis may render the compound more hydrophilic, thus facilitating movement. Again, there is evidence that chlorination of the ring may increase the penetration of phenoxyacetic acid and benzoic acids into the leaves of Phaseolus vulgaris L. (Sargent, Powell & Blackman, 1969), possibly reflecting the increased lipid solubility of highly chlorinated molecules.

There is substantial evidence in the literature to indicate that, in general, water-soluble compounds penetrate most readily in the undissociated forms. An exception exists in the case of methyl-4-aminobenzene sulphonyl carbonate (asulam) which is much less effective when applied at pH 5 or below, at which levels it is mostly undissociated (pKa 4.9) (Savory, private communication). It has been suggested that below pH 5, a large proportion of the constituent long-chain mono and dicarboxylic acids of the cutin are undissociated and the cutin thus becomes more permeable to anions; above this pH the acids dissociate and the cutin matrix tends to repel anions (Crowdy, 1959). It is possible that in these circumstances, absorption would be enhanced by the use of cationic wetters and certain cations which would neutralise the charge on the cuticle.

4. Preferential sites of entry

Crafts (1961) believed that the cuticle was perforated by micropores which were more or less filled with an aqueous phase and which allowed polar substance to pass while non-polar substances moved by lipoidal pathways. While the work of Scott (1966) and Hall (1967) suggest the presence of such pores, the great majority of studies have failed to demonstrate the existence of large discrete structures corresponding to cuticular pores (Hull, 1970). 'Channels' (average diameter 2.5 mm) which traverse the entire thickness of the adaxial and abaxial cuticle of Plantago major have been reported by Fisher & Bayer (1972). These channels did not appear to be preferentially associated with guard cells or anticlinal walls and are thought to be sites of wax precursor transport.

Stomatal pores would, at first sight, appear to be obvious routes of entry for foliage-applied herbicides. These pores are formed due to the unique structure of the guard cells, turgidity of which determine the size of the aperture; this in turn influences the rate of gaseous diffusion and transpiration. Their role in herbicide penetration is, however, a subject of considerable controversy. Currier and Dybing (1959) and Dybing and Currier (1961) found that herbicides and fluorochrome dye penetrated the stomata of a variety of species, provided a suitable wetting agent was incorporated in the solution. The reduced surface tension apparently enabled stomatal penetration to take place. Using leaf discs of Phaseolus vulgaris L., Sargent & Blackman (1962) found a direct relationship between penetration and the number of stomata, however the relationship was still valid in darkness when the stomatal pores were closed. These authors suggested that preferential sites of entry occured in the guard and subsidiary cells of the stomata. There is some evidence to substantiate this view, since several authors have reported a diminished density of surface wax platelets in the vicinity of the stomata (Juniper, 1960; Holly, 1964; Wortman, 1965). Further, the walls of the guard cells and subsidiary cells are believed to be well endowed with ectodesmata (Franke, 1967) (see later). The fact that plasmodesmata have been demonstrated between guard and accessory cells (Litz & Kimmims, 1968) suggests that a route may exist for the movement of absorbed materials out of the guard cells.

There is also evidence that the regions immediately adjacent to the mid-vein of leaves offer preferential sites for the absorption of aqueous solutions. Norris & Bukovac (1968) working with Pyrus communis L. leaf cuticle found that embedded birefringent waxes decreased to varying extents over the anticlinal wall areas and appeared to be broken over the major veins; these areas corresponded to regions of increased penetration. Leonard (1958) reported that maximum absorption occurred at the base and central part of the bean leaf midrib; thin-walled bundle sheath cells between the epidermis and vein may provide an easy route from the cuticle to vascular system.

Glandular hairs called trichomes, which emerge from the cuticle surface, may also provide sites of entry since they are generally more readily wetted than the remainder of the cuticle (Hull, 1964). Penetration appears to take place through the basal cells which have thinner walls or less cuticle (Hull, 1970). They are also reported to have ectodesmata in their walls (e.g. wheat leaf trichomes, Franke & Panic, 1967) and a particularly high metabolic activity (Miroslavov, 1959).

It has been suggested that ectodesmata (or 'ectocythodes' Franke, 1971) may serve as portals for entry of herbicides and other compounds (Neumann & Jacob, 1968; Franke, 1968; 1971). The actual nature of ectodesmata is a matter of controversy. Franke (1971) has described them as bundles of interfibrillar spaces within the cellulosic walls, made visible under the light microscope by precipitation of mercury formed by reduction of mercuric chloride. These 'spaces' extend between areas of the cuticle, permeable to aqueous solutions, and the plasmalemma of the epidermal cell. Since they are normally filled with an aqueous liquid Franke believes that they can serve as pathways of penetration for water-soluble compounds and cites the work of Panic (1970) who found that the absorption of 2,4-dichlorophenoxyacetic acid (2,4-D) increased with increasing numbers of ectodesmata. Using microautoradiography, Panic showed that the occurrence of silver grains coincided with the localisation of ectodesmata in the outer walls, especially in the guard cells, hairs and along the anticlinal walls. Previous investigations by Franke (e.g. 1969) using onion leaf epidermis revealed a high intensity of ectodesmata in the guard cell walls around the stomatal pores and also in rows, along the anticlinal walls of epidermal cells above the veins. However, this 'classical distribution pattern' disappeared when the leaves were dewaxed (Schonherr & Bukovac, 1970a). Using leaves of Convallaria, Schonherr & Bukovac (1970b) found that sites of mercury precipitation or ectodesmata could be produced experimentally by brushing the leaf surface; they doubt that ectodesmata act as specific pathways of penetration.

5. Penetration of the symplast

Following entry of the cuticle and periclinal wall of the epidermis the penetrating compound, may or may not enter the symplast (the living cytoplasmic continuum). The characteristics which determine the route of movement are still uncertain, but are thought to include molecular size, polarity, solubility, and the affinity which certain molecular configuration have for certain constituents (Hull, 1970). Entry of the symplast involves penetration of the plasmalemma, a membrane generally thought to consist of a central bimolecular leaflet of phospholipid bounded by protein and possibly carbohydrates. Pardee (1968) suggests that the membrane consists of a protein-lipid mosaic with proteins extending through the membrane in certain places, providing specific sites for transport processes. He believes that these are the molecules which discriminate between possible substrates.

In penetrating a membrane with selective permeability, a molecule may have to overcome resistance 1. as it passes into the membrane, 2. within the membrane and 3. as it passes from the membrane into the second aqueous phase. (Hull, 1970). Evidence has been presented which indicates that molecules which form 3 or more H bonds with H_2O are limited by stage 1; non-polar molecules having 7 or more CH_2 groups are limited by stage 3, while those with an oil/H_2O coefficient of 0.1-0.005 are limited principally to stage 2. (Brian, 1964).

It is possible, however, that membrane integrity may not long survive the absorption of a foliage-applied herbicide. For example, there is evidence that 4 hr after treatment in light, 2,4-D causes an apparent breakdown in the structure of the membrane systems of the cells of the epidermis, palisade and mesophyll. After 8 hr, the chloroplasts are distorted (Hallam, 1970). Similar damage to chloroplast membrane systems has been reported for certain other herbicides.

6. Movement within or from the treated leaf

Compounds vary with regard to the route and efficiency with which they are translocated from the treated leaf. Where the herbicide molecule fails to penetrate the symplast then apoplastic movement may take place in the mesophyll via the cell walls, intercellular spaces and the xylem, accummulation taking place at the tip and margins of the leaf in the characteristic wedge-shaped fashion described by Crafts (1964). This type of movement is characterised by the substituted urea and triazine herbicides.

If penetration into the symplast is achieved then short distance transport takes place, possibly via intercellular cytoplasmic strands (plasmodesmata) (Leonard, Donaldson & Bayer, 1968; Shih & Currier, 1969). The ultrastructure of the plasmodesma can be seen for example by reference to the work of Robards (1968). If loading into inner veins is effected then 'long-distance' transport in the phloem may result in effective translocation throughout the plant, accummulation characteristically taking place in the centres of high metabolic activity (the 'source to sink' movement of Crafts, 1961). This type of movement is typically seen in many of the phenoxy-acid herbicides such as MCPA and 2,4-D, aminotriazole and MH.

In addition to apoplastic and symplastic routes of movement some herbicides are believed to move, at least in part, in the vapour phase (e.g. dichlobenil, Verloop, private communication).

The importance of movement in the present context lies in the fact that removal and transportation of herbicide molecules from the inner surface of the cuticle to regions of metabolic activity must presumably enhance the concentration gradient across the cuticle. Further, although the mechanism of long-distance transport is still a matter of conjecture (e.g. Fensom, 1972) it is believed to involve active metabolism, at least in the process of loading of the minor vein. (e.g. Geiger, Malone & Cataldo, 1971). Thus inhibition of energy metabolism by a foliage-applied herbicide may inhibit translocation of assimilates and the herbicide *per se* (e.g. Matlib & Kirkwood, 1970; Matlib, Kirkwood & Smith, 1971; Matlib, Kirkwood & Smith in press, Kirkwood *et al*, 1972), thereby indirectly influencing herbicide absorption.

7. Plant and environmental factors influencing absorption

Leaf age at the time of spraying influences the efficiency of absorption, penetration generally being greater in young leaves (Crafts & Foy, 1962; Sargent, 1965); however, instances of enhanced penetration into mature leaves have been observed and partly attributed to discontinuities and cracks in the cuticle (Kamimura & Goodman, 1964). It has been reported that cotyledons are much more readily wetted and show greater absorption/translocation of ^{14}C-urea and 2,4,5-T than foliage leaves (Fogg, 1947).

Enhanced absorption through the abaxial (lower) as opposed to adaxial (upper) leaf surface has generally been recorded for broad leaved species. This is often attributed to the thinner cuticle and greater number of stomata found on the abaxial surface. However, Norris and Bukovac (1968) discovered that in pear leaves the total quantity of embedded wax was equally present in both upper and lower cuticles and pointed out that the quantity and continuity of molecularly-orientated (birefringent) wax was much greater in the adaxial cuticle. Another factor may be the corrugation of the lower cuticle, noted in some species, increasing the surface area (Davis, Bovey & Merkle, 1968).

With regard to the influence of environmental factors, there is evidence that moisture stress inhibits the absorption of foliage-applied solutes (Currier & Dybing, 1959; van Overbeek, 1956) and translocation of 2,4,5-T (e.g. Davies, Merkle & Bovey, 1968) and 2,4-D (Basler, Todd & Mayer, 1961; Pallas & Williams, 1962). The corollary that foliar absorption is generally enhanced by high humidity is also well documented. For example, Prasad, Foy & Crafts, (1967) found that foliar absorption and translocation of ^{14}C and ^{36}Cl-labelled dalapon was greater at high (88%) rather than medium (60%) or low (28%) humidity. The effects of rain have also been observed, and its effect is dependent upon quantity, the time interval at which it occurs following spray application, the solubility of the herbicide and physical nature of the surface. (Westwood, Batjer & Billingsley, 1960). Light dew or rainfall, insufficient to cause loss by run-off, may enhance absorption of spray deposits (e.g. Bukovac, 1965).

While cuticle penetration is primarily a diffusion process, a metabolic component is involved in penetration of the plasmalemma, consequently the overall process is characterised by fairly high temperature coefficients. Effects of temperature on foliage absorption have been reported for ^{14}C-2,4,5-T in Prosopis juliflora (Morton, 1966) and ^{14}C-dalapon in bean (Prasad et al, 1967).

There appears to be a positive relationship between light intensity and absorption though the results of certain studies are somewhat conflicting. Increased light intensity enhanced the absorptive capacity of Chrysanthemum and Coleus leaves (Bennett & Thomas, 1954); and increased absorption of 2,4,5-T (isooctyl ester) in four woody species (Brady, 1969). Sargent & Blackman (1965) found that increasing light intensity increased the penetration of ^{14}C-2,4-D into bean leaf discs, absorption being particularly rapid at intensities above 1000 f.c. This rapid penetration was inhibited at low temperature and reversed in darkness suggesting that absorption was influenced by a metabolic component which could become limiting under certain conditions.

Sargent & Blackman (1970a) subsequently reported that the pattern of penetration of chloride ions into the abaxial leaf surface of Phaseolus vulgaris L. had similar features to those of 2,4-D (Sargent & Blackman, 1969), 2,2,-dichloropropionic acid (dalapon) (Sargent & Ortino Martinez, 1969) and 4-amino-3,5,6-trichloropicolinic acid (picloram) (Sargent & Blackman 1970b). They concluded that penetration of chloride ions into the abaxial surface of young leaves was largely determined by a membrane system which decreased in importance as the leaf matured and the cuticle thickened. In the case of the adaxial surface, the cuticle is apparently a major barrier to penetration even in very young leaves and relatively high light intensities had no effect.

Conversely, there is evidence that activity of bromoxynil, ioxynil and DNOC may be inversely correlated with solar radiation (Riepma, 1960). Again Brian (1967) found that in vivo penetration of paraquat and diquat into leaves of Beta vulgaris and tomato plants was greater in dark than light suggesting that penetration was through the cuticle. Davis et al (1968) report that absorption of picloram was inversely related to light intensity. Apparently the effect of light intensity is dependent upon humidity, when humidity is adequate an increase in light intensity enhances absorption. (Gustafson, 1956; Barrier & Loomis, 1957; Sargent & Blackman, 1962; Middleton & Sanderson, 1965).

To summarise, spray retention is largely dependent on the physical and chemical nature of the cuticle wax and this in turn is determined by the stage of leaf development or region on a particular leaf and climatic conditions. Absorption is largely cuticular with preferential sites of entry associated with cracks, aphid punctures, veins, guard cells and subsidiary cells of the stomata, trichomes and other features of the cuticle. Ectodesmata may act as portals for entry of aqueous solutions. Factors such as the degree of dissociation, partition coefficient and formulation of the herbicide may greatly influence uptake by influencing solubility in the cuticle. Once inside the cuticle, the fate of the molecule is largely dependent upon whether it enters the symplast or remains in the apoplast. Penetration of the epidermal plasmalemma may enable intercellular movement within the mesophyll and subsequent loading into the minor vein generally resulting in a 'source to sink' type of movement. Transport away from the region of entry presumably enhances the concentration gradient of herbicide molecules across the cuticle, as will metabolism or fixation at non-metabolically active sites. All of these factors may be interrelated to create a complex situation which may be extremely difficult to interpret. Further, climatic factors such as temperature, humidity and light may not only influence the process of retention and penetration directly, but also indirectly due to effects on the plant prior to herbicide treatment.

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FACTORS AFFECTING EFFICACY OF FOLIAGE-APPLIED HERBICIDES
APPLICATION FACTORS

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INTRODUCTION

Dr. Kirkwood's excellent review of leaf surface factors affecting the activity of foliage-applied herbicides has taught us a great deal about what happens when a herbicide reaches its primary target, the leaf surface, and proceeds to enter the treated plant. Arrival of the herbicide at the leaf surface requires an effective delivery or application system.

Application efficiency is influenced by two main variables; these are the composition of the herbicide formulation and the method of application.

Whilst the user has some control over the application of foliage-applied herbicides, usually as a spray, he has no control over the composition of the formulation provided by the manufacturer.

FORMULATION

What do we mean by formulation? To some the term formulation merely covers the difference between salts and esters of any particular herbicide. This definition is no longer adequate when it is remembered that 2,4-D ester is sold under at least eleven different approved labels in the U.K. alone. Although many of these products will contain similar esters of 2,4-D and a few may even have the same composition, it is more than likely that these products represent a wide variation in the nature of the other formulation components.

Table 1 shows an analysis of all herbicide products approved under the Agricultural Chemicals Approval Scheme (1972).

Table 1

Herbicide products approved under the United Kingdom Agricultural Chemicals Approval Scheme - 1972

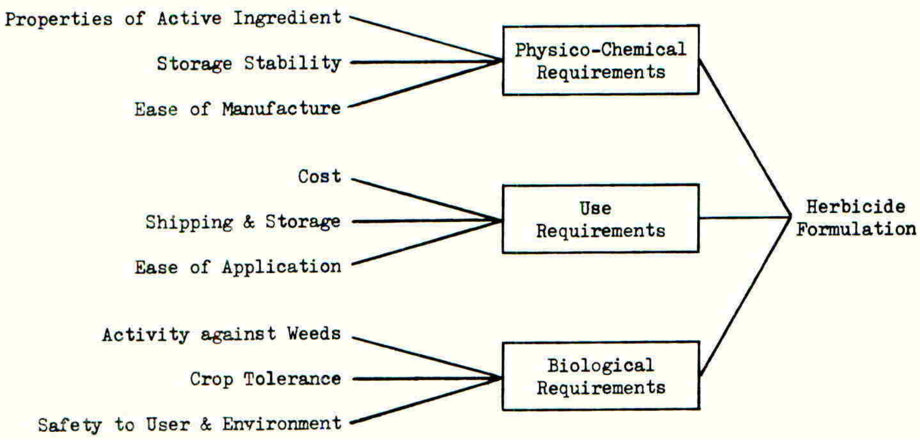
Type of Formulation	Mode of Action of Herbicide			Total
	Contact & Translocated	Contact & Residual	Residual	
Aqueous Solution	209	-	-	209
Emulsifiable Concentrate	60	17	12	89
Wettable Powder	5	25	31	61
Soluble Powder	30	1	-	31
Granules	-	-	6	6
Oil/Water Emulsion	1	-	-	1
Suspension	-	2	-	2
Total	305	45	49	399

Of a total of 399 approved herbicide products about 75% are intended for foliar application; of these nearly 70% are formulated as aqueous solutions, the majority of which contain salts of phenoxy-alkanoic herbicides. This still leaves about 100 foliage-applied herbicides in four different types of formulation.

The choice of formulation to be used for any particular herbicide depends on the requirements indicated in Fig. 1. Although inter-related they may be grouped under three main headings:-

Fig. 1

Requirements influencing formulation composition



It must be emphasised that the composition of any commercial herbicide formulation is a compromise involving consideration of all these requirements. Thus modification of one of the components of the formulation, perhaps to improve crop tolerance, can succeed only if it is consistent with the physico-chemical and use requirements.

Assuming an acceptable level of biological activity the most important requirement in determining formulation composition is, in nearly every case, the need to disperse the compound in water. Therefore the ideal compound, from the formulator's point of view, should be a low viscosity liquid with a very high solubility in water. It should be non-corrosive, non-toxic and non-inflammable; it should also be tolerated by crop plants when applied in high doses. Apart from being rather corrosive, water fits this ideal very well; unfortunately, no herbicide comes within "miles" of meeting the specification. Hence the need to formulate.

Fig. 2 shows the nominal composition of six different types of formulations which may be used for foliage-applied herbicides.

Fig. 2

Nominal composition of formulations of foliage-applied herbicides

	Formulation	Components	Form in which used
Liquid Formulations	Emulsifiable Concentrate	Active Chemical Emulsifier Organic Solvent	Emulsion
	Aqueous Concentrate	Active Chemical Wetting Agent Solvent (Water)	Solution
	Suspension Concentrate	Active Chemical Suspending Agent Suspending Medium Wetting or Emulsifying Agent	Dispersion or Emulsion
Solid Formulations	Soluble Powder	Active Chemical Soluble Carrier	Solution
	Wettable Powder	Active Chemical Suspending Agent Wetting Agent Inert Carrier	Suspension

The solubility of the herbicide in water and organic solvents is the main physico-chemical parameter influencing the choice of formulation type.

Water soluble herbicides

Many herbicides are insoluble in water. However, their salts may be very soluble. For example, asulam sodium salt is more than 40% soluble, whilst the free acid is only 0.5% soluble. Others, like the sodium salt of ioxynil, which is only 5% soluble in water, may require the addition of polar co-solvents to achieve a commercially acceptable concentration of active ingredient.

Other readily soluble compounds are formulated as soluble powders or granules. These formulations may also include flow promoting or anti-caking agents.

Common additions to both types of water soluble herbicide formulation are surface active agents to increase the wetting power of sprayed solution and sequestering agents to prevent precipitation of the active ingredient by hard water cations.

Herbicides soluble in organic solvents

A herbicide which is insoluble in water may be sufficiently soluble in an organic solvent to be formulated as an emulsifiable concentrate. For this purpose it is important to use solvents which are themselves insoluble in water to avoid precipitation of the active ingredient when the formulation is added to water (Norris 1972).

Solvents in common use for the formulation of foliage-applied herbicides include normal and isomeric paraffins used mainly in the formulation of phenoxy-alkanoic ester herbicides. Compounds not soluble in paraffinic solvents may be formulated in petroleum-derived aromatic solvents which are on the whole capable of dissolving much greater concentrations of herbicide.

The preparation of an emulsifiable concentrate formulation from a simple solution of herbicide in an organic solvent requires the addition of an emulsifying agent.

McCutcheon (1971) lists about 4,000 surface-active agents, the majority of which could be used as emulsifiers in herbicide formulations. The selection of emulsifiers is a good example of that "area where science and art meet" mentioned some time ago by Heywood (1966). Many attempts have been made to rationalise the process of emulsifier selection. The most widely used of these is the Griffin (1949 and 1954) hydrophile-lipophile balance or HLB system.

Beerbower and Hill (1971) are now developing an alternative to the HLB system known as the cohesive energy ratio (CER). So far the system has been developed for non-ionic emulsifiers only; it will be interesting to see how the CER system deals with ionic emulsifiers which form at least 50% of those used in agricultural formulations.

Herbicides insoluble in both water and organic solvents

Some herbicides are soluble in neither water nor in acceptable organic solvents. Generally such intractable compounds are formulated as wettable powders in which the active ingredient is finely divided by milling before or after admixture with a powdered carrier. Suspending agents and possibly wetting agents may be added at this stage.

Ease of preparation and field performance are dependent on the method used to effect size reduction (Vine 1966, Miles and Goette 1968, and MacDonald 1971).

An alternative means of dealing with insoluble herbicides is to formulate them as emulsifiable or dispersible suspension concentrates, or "flowables" as they are sometimes called.

In suspension concentrates the finely divided herbicide is dispersed in a fluid medium which may be water or an oil. On addition to water, aqueous suspension concentrates form simple dispersions of the herbicide. Oil based suspensions form oil in water emulsions in the manner of emulsifiable concentrates, except that the herbicide is suspended rather than dissolved in the oil phase. It is necessary to structure or thicken the suspension to prevent or limit gravitational settling of the herbicide. Similar structuring is necessary with aqueous suspension concentrates. Choice of the correct structuring agent can give products which are thixotropic (Martin et al 1969).

This brief look at various types of herbicide formulation has shown that the choice of formulation type is dictated largely by the physico-chemical properties of the herbicide. Cost and manufacturing requirements may dictate some detailed modification of the formulation. For example, it may be necessary to replace obsolete or expensive emulsifiers or other formulation components.

Use requirements

Use requirements which influence the composition of the herbicide formulation include shipping and storage. For shipping purposes the prime consideration, apart from any inherent hazard arising from the active ingredient, is the possibility of fire risk which is assessed by measuring the flash-point of the formulation. Special stowage conditions and therefore increased freight costs apply to all "highly inflammable" materials, that is those with a closed cup flash-point lower than 73°F (23°C).

Accelerated storage tests at elevated temperatures can give only approximate information on probable shelf life. Rogers (1970) suggests that such information may be only ± 20% to 50% accurate. All shelf life data are of limited value if product/pack interactions are not taken into account by testing formulations in commercial packs. The stability of the formulation can be equally "strained" by storage at very low temperatures. With aqueous concentrate formulations, glycols or alcohols may be used to depress the freezing point. The freeze/thaw characteristics of any formulation require very careful examination to avoid wrong predictions about low temperature storage stability being made as a result of the occurrence of super-saturated solutions.

Ease of application

This is perhaps the "consumer" end of the formulation use chain.

Food and Agricultural Organisation specifications for plant protection products describe methods for assessing ease of dispersion of various formulations together with other methods for assessing storage stability, emulsion stability, suspensibility, etc. These specifications are finding wider acceptance in countries purchasing agricultural chemical formulations from the United Kingdom and will undoubtedly form the basis of even more purchasing specifications.

Foaming of spray solutions can be a nuisance to farmers. Unfortunately, foaming is as much an inherent property of surface active agents as is wetting (Tschakert 1967). Foaming can be suppressed or eliminated altogether by the use of anti-foaming agents such as silicones or some of the higher alcohols. Replacement of all or part of the wetting agent by the low foaming ethylene oxide/propylene oxide co-polymers may also help but most methods result in an overall loss of wetting power, and an increase in the cost of the formulation.

Compatibility problems are less common with herbicide sprays than with horticultural sprays. Nevertheless, increasing quantities of herbicide are being applied in conjunction with fertilizer solutions containing high concentrations of inorganic salts. Townsend (1968) noted a reduction of herbicide activity with such mixtures. On the other hand, Turner and Loader (1972) have now demonstrated synergistic herbicide activity with various ammonium salts and, in some cases (Turner 1972), with alkyl phosphates. Cereal crops are now more frequently sprayed for the control of fungus diseases; this will undoubtedly lead to a need for mixed herbicide/fungicide sprays.

Biological effects

The foregoing examination of non-biological factors shows how the composition of any herbicide formulation is circumscribed by purely physico-chemical considerations.

There are still non-herbicidal biological requirements to be met. The most important is that of safety to man.

Apart from the possibility of skin irritation resulting from prolonged exposure to undiluted products, the wetters and emulsifiers used in herbicide formulations are generally safe chemicals.

Solvents pose some problems, not so much because some are known to be somewhat toxic if administered in quantity (Browning 1965) but because of the unpredictable effect they may have in enhancing any intrinsic toxicity of the dissolved or suspended herbicide. However, such effects become apparent during routine toxicological testing of herbicide products and are soon corrected.

The detergents industry, having some time ago switched from branched chain alkyl-aryl sulphonates to the more readily bio-degradeable straight chain homologues, may be faced with the possibility of making a similar change in the alkyl and alkyl-aryl ethyloxylates used so widely as emulsifiers and wetters in agricultural formulations (Warner 1972). Bio-degradeable equivalents of these materials are now available for evaluation but it is too early to say whether they will be satisfactory substitutes or even whether they will be needed. The quantities released into the environment are, after all, extremely small when compared with detergent sources.

APPLICATION

The effects of application factors on herbicidal activity are so inextricably linked with the type and composition of the herbicide formulation that it is difficult to consider one without the other. Each component of the formulation plays its own part in influencing the activity of the herbicide. Of these, the two most important are surface-active agents and solvents. Other application factors influencing activity are spray volume and droplet size.

Surface-active agent effects

Of all herbicide formulation components which affect biological activity, the water-soluble surface-active agents, or surfactants or wetters, have received the greatest attention.

The effect of surface-active agents on the activity of most water soluble herbicides, from 2,4-D to paraquat, has been studied in detail. The voluminous literature generated by these studies has been reviewed by Foy and Smith (1969), who concluded that the main role of wetters in improving the activity of water-soluble herbicides was concerned with penetration of plant cuticle. They also concluded that the transport of herbicide within the plant was unaffected by the use of wetters.

Hull (1970) draws attention to the positive relationship of herbicidal activity of 2,4-D to wetter HLB value demonstrated by several workers, although others have found a negative correlation with paraquat. Smith et al (1966) and Jensen (1965) have demonstrated a three to five-fold increase in the activity of water-soluble herbicides resulting from the addition of wetters.

Many investigations have shown that the addition of wetting agents to sprays applied to broad-leaved and grass species can result in as much as a ten-fold increase in the quantity of spray retained by treated plants, followed by a proportionate increase in herbicidal activity (Ennis et al 1952, Blackman et al 1958, Davies et al 1967 and Hibbitt 1969). It seems likely, therefore, that much of the increase in herbicidal activity noted by earlier workers may well have resulted from increased spray retention. One practical consequence of this increase in spray retention is a possible reduction in the weed/crop selectivity margin, although this may be corrected by beneficial differences in spray distribution as with the use of asulam to control Avena fatua in linseed flax (Hibbitt 1969).

Many workers have noted that maximum improvement in biological effect of foliage-applied herbicides is obtained by use of from 0.5% to 1.5% wetter (Martin and Hull 1971, and Bayer 1971). This range of concentrations is well above the normal critical micelle concentration (C.M.C.) for surfactants. The C.M.C. is usually in the region of 0.1% to 0.2%. It is the concentration at which surface tension reduction and other surfact-active effects are at a maximum (Moilliet et al 1961). Spray retention, involving droplet impingement on, and possible reflection from, leaf surfaces, is undoubtedly a surface activity conditioned phenomenon (Fogg 1947).

Formation of a spray containing droplets with a uniform diameter of 500 µm involves the production of 120 cm^2 of liquid/air interface for every cubic centimetre of fluid atomized. It is generally accepted that surface-active effects result from the concentration of molecules of surface-active agents at the phase interface.

It has been shown that the speed with which surfactant molecules concentrate at a solution/air interface is proportional to their concentration in the bulk fluid (Schwartz and Perry 1949). Redistribution times for dilute solutions of surfactants can be very long; Moilliet et al (1961) mention that solutions at the C.M.C. may take hours to reach surface-active equilibrium. It would not, therefore, be surprising if a droplet containing a low concentration of wetter failed to develop full surface activity by the time it reached the leaf surface. This may explain why unexpectedly high concentrations of surface-active agents are required to achieve maximum spray retention and herbicide activity.

When the spray has reached the leaf surface it is likely that the absorption effects discussed by Foy and Smith (1969) come into operation. Enhanced absorption is likely to be dependent on surfactant concentration, particularly if solubilisation of the herbicide is necessary to pass the cuticular barrier. Effective solubilisation usually requres the concentration of surface-active agent to be about five times that of the solubilised compound (Mulley 1964). Thus, 8 oz herbicide dissolved in 50 gallons of water to give a 0.1% solution may require at least 0.5% surfactant for complete solubilisation.

Solvents/Oils

Three uses of oils are known in herbicide application technology:

a) as herbicides, applied undiluted for total and selective weed control;

b) as solvents or carriers for herbicidal chemicals;

c) as emulsifiable oils containing an emulsifier for addition to aqueous solutions or dispersions of herbicide formulations.

The first of these applications arose from the early use of undiluted, crudely separated petroleum fractions for total weed control. Later, more highly refined petroleum fractions, such as Stoddard solvent, were used for the selective control of weeds in carrots (Crafts and Reiber 1958). Many attempts were made during the 1940's and 1950's to relate the herbicidal activity of oils to their chemical composition. It was generally concluded that in petroleum fractions aromatic compounds are among the most phytotoxic, whilst aliphatics are comparatively safe

(Harris et al 1952 and Van Overbeek and Blondeau 1954). Leonard and Harris (1952) used crop plants (cotton and soya) and weeds (Cyperus rotundus, Sorghum halepense, etc.) to assess the phytotoxicity of a very large number of non-aromatic hydrocarbons applied undiluted at a rate of 5 gal/ac. They concluded that selective weed control in soybean should be possible by using low boiling straight chain paraffins applied when both crop and weeds were at an early growth stage. On the whole the olefines were most phytotoxic to both crop and weed species, whilst branched chain paraffins were among the least toxic compounds tested.

The introduction of selective chemicals, including the dinitro compounds and phenoxy-alkanoics, led to the development of emulsifiable concentrate formulations which largely replaced wholly oil sprays. Nevertheless, the information on oil phytotoxicity gained by earlier workers is still valuable when selecting solvents for emulsifiable concentrate formulations.

The range of petroleum products available for agricultural formulations has been reviewed by White (1970), who suggests that the naphthenic compounds should be given more consideration as a phytotoxic component.

With the commonly used paraffinic solvents, unsulphonateable residue (U.R.) has become accepted as an index of phytotoxicity. Solvents with a high U.R. value contain a low concentration of unsaturated hydrocarbons such as aromatics and olefines, although, contrary to earlier authorities, Hunt and O'Neil (1968) state that olefines are rarely found in petroleum products.

The remaining use of oils in herbicide application involves the addition of from 0.5% to 10% by volume of emulsifiable oil to aqueous sprays of water-soluble herbicides or aqueous dispersions of wettable powders. Twenty years ago Ennis (1951) showed that it was possible to increase the phytotoxicity of 2,4-D and 2,4,5-T by emulsifying 5% of a non-phytotoxic oil (deobase) or diesel oil into the spray fluid. It has also been shown that the addition of 10% oil can increase the activity of 2,4-D amine and a 2,4-D ester against beans (Phaseolus vulgaris) (Gertsch 1952).

Aya and Ries (1968), using various paraffinic and naphthenic oils as 10% emulsions, improved the activity of amitrole against Agropyron repens to a greater degree than is usually achieved with ammonium thiocyanate. In view of the low cost of ammonium thiocyanate it is unlikely that the oil addition would offer any economic advantage.

Recently there has been an even greater interest in the addition of emulsifiable oils to herbicide sprays. In the United States this has been centred on attempts to improve the post-emergence activity of atrazine applied for weed control in maize and grain sorghum. Using 1 to 2 lb atrazine plus 1 to 2 gallons of oil emulsified in 15 to 20 gallons of water per acre, it has been shown that addition of oil improved the control of grass weeds without reducing yields of maize (Bandeen 1968, Worsham 1969, and Almodovar and Ilnicki 1971). Similar findings have been reported from New Zealand (Cumberland et al 1970).

Studies using ^{14}C-labelled atrazine have shown that commercial emulsifiable oils increase the foliar uptake of the herbicide by both grass and broad-leaved species; oil additions also increase spray retention on grasses by a factor of three to five (Strand 1969, Schrader 1970 and Peacock 1971).

An interesting "re-cycling" of oil is described by Coats and Foy (1971) who found that vegetable oils improved the uptake of atrazine and of 2,4-D by the crop species in which the oil originated. Strand and Behrens (1970) noted a negative correlation between the solubility of atrazine in specific oils and the foliar uptake of ^{14}C-atrazine applied in emulsions of the oils. This suggests that atrazine follows a hydrophilic route into the leaf tissue.

Whilst the addition of emulsifiable oils seems to improve the post-emergence activity of a primarily pre-emergence herbicide such as atrazine, the addition of similar oils to the contact herbicide MSMA used for weed control in cotton reduced both the weed control and crop yields (Hogue 1970).

There is clearly a need for more work of a less empirical nature to establish the role of oils in oil/herbicide mixtures. Some work on these lines was carried out by Peacock and Dybing (1969) who list a number of physico-chemical properties of oils which were positively correlated with the enhancement of atrazine activity against Setaria viridis and Sorghum bicolor. Increased activity of atrazine plus paraffin oil was associated with high distillation temperature, refractive index and percentage aromatics, etc. Negative correlation with activity was found for the same properties when using naphthenic oils which were on the whole less effective than the paraffins.

The emulsifiable oils used in many of these experiments probably contain about 5% emulsifier. Spray solutions containing 2 gallons of oil in 20 gallons of water will therefore contain 0.5% of a surfactant, a concentration already shown to have considerable effect both on spray retention and herbicidal activity. The use of herbicide/surfactant controls would have helped define the true effect of oil additions.

Shellborne and Hull (1971) improved the activity of picloram and 2,4,5-T against Prosopis juliflora (velvet mesquite) by formulating in a mixture of iso-paraffin, glycerol and dimethyl sulphoxide (DMSO). The brush killing effect of 2,4,5-T has also been increased by the use of DMSO (Hull and Saunier 1970). The role of individual solvents in these mixtures is not clear but DMSO has been shown to improve the absorption of many chemicals through both plant and animal cuticle (Smale 1969).

Non-phytotoxic petroleum-derived iso-parallins are currently in vogue with research workers in the United States. They have been used undiluted at rates of 5 - 20 gal/ac as carriers for selective herbicides.

Post-emergence applications of chlorpropham for the control of Setaria faberii and Ipomoea hederacea in onions were considerably improved when the herbicide was applied in an iso-paraffinic oil rather than water. Onions were moderately tolerant of 4 lb chlorpropham applied in 10 to 20 gallons of oil per acre.

Where comparative data are given, the effect of most successful oil additions is to reduce the rate of herbicide required to achieve acceptable weed control by one half or one quarter.

It would be interesting to know whether the reduction in herbicide dose-rate made possible by some of the oil or oil/water systems would be sufficient to meet the cost of the oil. The cost of, say, 1 lb atrazine would be about equal to the cost of between five and ten gallons of oil, depending on quality. It appears, therefore, as if oil costs may be sufficiently low to justify looking for uses with foliage-applied herbicides.

It may be possible, of course, to achieve the same improvement in herbicidal activity by using high concentrations of wetter. The wetter may more than compensate for the absence of oil as was the case reported by Mindreboe and Brown (1969) in which chloroxuron plus wetter was more effective against a number of grass and broad-leaved weeds than was a chloroxuron/iso-paraffinic oil mixture sprayed undiluted.

It should be remembered that the surface tension of most oils, like that of wetter solutions, is much lower than that of water; this undoubtedly contributes to the observed improvements in herbicidal activity resulting from the use of oils.

Spray characteristics

Conventional tractor-mounted boom sprayers are widely used for the application of herbicides in arable crops using spray volumes of from 4 gal/ac to 100 gal/ac, although volumes above 60 gal/ac are unusual (Byass 1968).

Aerial applications of herbicides in spray volumes below 5 gal/ac are becoming increasingly common. According to Schedler (1969) herbicide application forms a substantial proportion of the total area sprayed from the air in many countries. For example, U.S.A. - 18%, Argentina - 50% and U.S.S.R. - 10%.

Modification of spray properties following the addition of a surface-active agent has already been shown to have a marked effect upon spray retention, distribution and subsequent herbicidal activity. Effects of the same magnitude may be achieved by varying spray volume and droplet size.

The classical work of Blackman *et al* (1958) demonstrated that, within the spray volume range 12.5 to 127 gal/ac, spray retention by plants with difficult-to-wet leaves (*Pisum sativum* and *Hordeum vulgare*, both of which have large contact angles) was linearly related to spray volume. The relationship between spray volume and retention for plants with easily wetted leaves (*Brassica alba* and *Helianthus annuus*, low contact angle) was curvilinear and tended to reach a maximum at 45 to 89 gal/ac depending on species.

Herbicidal activity of translocated, phenoxy-alkanoic herbicides was linearly proportional to the quantity of herbicide retained. The rather sparse distribution of herbicide droplets at low spray volumes was presumably compensated for my movement of the herbicide within the plant. The less well translocated dinoseb was most active when better distributed as a high-volume spray.

This and other related work was reviewed by Holly (1964), who concluded that, in a situation requiring the control of easily wetted broad-leaved weeds in a poorly wetted crop, selectivity could be decreased by two opposing effects; at high-volumes because of loss of spray from weeds by run-off and at low-volumes by retention of small droplets by crop. Both these effects may be exacerbated by the use of wetters in the spray. Holly (1970) has also pointed out that farmers seem to be too willing to continue the practice of hauling unnecessarily large volumes of water over their fields.

More recent work on the effects of spray volume on herbicide activity is not entirely unanimous in its conclusions. Although there is further evidence that low-volume sprays give greater retention on both weeds and crop (Bisschof 1970) other workers have found that not only can low volume sprays result in reduced crop tolerance, but in some cases weed control may be reduced (Gosset and Riech 1970). Low spray volumes may also result in greater spray drift (Tisler 1970). It seems very unlikely that it will ever be possible to meet the call made by Tilley (1971) for one standard spray volume and one dose rate for farm chemicals.

Many commercial herbicides are, of course, successfully applied in crop/weed situations in volumes as low as 5 gal/ac by ground crop sprayer and in 2 - 5 gal/ac from the air (Haagsma 1971 and Soper 1972).

Among the problems associated with low volume aerial spraying of herbicides are spray drift and droplet evaporation. Theoretical and practical aspects of spray drift and evaporation were considered by Seymour (1969), who also took into account evaporation of the drifting droplets. He concluded that aqueous droplets with a diameter of 100 µm or less constitute the major source of drift potential. Drift was reduced by the use of polymers and invert emulsions which increased spray fluid viscosity and reduced evaporation. These experiments were given practical expression by Laning and Byrd (1971) who demonstrated, by means of bio-assay, effective control of 2,4-D spray drift by using thickened sprays.

Under practical conditions reduction in spray volume is usually accompanied by a reduction in spray droplet size which has been shown to have a profound effect on spray retention and subsequent activity. Buehring et al (1969) investigated the effect of droplet size in some detail. They applied a number of herbicides to various crop and weed species in sprays ranging in droplet size from 300 µm to 1208 µm. Large droplet sprays were generally less damaging to the plants in the following crop or weed/herbicide combinations - paraquat/cotton, diuron/Abutilon sp. and fluometuron/oat. No droplet size effect was evident with MSMA/bean or amitrole/Ipomoea sp. This work confirmed earlier indications that droplets of 400 µm to 500 µm were most effective for paraquat sprays (Douglas 1968). Uniform droplet size sprays of phenoxy-alkanoic herbicides applied to Phaseolus vulgaris showed a five-fold increase in activity when spray droplet size was reduced from 500 µm to 125 µm (Hurtt et al 1969).

Ennis and Williamson (1963) used a pneumatic apparatus which generated droplets of constant diameter to examine the effects of droplet diameter variation on the herbicidal activity of several phenoxy-alkanoic esters by measuring yield inhibition for a number of crop plants. Within the diameter range 100 µm to 800 µm yield inhibition for all species was approximately inversely proportional to droplet diameter. The greater activity of the smallest droplets was ascribed to more efficient absorption of herbicide from more uniformly distributed deposits. The authors dismiss the equally likely possibility that the smaller droplets were better retained by the test species, particularly wheat and flax.

Some of our own work has shown that it is possible to increase the quantity of herbicide retained by both Sorghum halepense and Pteridium aquilinum (bracken) by spraying with reduced volumes of water. In both the following examples herbicide deposits were calculated following determination of the quantity of dye recovered from plants treated with a dyed spray solution.

Greenhouse experiments with S. halepense showed that although there was a four-fold increase in volume of spray retained when spray volume was increased from 5 gal/ac to 90 gal/ac, there was a four to five-fold reduction in the quantity of herbicide retained (Fig. 3).

Similarly, when bracken was sprayed in the field at 30 gal/ac using a tractor and at 4 gal/ac using a helicopter, the quantity of herbicide retained following aerial application was almost treble that deposited by the tractor (Fig. 4).

Fig. 3

The effect of spray volume on the retention of asulam sprays by *Sorghum halepense* (Potted established plants sprayed with 2 lb/ac asulam when the foliage was 24 to 30 in. high)

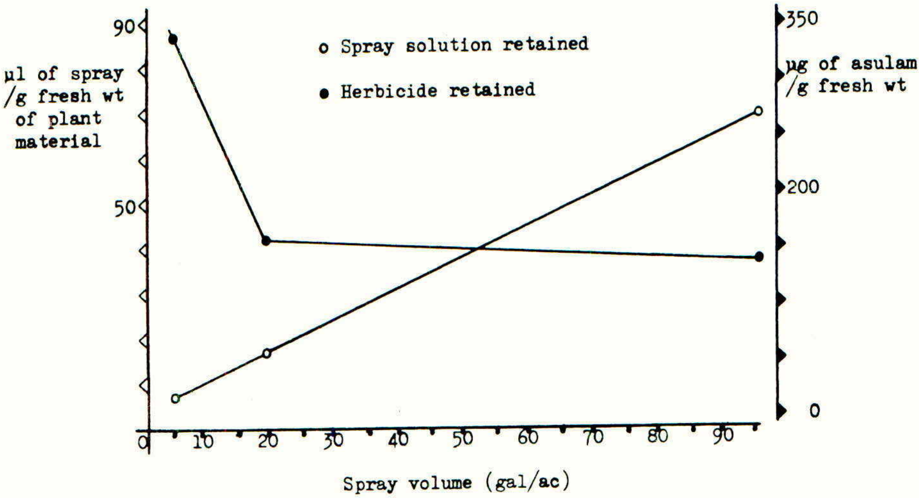
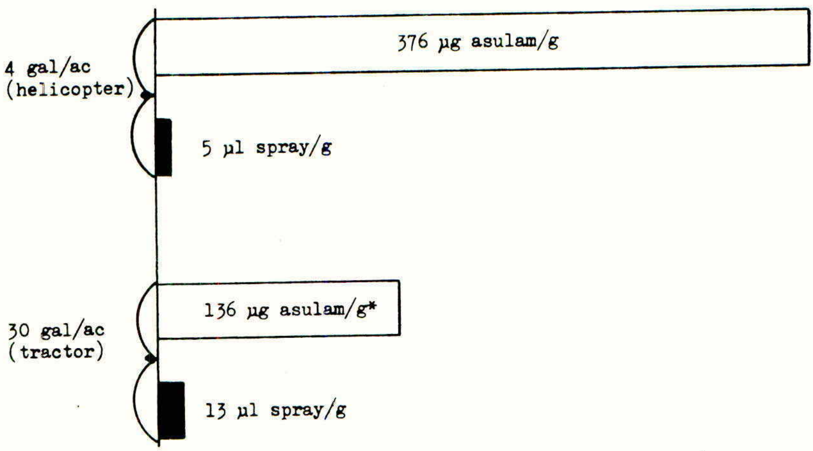


Fig. 4

The effect of spray volume/application method on the retention of asulam sprays by *Pteridium aquilinum*. (3 lb/ac asulam applied to a natural stand of bracken 3 to 4.5 ft high. Data expressed as retention per gramme of plant fresh weight)



* Calculated from applications of 4 lb asulam/ac.

These experiments and the experience of other workers leads to the conclusion that for each plant species there is a maximum spray fluid retention capacity which is dependent on both plant factors, such as growth stage, water stress, etc., and spray factors including volume, droplet size, dynamic surface tension, etc. A better knowledge of the interdependence of these factors is an indispensable prerequisite to our understanding of the application factors affecting the activity of foliage-applied herbicides.

Future developments

Future developments will include work along two fronts, the first in the field of formulation.

There is some interest in the possibility of micro-encapsulation of agricultural chemicals to allow better control over their rate of release at the site of action, to reduce losses due to weathering and evaporation and possibly to reduce contamination of the environment and toxicity to spray operators. At present micro-encapsulation techniques are expensive but there is no doubt that in the future, as increased use reduces manufacturing costs, micro-encapsulation of herbicides will become a practical proposition (Flinn and Nack 1967 and Luzzi 1970).

Controlled release of herbicides is also one of the objects of a process involving the polymerisation of herbicide acids, etc., with macro-molecules such as cellulose and lignin derived from wood and bark or proteinaceous wastes (Alan et al 1971). In brushwood control experiments carried out by Bovey et al (1972), polymerised forms of various herbicides including 2,4-D and 2,4,5-T were similar in activity to conventional formulations.

Application techniques of the future include the use of foam nozzles to allow the spraying of herbicides as fairly fluid but stable foams; expansion rates of 4 to 7 are common. Advantages claimed for this method include low spray drift and visible spray deposit as a check on uniformity of cover (Clack 1972).

Ultra-low-volume sprays have been used for application of insecticides for many years. Recently, ULV applications of various phenoxy-alkanoic herbicides have been made for the control of weeds in pastures and for the control of seedling trees (Maas 1971 and Hovind et al 1968). The main obstacle to the growth of ULV herbicide applications is, of course, the problem of spray drift, but with many ULV spray generators it is possible to produce coarse droplet sprays, although spray distribution tends to be rather poor. As mentioned earlier, this may be less of a problem with translocated herbicides.

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TRENDS IN CHEMICAL AND CULTURAL WEED CONTROL SYSTEMS

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INFLUENCE OF CROP SEQUENCE AND MECHANISATION CHANGES ON WEED PROBLEMS

A system of farming considers the whole farm, the integration of crops, cultivations, planting, harvesting, storage and marketing. Weed control has an influence on all these aspects of the system; conversely weed control will itself be affected by the way in which these particular activities are carried on. Few farmers practise a rotation in the accepted sense, rather do they have a sequence of crops perhaps in some cases following a broad pattern and including crops which provide an entry for other crops such as Winter Wheat. Satisfactory conditions for winter wheat are provided by potatoes, ploughed out grass or other similar crops; these provide a break from soil borne cereal diseases, leave fertiliser residues and control certain weeds, they also leave the soil in a suitable condition for the following crop. The sequence of operations and the demand for labour on the farm is also influenced by the sequence of cropping and the balance between the "entry" crops and the cereal acreage is clearly an important one. A rigid rotation which preordained the crop in each field for years ahead did more than provide a balanced farm and control of disease - it controlled weeds, and at the same time developed a weed flora for the farm depending on the soil type and the rotation. A farmer practising a strict rotation achieved a balance with the weed flora on his farm. Modern crop sequences have brought about changes in weed problems and weed control systems have to be built into the new situation if profitability is to be maintained. Because rotations are no longer so rigid we find that despite, or perhaps because of, the availability of herbicides very special weed problems occur which appear to have no ready solution. The fact that weeds can be controlled has led to a change in farming systems and these new systems have themselves given rise to new weed problems.

The striking feature of present day farming is of course the reduction in the labour force which has taken place and is still continuing. In the last 5 years the number of workers employed in agriculture in England and Wales has declined by 12%. The agricultural industry has become highly mechanised and increased mechanisation has seen the introduction of larger machines capable of very high rates of work. The pressure to get work done quickly when conditions are right is very considerable and the time available to carry out cultivations, to drill seed, or to apply herbicides is limited. This means that speed when carrying out operations is essential. But speed introduces problems, work may be carried out less thoroughly and sometimes it has to be carried out under conditions which are anything but ideal. These changes of increased use of machines, higher rates of work and the sheer pressure of trying to get things done could lead to changes in the pattern of the weed flora of farms, perhaps encouraging some species which have not in the past been troublesome.

INTRODUCTION OF WEEDS ONTO LAND

Machines themselves may of course spread weed seeds, I suspect that they always have but today they cover larger areas both on the individual farm and in the general locality through contract work. Weed seeds are undoubtedly spread in this way and the combine harvester is an obvious example. Here too the size and the cost of modern combine harvesters encourages high rates of work over as large an area as possible so the potential for spreading troublesome weed seeds about becomes even greater.

Seed supplies themselves are obvious sources of weed seed contamination both seeds retained on the farm and seed which is bought in. A survey (1) carried out in 1970 showed surprisingly high rates of contamination of wild oats in cereal seeds. (A summary of the report is given in Appendix I). Although merchant seed was not entirely free from wild oats the level of contamination was very much lower than farmer saved seed. The arrival of 20 seeds per acre in previously uncontaminated soil could lead to the serious infestation of the field during a period of repeated cereal growing, especially if no effort were made to eradicate the weed.

EEC grain requirements are strict and increased costs consequent upon the application of higher standards may encourage farmers to make some use of home grown seed rather than purchase regularly from merchants. Although seed may remain on the same farm, if it is contaminated it will still mean a spread of certain weeds and on a much greater scale than before. Farmers would be wise to consider the matter carefully before deciding to save all their own seed and abandon the merchant. Weeds such as black grass and wild oat are particularly important here because they can be introduced on to farms where previously they were not a problem. Broadleaved weeds are less important as the amount of these weeds contaminating seed samples must be very small in relation to the enormous quantities of broadleaved weed seeds present in normal farm soils.

The degree of purity of seed which is required depends on the level of the problem on the farm. If wild oats are already present in large numbers then adding a few more from contaminated seed will not make much difference. Where a farm is free from serious weed infestation then it is certainly worthwhile buying good quality seed free from contamination.

Attempts to cut costs by making savings in the supply of cereal seed can therefore have the long term effect of raising overall farm costs and introducing serious weed contamination.

DEALING WITH WEEDS PRESENT ON THE FARM

The individual farmer seeks the largest margin between his output and his costs of production. He wants high yields and low costs. In weed control this leads to a number of interesting developments, some farmers have found that they can use low doses of MCPA for example to control the common easily controlled weeds and check others so they do not damage the crop. This gives less than complete control but has been perfectly satisfactory for their farming systems. We don't really know what degree of weed infestation can be tolerated. Is routine spraying really necessary? In some areas farmers when they meet will say in the early summer that they are "sprayed up" meaning they have sprayed for weed control every field on the farm. This may not be necessary and may cause a reduction in yield if spraying is carried out at the wrong time or when there is a small weed population.

A paper by I Munro of ADAS on Late Spraying of Winter Wheat and presented to this Conference discusses some aspects of this problem. Selective spraying can result in a saving in materials and costs of application and reduce crop damage from the machines, but it may leave the odd weed in the crop. In order to practise this selectively it is of course necessary to have a basically clean farm and a high degree of judgement on the part of the farmer. Although advice may be available it is clearly going to be impossible to supply sufficient staff, either from private or government resources to advise individual farmers on this subject.

A weed control policy based on assessing the degree of weed infestation and control needed is to be commended and allows concentration on the really serious weed areas of the farm. How far can we apply this philosophy, certainly to the easily controlled broadleaved weeds but what about wild oats, blackgrass and couch. How much couch can we tolerate and just what harm does it do and at what level does it become serious? It would be useful to have answers or at least guidance on these questions. In his paper Mr H A Friesen refers to work at Lacombe Research Station in Canada and in this country ADAS and WRO have carried out studies on blackgrass in winter wheat and couch in barley. What I am asking for is more work on the inter-relationship between crops and weed infestations and crop population studies. I realise that these are very difficult and that it is particularly difficult to translate the results into practical terms. However if there is to be a degree of precision in weed control and in the use of herbicides this type of information will be needed. Lack of this information hinders the development of soundly based weed control systems.

LEVEL OF WEED CONTROL

It seems that there is sufficient evidence to indicate that it is possible to use low doses of MCPA in order to check weeds and keep them under control without achieving a high degree of kill. The same principle can be applied to other herbicides so that we may use low doses of Barban and Dalapon to check weeds like couch, not to kill outright but to keep the weed sufficiently under control so that the crop can dominate it. Could this be applied to other weeds and herbicides?

It seems that we need a clear definition of 'control' - to most farmers this will be the complete removal of weeds by killing them and this is what manufacturers of herbicides aim to provide. Anything less is likely to result in claims for failure! In fact satisfactory control in the sense of reducing crop competition may be achieved by using lower dose rates and such control of growth and seeding of the weeds may be obtained at lower cost in materials. Perhaps labels and literature could be more helpful in setting out the conditions under which lower dose rates might be used so helping towards the economic use of herbicides.

It has been suggested in some quarters that continual low doses of a herbicide which checks weeds but does not kill them might result in the production of resistant strains of weeds, resistant that is to those particular herbicides. There does not seem to be much evidence of this happening although there has been a report from the USA of a strain of groundsel resistant to Simazine. Fortunately we have a wide range of herbicides and by varying the materials it should be possible to control weeds resistant to a specific herbicide.

FORECASTING WEED PROBLEMS

It would be immensely valuable to be able to predict weed problems that are likely to be experienced at harvest by inspecting crops during their early stages of growth. This is of course extremely difficult because such great changes occur during the development of the crop and these changes can be quite considerable even during the last few weeks of the crops' growth. Earlier harvesting may be necessary in order to avoid weed problems at that stage. Work is taking place at Experimental Husbandry Farms sponsored by ADAS and the NIAE to find whether it is possible to reduce losses at harvest through cutting cereals at an earlier stage.

Weed problems on farms are not usually spread over all the fields, certainly they do not arise evenly in all fields at the same time. A field diary of weed problems would be a most valuable aid to the management of any farm, particularly large arable units. This would show the weeds present in each field and as it would be completed in the summer would allow accurate identification. Such a diary would be invaluable in planning a herbicide and weed control programme.

Weeds brought in through contaminated seed will first appear in defined areas and it is as well to take action before the problem becomes serious. Wild oats and couch usually begin as patches in fields, these should be noted and recorded on a map during the farming season so that intensive and perhaps costly chemical and cultivation treatment can be carried out on that area during the autumn and spring.

Rouging wild oats is not a welcome task but concentration on bad infestations in patches by cultivations and chemical means followed by rouging has been shown to be a way of dealing with the wild oat problem on some farms. It needs care and enthusiasm for the task. Rouging is possible if it can be carried out at the rate of 4 to 5 acres per man, per day. Selective chemical treatment can reduce the infestation to a level when rouging becomes economically possible. The chemical rouging glove developed by WRO is a useful addition to control methods.

CULTIVATIONS

A concentrated attack on bad weed infestations may involve a half or full fallow and if this is carried out properly it can certainly control couch. Couch grass usually comes back into the field from the headlands although on some shallow and poorly drained soil it can return in patches in the field.
There is a good case for rotovating the headlands in order to prevent couch and other weed grasses getting back into the field. Very little ground is lost and the rotovated headland offers a useful turning place for tractors and equipment, it prevents couch being dragged on cultivators out of the hedge into the field and a valuable side effect is that the rotovated ground is a useful place for partridges and other game birds to dry off when the birds are young. Headland crops are usually pretty thin and I would suggest that this method is to be recommended in that there will be a full crop in the field with very little overall loss. This could well be work which Experimental Husbandry Farms might undertake in examining just what the losses would be in rotovating headlands in this way as compared with drilling right to the hedge. This is not of course a complete control for couch as it must not be forgotten that couch grass seed is viable and may in some cases be brought on to the farm as a contaminant of cereal seed.

Systems involving reduced cultivations can encourage couch unless great care is taken and chemicals used if necessary in order to increase control of the weed in the autumn. Systems like this really demand careful selection of suitable soils and highly skilled operators who take advantage of the power and equipment which is available in order to do the job at the right time. Unfortunately the impression has been created in some quarters that intensive cereal growing combined with reduced cultivations is the mark of a lazy farmer and something that can be practised by anyone without due regard to detail. This is not so, this system of farming demands a very high degree of skill and care and attention to detail. The failure of reduced cultivation and intensive cereal systems is more often due to the operator and not due to the system.

Where a no ploughing system is to be followed then cultivations must be timely and thorough in order to keep couch and other grass weeds at bay and to kill off volunteer cereals; as yield suppressors and disease carriers these spell disaster for intensive cereals. If done well, that is in a thorough and timely fashion then there will be no need for chemicals as has been shown by some successful farmers.

The pressure on farming in this country must lead to larger units with a small labour force and alongside this the development of the large family unit. This will probably be 400/500 acres operated by the farmer and his family, perhaps with one man. We may also see the development of co-operative farming where the actual operations are carried out by one partner the other owning the land and both sharing the profits. This system and the other more conventional ones all have a common feature namely a lot of work to be done in a very short time raising the importance of timeliness and the need for simplicity. There is no time today for the slow march of a sequence of cultivations. Reduced cultivations and a simple cropping system are here to stay and will continue to develop.

This must mean getting the land clean and keeping it clean, which implies a system of integrated cultivations together with the use of chemicals with the work being carried out quickly and at the optimum time. This the Weed Research Organisation and ADAS are now looking into, and we await the results of their investigations with interest. Working against the weather is one of the quickest ways to reduce crop yields, to damage the soil and to encourage weeds. However it is possible several chemicals should be combined and used together and cultivations and chemical application should be carried out at one and the same time so that fertilisers may be applied and a wide range of weeds controlled with fewer applications. I would refer you to the paper by J E Palmer of J W Chafer Ltd.

INTENSIVE CEREALS

Reduced cultivations and recent knowledge has encouraged more farmers to take wheat more often in the rotation, there is also the attraction of an extra gross margin of up to £20 an acre over a barley crop.

An increasing problem arising from reduced cultivations in an intensive cereals system is the contamination of the crop by other crop plants. Wheat may be taken after barley or after oats and shed barley and oats appear in the wheat as weeds. Here is a problem which is becoming serious and needs the attention of the agronomist in devising methods of harvesting and cultivations to reduce the problem and the attention of the chemist to produce a selective crop killer.

The plant breeder is producing shorter strawed cereals, particularly wheats. These are less likely to lodge and will deal with higher levels of nitrogen. The extreme example is of course the Mexican dwarf wheats. Shorter strawed cereals may well allow and encourage greater weed competition because they provide an entirely different environment in which the weeds develop. The demand on a herbicide is therefore greater and herbicides used on short strawed cereals have to deal with a different range of weed and offer a different pattern of control than herbicides used on taller more densely growing cereals.

Following our entry into EEC it may be a financial advantage to increase the emphasis on wheat rather than barley and other crops such as oil seed rape may become part of the United Kingdom farming scene. Those farmers who are able to take advantage of mechanisation and modern methods in order to operate flexible systems whilst at the same time retaining soil structure and the positive control of weeds and pests will benefit from being able to make changes quickly.

Of course if you are unfortunate enough to have couch and wild oats then you have a problem. Do you wait in the autumn for the wild oats to grow and practise late cultivation to kill the seedlings, thus allowing the couch to get a real hold, or do you hammer the couch early and then bury the wild oats. J F Roebuck of ADAS has submitted two papers dealing with some work carried out in the South East region. This is a problem which can only be answered on individual fields but it is a real difficulty for some. In fact concentration on the control of one weed may lead to dominance of another. Is it possible to develop a chemical or combination of chemicals which will deal with wild oats and couch, wild oats and blackgrass or wild oats and annual weeds in one application.

FUTURE WEED PROBLEMS

Intensive cereal growing is producing problems with wild oats, couch, blackgrass and shed corn from the previous crops where the species is changed. Creeping thistle may become a problem because this plant is not destroyed so easily by cultivations as it is through ploughing. In some isolated cases, certain weeds like coltsfoot may only really be controlled by sowing the field down to a ley.

Systems involving cereals and roots will allow a greater control of weeds by changes in cultivations. Continuous inter-row cultivations certainly control weeds, but it is not always the answer. There have been cases of potato crops cultivated thoroughly in the early part of the season thus breaking up the couch into small pieces which then grew vigorously after cultivation ceased, so leaving the field with a really heavy infestation of couch following the potato crop. Potatoes grown with minimum cultivations and the use of herbicides can also allow couch to get a real hold and so the potato crop may on occasions leave the field with more couch than before the crop was grown. We can no longer automatically regard potatoes and sugar beet as cleaning crops. However in the main a widely based farming system with roots and cereals will allow a greater degree of weed control, especially control of perennial weeds by varying cultivation times and by allowing a change in cultivation techniques. Wild oats will still be a problem and potatoes themselves in the form of ground keepers which may persist for several years afterwards in cereal crops.

A grassland and cereal system reduces the pressure on the timing of cultivations over large areas and leys which are well managed can control some weeds, such as blackgrass, but wild oats may remain dormant for 5 years or more under a ley so whilst long leys may help to control this weed shorter leys will not be very effective. Couch can of course increase under leys and special treatment may be needed for the weed after the ley is ploughed out.

One of the effects of leys is to reduce the area with weed problems which have to be dealt with each year. In intensively managed grassland docks may become a problem and special treatment may be needed when the field returns to arable. Spraying with Paraquat before ploughing out helps prevent the regeneration of grasses. A further problem in the case of ryegrass leys especially short leys, is the presence of ryegrass in following cereal crops which can in some cases be sufficient to compete with the crop and affect yields.

Another question which is sometimes raised concerns the timing of weed control operations in a rotation. Do we control the weeds in each crop as they appear or attempt to control the weeds in the rotation in preparation for certain crops. Just as some crops may be grown in preparation for others, so we might practise weed control measures to prepare for a special crop, such as Brussels sprouts for example. If we had available a herbicide which would deal with all the weeds in every crop it would of course solve the problem but it seems unlikely that such a panacea will ever be available. It seems to me that whilst it is possible to control perennial weeds for the rotation by cultural and chemical means, the annual weeds must still be dealt with in the individual crop as and when they appear.

Some minority crops also raise problems - clearly manufacturers research must be concentrated on crops grown on a large scale so that herbicides when produced, have the possibility of reasonable volume of sales and will produce a profit. Who then looks after the weed problems in minority crops, grown nationally on a small scale but of importance to individuals. The prospects for volume sales of herbicides being unlikely. Examples here are herbage seed, rhubarb, and asparagus and a crop on which a lot of work was done by the NAAS - rose stocks. Here the basic work was carried out by the advisory service and perhaps there is a case for official research which will handle weed problems in minority crops which are not likely to be of interest to the larger manufacturers.

Summary This paper has posed a number of questions and I have attempted to indicate the problems which are facing the farming industry and which have been brought about, not only through economic and political pressures, but also through the application of modern techniques.

Changes in the pattern of crop production, the crops grown, cultivations and methods of production and the quality of crop demanded all influence the type of weeds which will be present and those which will be most troublesome to the farmer. A change in any or all of the factors of production will influence the weed flora the control measures used and the degree of control demanded.

A smaller labour force, larger farms practising reduced cultivations and intensive cereal systems with a greater emphasis on wheat will raise problems from mixed grass weeds and volunteer crops behaving as weeds.

These problems can only be solved by considering all the factors together, in order to develop farming systems which will integrate cultivations, husbandry and the systematic and economic use of herbicides.

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Appendix I

REPORT ON A JOINT SURVEY OF THE PRESENCE OF WILD OAT SEEDS IN CEREAL SEED DRILLS IN THE UNITED KINGDOM DURING SPRING 1970

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SUMMARY

Following a pilot survey in 1969, a survey of the presence of seed of wild oat Avena spp. in cereal seed drills was carried out in the United Kingdom during September 1970. From a random selection of farms, samples of cereal seed of about 7 lb weight were collected by a pre-determined method from 620 seed drills found operating in fields. At the same time information relevant to the samples was obtained. The samples were analysed by the appropriate seed testing station in England, Scotland or Northern Ireland. The survey was arranged to ensure the privacy of individual farm contributions.

The proportion of samples in each country found to contain seeds of wild oat was: in England and Wales 19%, in Scotland 16% and in Northern Ireland 3%. The contaminated samples were widely distributed throughout England, Wales and North and East Scotland; there were markedly fewer contaminated samples found in West Scotland and in Northern Ireland. Appreciable contamination was found in spring barley and spring oats, the two crops most commonly encountered. The number of samples of wheat and mixed corn were too few to allow comparisons to be made with the other crops.

In England and Wales 11% of the samples of cereal seed supplied to the farmers by merchants and 41% of the samples of cereal seed harvested on the same farm or obtained direct from another farm contained wild oat. The equivalent figures in Scotland were 10% and 24% respectively, and in Northern Ireland 5% and 2%. The contaminated samples of cereal seed obtained direct from the same farm or another farm contained variable numbers of wild oats to a maximum of more than 50 seeds per sample. In contrast, the contaminated samples of seed supplied by merchants, with one exception, contained less than 11 seeds of the weed, and the majority of them contained only 1 seed.

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SOME CURRENT WEED CONTROL RESEARCH FINDINGS AND PRACTICES IN WESTERN CANADA

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The Prairie Provinces of Alberta, Saskatchewan and Manitoba are well suited to the production of spring sown cereal grains, notably wheat. Land use statistics place the acreage sown annually to wheat, barley, flax, oats and rapeseed at about 44 million acres, Figure 1. In 1970, due to a government wheat acreage reduction programme, the acreage sown to wheat dropped from the usual 23 million to 12.5 million acres and the total acres of all grain crops dropped to 34 million. The acreage in summerfallow increased from the normal 27 million to over 30 million acres with most of the remaining reduction being sown to forage crops. Improved market conditions in 1971 resulted in the wheat acreage climbing back to nearly 19 million and in striking increases in barley and rapeseed. Barley production rose from 9 million acres in 1969 to 14.6 million in 1971, while rapeseed increased from 2 million to 5.4 million acres during the same period. In 1972 wheat further increased to 21 million acres at the expense of barley and rapeseed acreage.

As might be expected weed control research in Canada has centred largely on wheat although in the past few years barley and rapeseed have commanded increasing attention. Since these crops are grown under a pattern of almost exclusive grain production, interspersed by summerfallow, their husbandry practices and weed problems are quite similar.

Wild Oats - Cereals

Because of its strong competitive nature and its prevalence, Table 1, wild oats are still a weed of major concern in the weed control programme. The current objective in wild oats control in cereal and oilseed crops is a herbicide equal to or better than barban with a longer period for application. Other factors such as sprayability, cost and compatibility with broad-leaf herbicides must also be equal or superior. FX-2182, (Endaven, Shell Co.), has proved superior to barban at the 3- to 5-leaf growth stages (Table 2), and the yield advantage from early wild oats removal is clearly evident. It can be safely tank mixed with bromoxynil-MCPA but loses its effectiveness if so mixed with 2,4-D amine or dicamba. Barley was highly sensitive to these treatments but wheat and Polish rapeseed (*Brassica campestris*) appeared tolerant. Although FX-2182 [ethyl-N-benzoyl-N-(3,4 dichlorphenyl)-2 amino-propionate] was registered in Canada under the trade name "Endaven" in 1972 for the control of wild oats in wheat, price may be a serious deterrent to its widespread use.

In 1971, AC-84,777 (American Cyanamid) appeared promising as a post-emergence herbicide for wild oats control in barley. In our 1972 field trials its performance was comparable to FX-2182 in that control improved as the wild oats advanced toward the 5-leaf stage. When efficacy and crop safety were considered the 0.56 kg/ha rate appeared best for wheat. Barley showed much greater tolerance than wheat, up to 1.68 kg/ha, but there was no improvement in wild oats control with dosages greater than 1.12 kg/ha. Polish rape showed fair to good tolerance but Argentine rape (*Brassica napus*) was highly sensitive.

Table 1

Wild oats infestation in the Prairie Provinces. ('000 ha)

Infestation *A. fatua* plants/m^2	Manitoba	Saskatchewan	Alberta	Total
Severe 180	325	2,226	1,196	3,747
Moderate 1.2 - 180	1,097	3,929	3,938	8,959
Light - less than 1.2	632	1,631	2,317	4,579
Total	2,054	7,785	7,446	17,285

Alex, J.F. Survey of Weeds of Cultivated Land in the Prairie Provinces. Canada Department of Agriculture. 1966.

Table 2

FX-2182 at two dates, effects on wild oats control and wheat yield

Treatment	kg/ha	Leaf Stage	Wild Oats--plants/m^2 1970	Wild Oats--plants/m^2 1971	Wheat--g/m^2 1970	Wheat--g/m^2 1971
FX-2182	Nil	-	178	99	136	261
FX-2182	1.12	3	109	17	298	353
	1.12	5	45	7	274	314
FX-2182	1.40	3	60	6	286	367
	1.40	5	18	3	242	329
Barban	0.28	2	-	32	-	331

Wild Oats - Rapeseed

A large part of the weed research effort at Lacombe over the past five years has been devoted to rapeseed -- the so-called "Cinderella" crop of the prairies. Although a large number of potential herbicides have been investigated in the programme the greatest effort has been with trifluralin, a soil incorporated compound. Briefly stated a series of experiments have indicated that: (a) placement of trifluralin in the soil was most important because the main site of activity on wild oats (*Avena fatua* L.) was through the shoot or coleoptile; (b) Polish rapeseed was not affected by trifluralin up to 1.4 kg/ha regardless of placement; (c) activity was not seriously reduced by soil moisture as low as 10%, i.e. lower than air dry soil; (d) activity was reduced by high soil organic matter and by incorporating the herbicide to depths below 7.5 cm.

In field experiments trifluralin sprayed in the spring at 1.12 kg/ha and tandem disced to a depth of 7.5 cm immediately, resulted in upwards of 80% control of wild oats without injury to rapeseed. Yield increases depended on the density of the wild oats infestation. Bioassay showed a loss of 90% or higher of trifluralin activity in one growing season and cereals planted the year after trifluralin treatment were not affected.

Spraying and incorporating trifluralin in October prior to seeding rapeseed the following May resulted in nearly equal wild oats control to spring application, Table 3. This procedure has important practical implications in that it avoids the excess tillage and consequent soil drying associated with spring application.

The above rates of trifluralin also gave excellent control of (*Setaria viridis*), (*Chenopodium album*) and (*Amaranthus retroflexus*). Control of (*Galeopsis tetrahit*) and (*Convolvulus arvensis*) has been fair to good. Recent tests indicate some control of (*Galium Vaillantii*).

Table 3

Response of rapeseed and wild oats to trifluralin applied in the autumn and spring at Lacombe 1969-1971

		Rapeseed			Wild Oats	
Date applied	Trifluralin kg/ha	Plants /m^2	No Injury = 9	Yield kg/ha	Plants /m^2	Control kill = 9
Sept 16	0.84	223	9.0	1540	65	5.6
Oct 15	0.84	198	9.0	1523	51	6.2
May 10	0.84	222	9.0	1510	53	6.4
Sept 16	1.12	202	9.0	1616	41	6.8
Oct 15	1.12	214	9.0	1660	29	7.9
May 10	1.12	196	8.1	1656	24	8.2
Sept 16	1.40	201	8.8	1615	32	7.6
Oct 15	1.40	204	8.2	1650	48	8.0
May 10	1.40	212	8.0	1646	36	8.0
Untreated	-	218	9.0	1480	135	Nil
Handweeded	-	221	9.0	1710	-	-

Perennial Weeds

Agropyron repens and *Cirsium arvense* are the most widespread and troublesome species. Phenoxy herbicides and dicamba give selective top growth control of the latter but tillage is the only economic control available for the former species. Glyphosate [N-(phosphonomethyl) glycine] Monsanto Co. may afford a breakthrough in the control of these and other perennial species.

Our preliminary experience suggested excellent translocation and kill of perennial root stocks, notably of *Agropyron* in the confines of greenhouse flats. Under field conditions it would appear that root translocation and phytotoxicity was not quite good enough to result in complete kill with one treatment. However, the striking stand reduction in both species from early spring treatment resulted in highly significant yield increases of barley. The potential of this herbicide is most exciting but a great deal of study is needed to determine the use patterns which will exploit this potential.

Weed Competition

Many workers have evaluated crop losses due to varying densities of a single weed species. They were able to determine the number of weeds required to result in a statistically significant loss in yield or a "critical density" by the use of seeded weed infestations, to obtain the desired populations. However, these methods did not recognize that crop losses increased with increasing weed populations. Work at the Lacombe Research Station has developed an "index of competition" which permits the prediction of crop losses due to weeds when weed species and populations in a given crop are known (Dew, 1972).

He used data from the published works of Bowden and Friesen (1967), Bell and Nalewaja (1968) and Alex (1968) to develop a mathematical model to predict the effect of increasing weed densities on the yield of barley, wheat and flax. Regressions calculated, after applying the square root transformation to the wild oats populations, were highly significant. A curvilinear relationship between yield and wild oats populations was predicted by the equations developed. The regression coefficient was calculated and defined as an "index of competition" which is unique for each weed and crop combination and is independent of the estimated weed free yield of the crop. The loss equation developed from the data used was:

$$L = ab_1\sqrt{x}$$

where L = loss
a = weed free yield
b_1 = index of competition
x = wild oat population

The index of competition calculated from these data for each crop was:

wild oats in barley = .0230
wild oats in wheat = .0339
wild oats in flax = .0601

This equation $L = ab_1\sqrt{x}$ can be used to readily predict the losses under different field situations and to determine which control measures would be economically practical. For example, a field of wheat which is estimated to yield 270 g/m^2 (40 b/ac) if weed free, is found to have an average of 45 wild oats plants/m^2 at or very soon after crop emergence. The predicted loss due to this infestation would be:

$$L = 270 \times .0339 \times \sqrt{45}$$
$$= 61\ g/m^2\ (9.1\ b/ac)$$

The cost of herbicide application and probable benefit can then be calculated, provided the efficacy of the herbicide is known.

The work to date was based on the following assumptions. First, that crop plant counts were similar across all trials because it has been shown by Pfeiffer and Holmes (1961) and others that seeding at above average rates results in higher grain yields under weedy conditions. Second, that the crops and wild oats emerged at the same time. Weeds emerging later than the crop were less competitive (McBeath et.al. 1970) than those which emerged at or before crop emergence. Third, that the wild oats and crop had equal access to nutrients, soil moisture, light and space. Wild oats and flax are cases in point.

Mr. Dew's current studies are designed to furnish data from which "indices of competition" can also be calculated for populations of (Fagopyrum tataricum), (Polygonum scabrum) and (Setaria viridis) in barley, wheat and rapeseed. Data on the effect of relative emergence of the weed and crop and the effect of time of removal by herbicides and by hand are being collected. It is anticipated that by the use of regressions, mathematical models can be developed which will measure the input of these additional variables in predicting crop losses due to weeds. Because of the importance of this work several Research Stations are cooperating with Lacombe.

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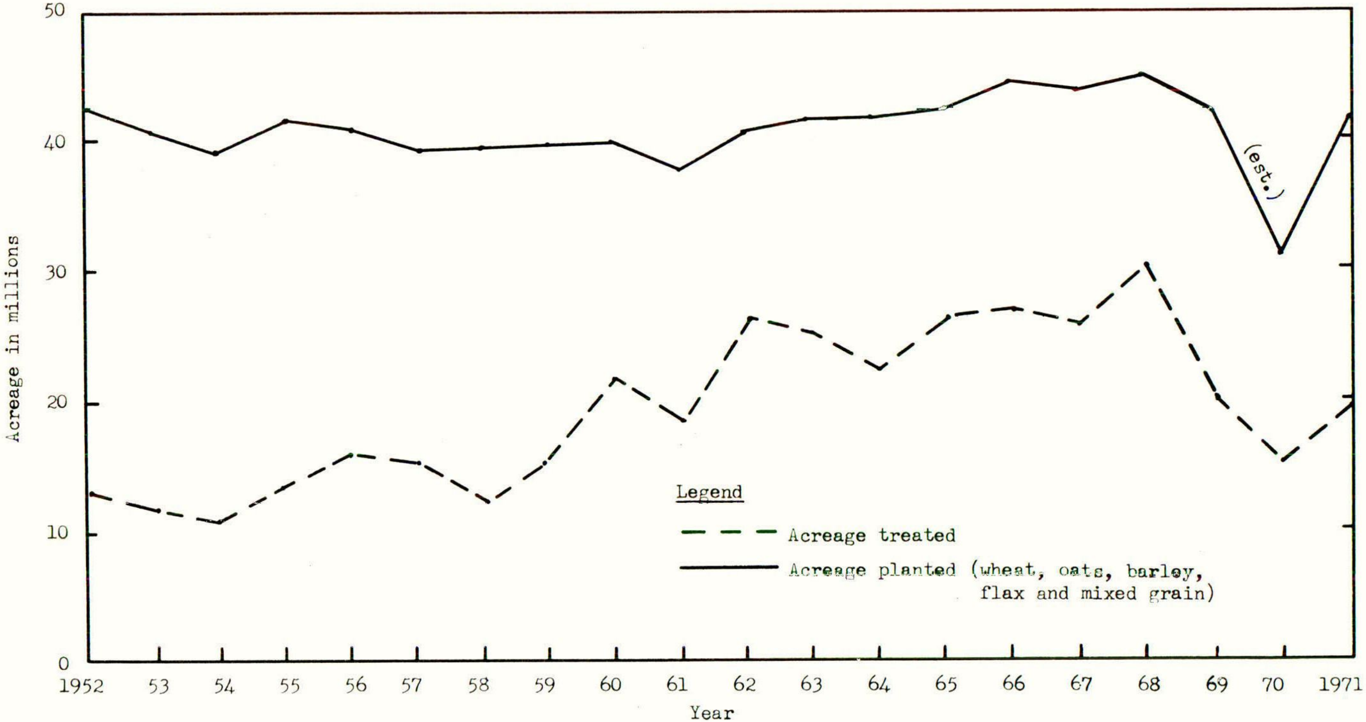
Figure 1. 2,4-D and MCPA use in the Prairie Provinces

(1952 - 71)



By: Alberta Department of Agriculture, Edmonton.

1160

Proc. 11th Br. Weed Control Conf. 1972

CAN WEED PROBLEMS BE REDUCED BY IMPROVING CROP ESTABLISHMENT. SOME POSSIBILITIES FOR ENHANCING SEED GERMINATION.

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The period of seed germination is a most hazardous stage of plant growth. From the time the seed first takes up water until the seedling emerges above the soil the potential new plant must combat stresses of heat, cold, drought and attacks by fungal or bacterial pathogens that place its existence in jeopardy. The ability of the developing seedling to survive these stresses depends in major part upon the initial vigour of the embryo contained within that seed.

Vigour is a loose term with far ranging definitions (Roberts, 1972), but all of them can be included in a general concept - the capacity to undergo and complete the sequential biochemical and physiological changes associated with germination.

In any batch, large seeds have an advantage over small seeds, but small seeds are not necessarily less efficient than larger ones in physiological and biochemical terms. The performance of a seed is primarily determined by its past history, so that the conditions under which the parent plant grew, the conditions of maturation of the seed, of harvesting and of drying are extremely important. But equally important are the subsequent conditions of seed storage and the duration of such storing.

Any one of these factors will influence the performance of the seed when water is eventually supplied and if the conditions have been unfavourable, then the potential performance of the germinating embryo will be sub-optimal. In other words the vigour of the seed will have been reduced and the time for the seedling to accomplish the essential changes required in seed germination will be longer.

A seed which germinates slowly is therefore faced with an extended period in the hazardous stages from imbibition of water to emergence above the soil, the period during which it depends entirely upon its capacity to mobilise and utilise its own resources of stored substrates and to withstand heat, cold and water stress and pathogen attack. As far as crop plants are concerned, the ability of the crop seed to keep pace with or outstrip the germination and emergence of the vigorous weed seed competitors is perhaps the initial major factor that determines the establishment of the crop and the resulting yield for the farmer.

The question we now ask is can we improve the performance of seeds in these initial stages of germination, the stages during which the embryo is living entirely at its own expense.

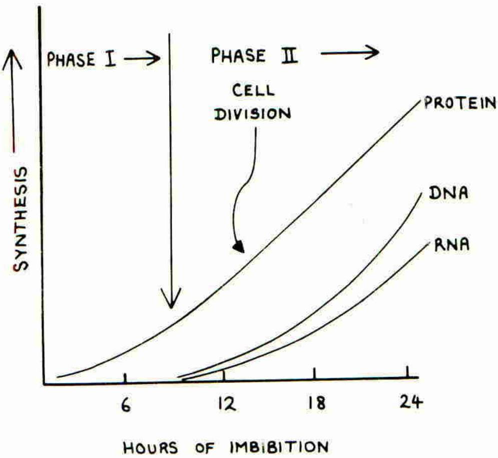
Our own experimental studies have been carried out with cereal seeds - rye, *Secale cereale*, or wheat, *Triticum arvense*. But in my talk I shall illustrate some of the ideas that are now of interest to workers on germination and emergence by quoting some of our own results as well as those that have been obtained by others with vegetable and cereal crops.

Germination

There are two major phases to germination. The first, Phase I, in which the embryo takes up water and starts to synthesize protein: the second, Phase II, in which RNA synthesis and DNA synthesis commence and the embryo becomes fully biochemically active. The point at which cell division starts may be variable and depends upon the number of copies of the chromosomes in the nuclei of the cells of the embryo at the time of maturation and dehydration of the seed. Where cells contain nuclei that replicate their DNA just prior to dehydration their DNA content in the dry embryo is 4C instead of the 2C diploid value. At the time of imbibition of water at germination they therefore contain cells that can divide to give two daughter cells each with 2C nuclei without first replicating or synthesizing new DNA. It is important therefore to consider that the onset of cell division at germination may not necessarily coincide with the start of DNA replication.

Fig. 1.

Relationship in time between the synthesis of protein, DNA and RNA, and cell division in germinating embryos at 24°C.



ROBERTS + OSBORNE, 1972

In isolated rye embryos we know that the pattern of germination follows the course shown in Fig. 1 with DNA synthesis and cell division closely linked. During Phase I, certain proteins and new enzymes which are essential before the second phase of development can occur, are synthesized or activated. For example, in wheat the DNA polymerase necessary for DNA replication in Phase II appears to be synthesized during this period (Mory et al., 1972), so until Phase I is completed Phase II does not commence. When a seed is planted in the soil it must achieve Phase I before further growth can proceed and whereas high vigour isolated rye embryos imbibing water at 24°C in a laboratory incubator can complete the phase in 8 h, a whole grain planted in the inhospitable milieu of cold soil may take several days to reach the same stage.

Clearly anything that is done to hasten Phase I, or preferably to achieve Phase I before the seed is even sown will speed the emergence of the seedling and increase the chances of establishing a good crop stand in competition with the weeds.

Indeed, it is appropriate to quote here the classic study of Nelson and Nyland (1962). They showed that if the weed white mustard emerged 3 days before the peas in their experimental crops then the fresh weight of the pea vines was reduced 54% compared with a weed free control, whereas if the peas emerged 4 days before the mustard the fresh weight of the pea vines versus the same weed free control was lower by only 17%.

We now know that embryos and seeds of a number of plants can be imbibed with water and then, after a period of metabolic activity has been achieved, they can be dehydrated again to their original water content without harm. Such seeds are termed 'hardened' or 'enhanced', for they may subsequently germinate more rapidly then untreated seeds and since this period of seed hazard is reduced they stand a more favourable chance of establishing a vigorous stand of crop. The experiments of Berris and Drennan (1971) illustrate this point (Table 1).

Table 1

Mean germination time (G_{50}) for oat grains after increasing numbers of pretreatments

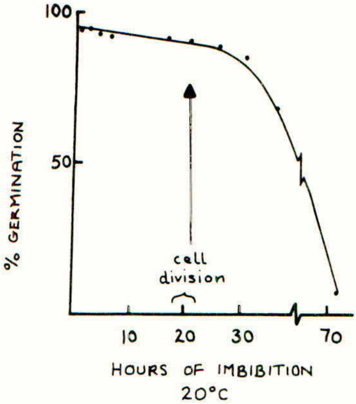
Imbibition No. cycles	Imbibition Duration (h)	Germination h to G_{50}
NONE		48
1	12	37
	20	31
2	12	26
	20	26

Berrie & Drennan, 1971.

They imbibed whole oat grains in water for either 12 or 20 h, then dehydrated them at reduced pressure over $CaCl_2$ and then either planted them 2 weeks later, or imbibed the grains again for a second cycle of wetting and drying before planting them. The time for 50% of such seeds to germinate can be reduced by about half if two cycles of 12 h imbibition are given as a pretreatment. Furthermore, as seen in Fig. 2, the percent germination was not impaired until the duration of pretreatment exceeded 20 h. This is the time (18-20 h) at which the first cell divisions were detected in the embryo.

Such results suggest that some biochemical changes achieved during the pretreatment are retained during the subsequent dehydration and one may speculate that they are the protein and enzyme changes of Phase I. One might ask can this hydration period include part of the Phase II stages also? From the evidence now available for cereals, it seems that imbibition followed by dehydration at a stage where DNA replication is well under way results in impairment or death of the seedling. Certainly once active replication and transcription of the DNA commences some change in the physical character of the chromatin occurs such that the macromolecular structure of the DNA is no longer retained through a period of subsequent dehydration (Chen et al., 1969).

Fig. 2. Effect of time of imbibition (followed by drying) on subsequent percent germination of grain.



BERRIE + DRENNAN, 1971.

We know that a seed of low vigour takes longer to complete Phase I than does high vigour seed. This is borne out by a lower capacity to synthesize protein in the early hours of germination (Table 2). As a result the time required to synthesize the enzymes and proteins for Phase II in increased and the period of hazard for such impaired grain stocks is unduly long.

Table 2

Protein synthesis in rye embryos from stocks of different percentage viabilities. Incorporation of ^{14}C-amino acids into TCA insoluble material at 5-7 hour of imbibition. (Adsorption background 1-200 cpm).

		cpm per embryo mg^{-1} initial wt.			
	Viability	90%	60%	2%(1972)	0%(1970)
Embryo	1	21,193	707	544	124
	2	10,970	12,864	167	134
	3	14,081	3,819	205	88
	4	2,582	2,155	152	124
	5	4,455	8,453	180	150
Mean		10,655	5,599	249	124

Sen & Osborne, 1972.

The achievement of Phase I before planting is therefore of greatest advantage for poor quality seed or for seed with poor performance under the conditions of test, for not only are the days to emergence reduced but the time over which emergence is spread is contracted. This could be of particular importance when considering the timing for the safe use of post-emergence herbicides. The experiments of Hegarty (1970) are relevant here. He found that when sweet corn kernels were imbibed for [illegible] h at room temperature and then air dried before sowing, the percentage emergence of those cultivars with normally low emergence values (20 or 28%) could be doubled by the pretreatment. However, cultivars with a normally high percentage emergence were not improved.

As aprt of our investigations into the kinds of biochemical changes that occur during germination of cereals we have carried out incorporation studies on rye embryos (90% viable stocks) that have been given increasing periods of imbibition followed by dehydration to their original weight. It is clear from the results so for that such pretreatments can achieve, and retain on dehydration, some of the changes that occur during Phase I for the capacity of the embryos to synthesize protein when they are again supplied with water is greater than that of non-pretreated embryos. Further, the lag period before the embryos synthesize DNA is abolished (Table 3) and the pretreated embryos develop sooner into small seedlings.

Table 3

Incorporation of a) ^{14}C-leucine and b) ^{14}C-thymidine into TCA-insoluble material by pretreated and control embryos. Embryos pretreated by imbibing for 12 h in water, then blotting and dehydrating to original weight in an incubator at 24°C (1 h). Embryos stored in stoppered bottles over $CaCl_2$ at 4°C.
For incorporation embryos subsequently imbibed for 1 h and exposed to radioactive precursor for the following 2 h.

		cpm incorporated mg^{-1} embryo	
a) Incorporation of ^{14}C-leucine into protein		Pretreated	Control Untreated
Embryo	1	19,908	9,313
	2	25,651	12,732
	3	41,003	6,544
	4	34,478	10,940
	5	19,272	7,871
Mean		28,062	9,488
b) Incorporation of ^{14}C-thymidine into protein			
Embryo	1	1,112	215
	2	963	205
	3	1,174	229
	4	2,553	146
	5	488	236
Mean		1,258	206

Sen & Osborne, 1972.

Increasing Resistance to Stress

Not only is the properly pretreated seed a faster and better competitor with the weeds, it has an added advantage: it is also a more resilient and hardy individual under stress conditions of heat, cold, drought and high salt. A number of examples of such "hardening" of seeds should be quoted here.

Experiments of Austin et al. (1969) have shown that 3 regimes of 24 h imbibition followed by 1-2 days drying in air leads to earlier germination of carrot seed in laboratory tests, to a shorter time to 50% emergence in greenhouse trials and to an enhanced yield of roots in field trials (Table 4).

Table 4

Effect of hydration and drying on performance of carrot seed

% germination on filter paper	8 days	16 days
Control	0	83
Pretreated	63	81
Days to 50% emergence in Soil Trays		
Control	7.8	
Pretreated	5.4	
Yield of roots in field crop t/ha		
Control	59.2 ± 0.85	
Pretreated	64.0 ± 0.85	

Seeds given 3 regimes of (24 h imbibed
(1-2 day air dried

Austin, Longden & Hutchinson, 1969.

Further, in emergence tests, the pretreated seed is more resistant to drought stress than the untreated control (Table 5).

Table 5

Effect of hydration and drying on performance of carrot seed

	Days to 50% emergence in Soil Trays	
	Fully watered	Unwatered
Control	7.8	9.8
Pretreatment	5.4	6.5

Seeds given 3 regimes of (24 h imbibed) (1-2 day air dried)

Austin, Longden & Hutchinson, 1969.

Using essentially similar techniques, Hegarty (1972) found that several cultivars of carrots that emerged poorly at low temperatures showed enhanced germination and a higher percentage emergence at 10°C if the seeds were given an imbibition pretreatment.

With cereals, experiments by Dr. A. Hansen, until lately of the Lord Rank Research Centre, have shown that hydration of Capelle Desprez wheat grains for 24 h at 15°C followed by dehydration for 24 h over $CaCl_2$ at reduced pressure for 24 h, enhances germination and growth of seedlings under stress. The pretreatment permits more vigorous growth than that of untreated controls when both sets of grains are subsequently planted in vermiculite and watered with a solution of polyethylene glycol (O.P. = 3 atm).

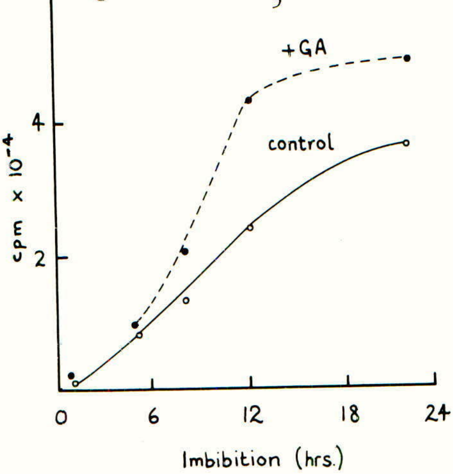
Enhancing Effectiveness of Pretreatments by Hormones

Although cereal embryos will proceed through Phase I as long as water is present, this stage can be enhanced still further by the addition of suitable hormones, such as gibberellic acid. Experiments with excised embryos of wheat treated with gibberellin, or with cell-free protein synthesizing systems extracted from such embryos, have shown that protein synthesis is enhanced when gibberellin A_3 is present during Phase I - this is an effect on the translation of natural messengers stored in the embryo for it occurs before replication or transcription of the DNA takes place (Fig. 3).

The effectiveness of the additional enhancement afforded by hormonal treatment has been demonstrated for a number of different seeds in field and greenhouse trials. For example, the early experiments of Taylor (1951) showed that celery seed that had been imbibed with water for 4 h, then held for $8\frac{1}{2}$-9 days at 100% humidity before planting, emerged above the soil at the same time as the fastest growing weed seeds. The controls emerged days later when they were readily overshadowed by the largest weeds. The pretreatment was partly an enhancement of germination and partly a protection against the stress of high temperature experienced in celery beds in Salinas, California. This is demonstrated more clearly in the recent experiments of Thomas et al. (1972) reported at this meeting, who have shown that pretreatment with solutions of GA_{4+7} in the hydration period affords some enhancement of celery seed germination at fabourable temperatures (21°C) but at stress temperatures above the optimum for celery germination - 27°C - the effect of gibberellin is highly advantageous (Fig. 4).

Fig. 3.

Incorporation of ^{14}C-amino acids into TCA insoluble material by control embryos or embryos germinated on GA_3 10^{-4} M. Incorporation 30 mins.



Incorporation by ribosomes extracted at 12 h in cell free system primed with poly U + ^{14}C-Phenylalanine. (Range 4 experiments).

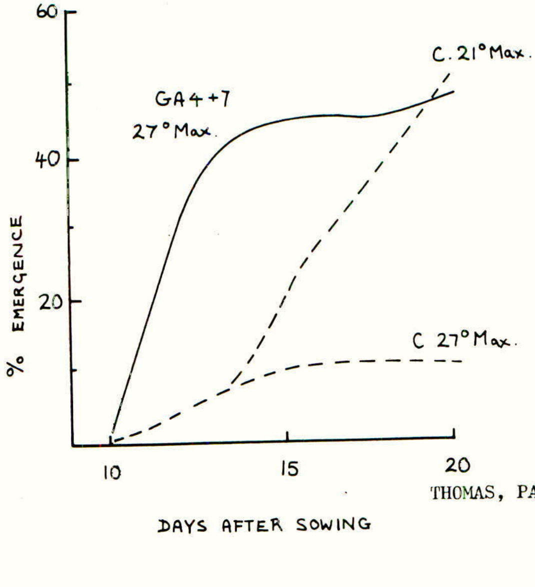
C = 9-10,000 cpm

GA_3 = 12-13,000 cpm

ROBERTS & OSBORNE, 1970.

Fig. 4.

Enhancement by GA_{4+7} of seedling emergence under heat stress.



THOMAS, PALEVITCH & AUSTIN, 1972.

Somewhat similar effects have been reported by Joshua and Heydecker (1971) for lettuce. They treated seed for 15 min with either gibberellin A_3 or kinetin at 10 mg/l. After drying and planting, the treated seeds gave a higher percentage of emerged seedlings at the soil surface when treatments and controls were planted at the unfavourable temperature of 29°C (Table 6).

Table 6

Percent emergence of lettuce seed after 7 days at 29°C

Seeds 1.2 cm below soil

Pretreatment	Cobham Green	Great Lakes	Little Gem
None	7	12	3
Imbibed 15 min			
GA_3 10 mg/l.	30	44	15
Kinetin 10 mg/l.	48	67	44

Joshua & Heydecker, 1971.

Another hormone produced during the early phases of germination, is ethylene. Applied ethylene is effective in enhancing the rate of germination in a number of species, including rape (Takayanagi and Harrington, 1971), oat (Ruge, 1948), corn (Haber, 1926) and wheat (Balls and Hale, 1940). Our electron microscope investigations have shown that the ultrastructural changes associated with the early hours of germination in rye are enhanced with 0.1-1 µl./l. ethylene is supplied in the air when the seed is wetted.

The greatest enhancements with ethylene are reported for seeds of low vigour, particularly for those from old batches or those that have been prematurely aged by storage under unsuitable conditions of temperature and humidity (Takayanagi and Harrington, 1971). Stewart and Freebairn (1969) showed that lettuce seeds that had been preheated at 97°C for 16 h germinated poorly, but if ethylene at 100 µl./l. was supplied in the air for the first 48 h, germination was greatly enhanced (Table 7).

It seems therefore that some enzymes in the ethylene biosynthetic pathway are highly labile and are inactivated by heat or on storage. Evidence from other sources suggests that ethylene enhancement may occur only over the early hours of germination, and probably only during Phase I.

These examples clearly demonstrate the potential value of hydration treatments and hydration plus hormone treatments, which permit Phase I changes to occur, whilst still maintaining a seed in a condition where it may be stored for further periods. From an economic point of view, it is important to ask how stable are the changes that are induced in the seed during these pretreatments.

Table 7

Effect of ethylene 100 µl./l. supplied during early germination of lettuce seeds subjected to a heat pretreatment

	Heat treatment at 97°C		
	None	8 h	16 h
% germination in air	82	48	1
" " " C_2H_4	85	87	81

Stewart & Freebairn, 1969.

As far as we can tell, the biochemical and physiological changes occurring during pretreatments are stable for long periods. For example, the rise of protease activity in oats during hydration for different pretreatment times can still be measured seventeen weeks later. The increase in amylase activity that occurs in the later hours of imbibition (30 h) is also still present (Table 8)(Berrie and Drennan, 1971).

Table 8

Enzyme activities after 17 weeks in dry seeds of oat after different pretreatment times

Duration of hydration	Relative activities	
h	Amylase	Protease
0	5.25	100
8	5.45	129
12	5.30	135
30	6.32	167

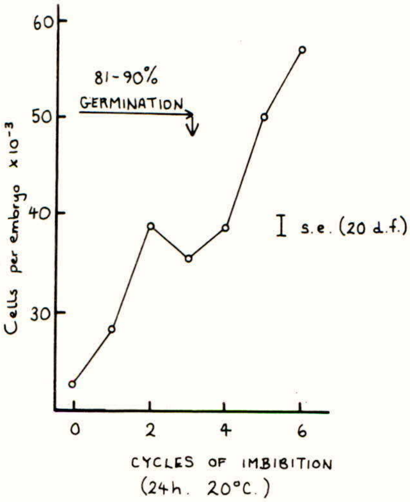
Berrie & Drennan, 1971.

It has also been shown that when partly hydrated light sensitive lettuce seeds (at above 15% moisture content) are exposed to a flash of red light to activate the phytochrome system, and then dehydrated to 7% moisture content (Vidaver and Hsiao, 1972), they retain the potentiation of germination due to the red light for more than 1 year.

From the foregoing results therefore, it would seem that the pretreatment of seeds by hydration, with the added enhancement afforded by hormones, is a feasible method for contracting the time taken for a seedling to emerge above the soil. The accomplishment of Phase I before sowing is a physiologically and biochemically sound approach to synchronizing the early growth of seedlings and overcoming some unfavourable features of seed batches of low vigour. But much more work must be done before such projects can be perfected. In carrot, for example, seed can be dehydrated with successful germination after hydration periods that are long enough to permit considerable cell division (Fig. 5). Is this because carrot embryos have a high proportion of cells with 4C nuclei and, unlike the wheat, DNA replication is not the prelude to cell division? This waits for the cytologist and the biochemist to provide the answers.

<u>Fig. 5</u>.

Changes in cell numbers per embryo
following imbibition of seed



AUSTIN, LONGDEN + HUTCHINSON,
1969.

The best method of planting these pretreated seeds is another major factor to be determined. Seed of such enhanced potential performance could be included in pellets with additional fertilizer and fungicide, or sown on tapes so that the spacing of such valuable seed would be optimal for a good stand of crop. These considerations may be of particular importance for the new high yielding cereal hybrids

This kind of project is an example of one which physiologists, biochemists, agronomists and engineers can jointly bring to a successful conclusion.

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DORMANCY IN WEED SPECIES

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It is now well known that large numbers of viable buried weed seeds are present in arable soils, figures of between 3 to 348 million seeds per acre having been calculated (Wesson & Wareing, 1969a; Roberts & Stokes, 1966). Clearly, with such numbers involved, the potential reservoir for weed infestation is enormous and it behoves us to try to determine the environmental and endogenous factors which will decide whether or not these seeds will germinate and by so doing to rationalize our attempts to control their emergence. Ideally we would hope to either prevent emergence until after a crop is established and thus reduce competition or to stimulate germination of the weeds before the crop and treat them with a conventional herbicide.

Much work on seed dormancy has been carried out in the last 25 years. Unfortunately, weed seeds are often small and inconvenient to handle and thus more work has been carried out on seed of crop plants or at any rate with seeds which are relatively easy to manipulate. However, weed seeds have not been entirely neglected and we know that the environmental conditions necessary to break dormancy vary substantially from species to species. Now, much work has indicated that where a developmental process in plants is controlled by environmental factors - whether in the long or short term - the effects are often mediated by hormones and it appears that this is often the case in the breaking of seed dormancy and subsequent germination. The role of hormones in these processes has thus attracted a good deal of attention and a very considerable body of relevant literature has accumulated.

There is unsufficient time to-day to cover all the possible aspects of this many faceted subject and I therefore propose to limit this discussion to a consideration of recent work and in particular some findings of our own which we think have considerable potential in the area of weed control. Nevertheless, I hope to relate our results to other broader aspects where appropriate.

The stimulus for our experiments came from the observations by Smith and Russell (1969) that concentrations of up to 10 ppm of ethylene may be found in the soil under conditions of anoxia or waterlogging, probably as a result of the activities of the soil microflora. Ethylene can influence a number of developmental processes in plants, including germination, and its role in a number of these systems is well documented. Curiously, ethylene is produced by plants themselves and is itself regarded as a hormone; thus we have the paradox of a plant hormone which may also be an environmental factor! In view of the large number of weed seeds in the soil we decided to investigate the possibility that their germination might be regulated by ethylene. The effect of ethylene upon seed germination of a range of weed species is shown in Table 1.

Table 1

Effect of ethylene on the germination of seeds of some weed species in the light.

Seed was imbibed, treated with ethylene at the concentration shown at 20°C under continuous white light: germination was recorded after the times noted.

*Germination light promoted.

SPECIES	GERMINATION % S.E. Ethylene concn. (ppm)				Germibation recorded after
GERMINATION PROMOTED BY ETHYLENE	0	10	100	1000	(days)
*Spergula arvensis L.	12.8±2.4	47.5±3.3	57.5±3.8	57.5±3.6	4
*Hypochaeris radicata L.	4.0±2.2	52.5±2.6	53.5±5.1	16.5±3.3	4
*Chenopodium album L.	0.8±0.3	-	10.5±1.9	13.3±0.9	7
*Rumex crispus L.	9.0±1.7	-	19.0±2.6	22.0±2.6	21
Trifolium repens L.	26.5±4.2	59.0±4.5	59.8±5.6	59.0±6.4	2
GERMINATION INHIBITED BY ETHYLENE					
*Chenopodium rubrum L.	17.5±2.6	-	0.5±0.3	0±0	14
*Plantago major L.	28.3±4.2	8.3±1.9	0.3±0.2	-	7
*Plantago maritima L.	55.0±4.7	38.0±1.2	39 ±3.7	33 ±8.9	3
GERMINATION NOT EFFECTED BY ETHYLENE					
Sonchus oleraceus L.	24.3±1.5	32.8±7.7	21.5±5.8	24.8±3.4	4
Silene dioeca L. Clairv.	41.0±3.7	31.5±2.2	34.5±5.7	34.5±4.3	11
Senecio jacobea L.	55.0±3.7	65.0±4.0	52.5±2.9	57.5±2.2	5
Taraxacum officinale Weber	43.0±4.0	39.5±1.7	40.0±1.6	43.5±3.0	4

Of the species investigated the germination of five was promoted by ethylene, in three it was inhibited and four were unaffected. I would stress that most of these seeds were freshly harvested. The most striking observation we made, however, was that all but one of the species affected by ethylene were also light sensitive. This is a particularly interesting finding especially since Hypochaeris radicata has not been previously considered as light requiring and Spergula arvensis has only been reported as light requiring after burial (Wesson & Wareing, 1969b). The reason for this will become apparent later in this discussion. Much of our subsequent work was carried out on S.arvensis because it remains dormant for some time, but we have reason to suppose that its behaviour is not in any way unique. The effect of ethylene upon seed of S. arvensis is shown in Table 2.

Table 2

Effect of eEhylene and light on germination of Spergula seed.

C_2H_4 concn. (ppm)	Light	Dark
0	8.3 ± 1.5	7.8 ± 0.9
10	40.8 ± 3.4	14.5 ± 2.4

There is little germination in the absence of ethylene, in the light or in the dark. In the presence of ethylene, there is some increase in germination in the dark but a very marked increase in the light. We have found that the threshold concentration for this effect is about 0.2 ppm ethylene, well within the range of concentrations reported to exist in the soil; the system also exhibits red/far red reversibility indicating that the light effect is phytochrome mediated.

One further point which will be of interest in the present context is that the ethylene releasing chemical 2-chloroethyl phosphonic acid (CEPA) is almost as effective as ethylene itself in breaking dormancy.

Now, while in a number os systems plant growth regulators can substitute for a light requirement, clearly this is not so here since in young seed at least breaking of dormancy by ethylene in the dark is small compared to its effects in the light. However, the question remains as to whether the light effect itself is ethylene dependent or whether the two processes are separable in time; for example, if seed is briefly irradiated with red light and maintained in the dark at various temperatures we found that even after two days, application of ethylene results in marked stimulation of germination compared to controls in the dark (Fig. 1).

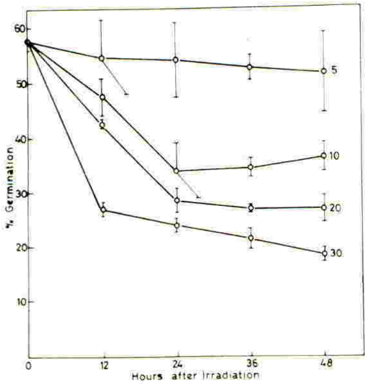

Fig. 1. Effect of temperature upon subsequent germination of Spergula arvensis seed pre-irradiated with red light. Seed was dark imbibed at 20°C for 24 hours, red-irradiated for 30 minutes and retained at temperatures of 5, 10, 20 or 30°C for various times after which it was treated with 100 ppm C_2H_4 and germinated in the dark at 20°C for 5 days. Standard errors are included.

This is, however, only true at low temperatures. At 30°C there is very little response to ethylene 12 h after exposure to light. We believe that this is related to the rate of reversion of the photosensitive pigment phytochrome from its active form (Pfr) to its inactive form (Pr) a process which is markedly temperature dependent in other systems. This proposition is supported by the fact that if seed which has been left at 30°C for 2 days after exposure to red light is re-exposed for a brief period then germination proceeds in the presence of ethylene in the usual way. The analogous experiment, that is if ethylene is supplied to the seed in the dark for a 24 h period and then removed, showed that seed will germinate readily if given a brief red light exposure even seven days subsequently. This is true even if the seed is redried after the ethylene treatment and reimbibed before irradiation. Thus, whatever events are affected by ethylene treatment they appear to be largely irreversible.

As I mentioned previously the seed used in these experiments was freshly harvested and very dormant; however, Spergula seed does eventually lose its dormancy and will germinate readily, even in the absence of ethylene. What changes occur in the seed between the two extremes? We have examined the dormancy of Spergula seed as a function of age (see Fig. 2).

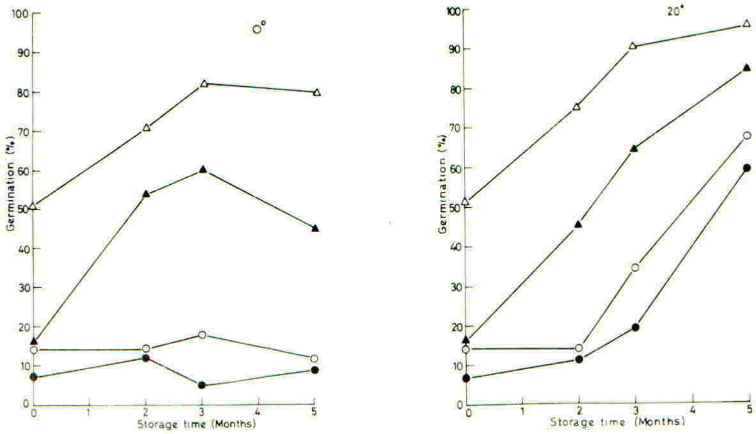

Fig. 2 Germination of Spergula seed as a function of age. Seed stored at 0°C or 20°C. Germination conditions: Dark ●—●, Light O—O, Dark + C_2H_4 ▲—▲ Light + C_2H_4 △—△.

At low storage temperatures the characteristics of the seed change little apart from a rise in the level of germination in the presence of ethylene. At 20°C however marked changes are observed. Firstly, germination in the absence of ethylene remains low for two months but thereafter increases markedly; furthermore, dark germination is as high as germination in the light. In the presence of ethylene germination rises continuously both in the light and the dark as the seed ages. It should be noted, however, that after five months the difference between ethylene treated and untreated seed is small. Is this because the seed is no longer ethylene requiring? The answer to this question was given by experiments with 12 month old Spergula seed. In the dark, germination was very high and addition of ethylene had no effect. In the light, however, germination was inhibited but the inhibition could be reversed by treatment with ethylene. The explanation of this paradox is that this older seed released ethylene on imbibition whereas freshly harvested seed did not. Furthermore, ethylene production appears to be light inhibited - an effect observed in other plant systems (Goeschl and Pratt, 1968). These results are reminiscent of the findings of Esashi & Leopold (1969) who showed that in Trifolium subterraneum ethylene evolved by the seed itself was instrumental in breaking dormancy. There is a further point to stress here. It is now established that methionine is a precursor of ethylene in plants (Yang, 1968) and we have found that it will substitute for the gas in breaking dormancy in Spergula whether or not the seed normally releases ethylene on imbibition. This would seem to indicate that the enzymes necessary for ethylene production are present in the seed at all times but that in fresh seed biosynthesis does not proceed on imbibition. The fact that this capacity is realised as the seed ages makes the situation analogous to that found with other growth hormones. Of course, the possibility that methionine induces the enzymes necessary for ethylene biosynthesis cannot as yet be excluded. Nevertheless, it is clear that whether or not Spergula seed will germinate at a particular time depends, amongst other things, upon the availability of exogenous ethylene from the soil or on the capacity of the seed itself to produce it. Thus both environmental and endogenous factors are involved.

Since both ethylene and light are necessary for the breaking of dormancy in *Spergula* we are faced with the problem of elucidating their respective roles. In a number of systems already studied which are phytochrome controlled it appears that the effect is mediated through the release or biosynthesis of growth hormones, in particular gibberellins: for example in wheat leaf unrolling (Beevers *et al.*, 1970) and in *Rumex obtusifolius* (Taylorson pers. comm.). An investigation of these possibilities in *Spergula* seemed appropriate. As regards the ethylene response this seems to act by removing some block to the expression of the phytochrome effect; this is true even where dormancy is broken by ethylene in the dark since if such seed is irradiated with far-red light no germination occurs as a result of subsequent ethylene treatment. In other words, the system is at all times under phytochrome control but some of the seed may contain sufficient pre-existent Pfr to respond to ethylene even in the absence of light. It is worth noting in passing that the sensitivity of the seed to light, besides varying with time, may also be modified by other factors. Thus, in fresh seed, germination will proceed rapidly after 0.5 min irradiation with red light in the presence of 10 ppm ethylene provided that 0.2% KNO_3 is present. In the absence of KNO_3 a much longer exposure to light would be necessary.

If the role of phytochrome in this system is involved with the biosynthesis or release of growth hormones it is attractive to suggest that ethylene mediates some of these effects, perhaps as a consequence of its effects on membrane permeability (Jones, 1968) or respiration (Olson & Spencer, 1968).

We have approached the problem in two ways. Firstly, by determining whether application of hormones to the seed will substitute for either or both ethylene and light; and secondly, by looking at changes in the levels of endogenous growth substances or inhibitors.

Table 3

Effect of gibberellic acid or ethylene upon germination of scarified Spergula seed.

	Pretreatment and incubation conditions		
	DARK 7 days	FR (2 days) DARK (5 days)	FR (2 days) WHITE LIGHT (5 days)
	Germination ± S.E.		
CONTROL	19.5 ± 2.6	4.0 ± 0.0	14 ± 2.0
100 ppm GA_3	83.0 ± 2.1	14.5 ± 1.5	35 ± 7.0
100 ppm C_2H_4	92.2 ± 2.0	12.0 ± 3.4	51 ± 8.2

The effect of GA_3 upon germination of *Spergula* seed is shown in Table 3. In order to achieve penetration of the hormone it is necessary to acid-scarify the seed and at first sight it appears that GA_3 will substitute for both light and ethylene in breaking dormancy since germination proceeds in the dark. However, if scarified seed is exposed to far-red light prior to gibberellin treatment germination is inhibited and furthermore this inhibition can be partially reversed by subsequent exposure to red light. Results with ethylene under these conditions are given for comparison. Thus, scarification appears to increase the efficiency of the phytochrome system and hence it seems that GA_3 substitutes only for ethylene in breaking of dormancy. This does not necessarily imply that phytochrome is not involved in some other way with gibberellin formation or release but it does suggest that the effect is not as direct as that in for example lettuce where treatment with GA_3 substitutes for the light effect (Lona, 1956). However, it indicates that some other factor is provided by the light reaction and in addition suggests that the mechanism of action of ethylene is closely involved with gibberellins. In fact inhibitors of gibberellin biosynthesis such as AMO1618 and chlormequat inhibit ethylene and light induced germination in Spergula. In addition, gibberellin induced germination at optimal concentrations is not enhanced by ethylene treatment.

What is the nature of the additional factor provided by phytochrome? Recently van Staden & Wareing (1972) showed that in Rumex obtusifolius where germination is also under phytochrome control marked changes in cytokinin levels occur in response to irradiation with red light; furthermore these changes are reversed by exposure to far-red light indicating that the process is under phytochrome control. In collaboration with Dr. van Staden we have looked at cytokinin levels in Spergula under inductive conditions. Our results are summarised in Fig. 3 a) b).

If we consider what happens in those fractions where we would expect to find free bases and ribosides then there is some increase in all fractions compared to dry seed. It is apparent however that whereas there is a marked difference between ethylene treated and untreated samples in the light, in the dark the difference is small. In contrast, those fractions containing ribotides show a striking synergism between ethylene and light, in cytokinin production or release. Is this the factor provided by phytochrome? Unfortunately for this hypothesis cytokinins have no effect whatsoever on germination in Spergula in any combination with light and/or ethylene. Curiously enough an exactly analogous phenomenon occurs in Rumex, the only difference there being that gibberellins will substitute for light in breaking dormancy. It is difficult to advance a hypothesis to account for the results observed, especially inasmuch as changes in cytokinin levels in seeds have been observed in response to dormancy breaking conditions (stratification) in Acer (van Staden, Webb & Wareing, 1972) and in that case cytokinins do stimulate germination. One explanation would be that applied cytokinins do not penetrate the seed, but perhaps an even more plausible possibility is that we have not yet tried the right cytokinin. As our techniques for the separation and identification of cytokinins improve to the level already attained by Macmillan and others with gibberellins it is becoming increasingly clear that cytokinins other than those at present identified do exist and it is not unlikely that these may show variations in specificity in the same way as gibberellins. One method whereby this sort of problem may be overcome is the use of the material from which the growth substance has been extracted as the test system for their activity. This procedure has been used successfully in a number of cases - for example in the work of Loveys & Wareing (1971) on the phytochrome controlled wheat leaf unrolling response where gibberellin like material extracted from induced tissue was many times more effective in causing unrolling that GA_3. We have used this technique with Spergula and although it is too early as yet for definitive results, there are marked changes in gibberellin levels in the seed in response to ethylene treatment and these changes are more readily observed in this way than by using a conventional gibberellin bioassay such as lettuce hypocotyl extension. The same is true of our studies on changes in endogenous inhibitor levels, but in this case the use of any bioassay must be considered with caution, particularly with seeds, in order that changes in the levels of active inhibitors are not confused with the high background levels of other non-specific inhibitor material such as phenolics.

This I think brings us to another more fundamental point which must be considered in any study on changes in endogenous hormone levels; that is, it is important not to consider levels at any one time in the progression of the seed from the dormant state to the moment when germination is initiated; instead we should look at the pattern of changes occurring during this period. In other words the requirement of a seed for a growth hormone may not be continuous. Sequential effects of growth hormones correlated with different phases of development are now well established in a number of systems for example in the Avena coleoptile (Wright, 1968) and it seems that similar phenomena may occur in seeds. The most convincing evidence for this has been shown in seed of Acer which I have already mentioned. The changes which

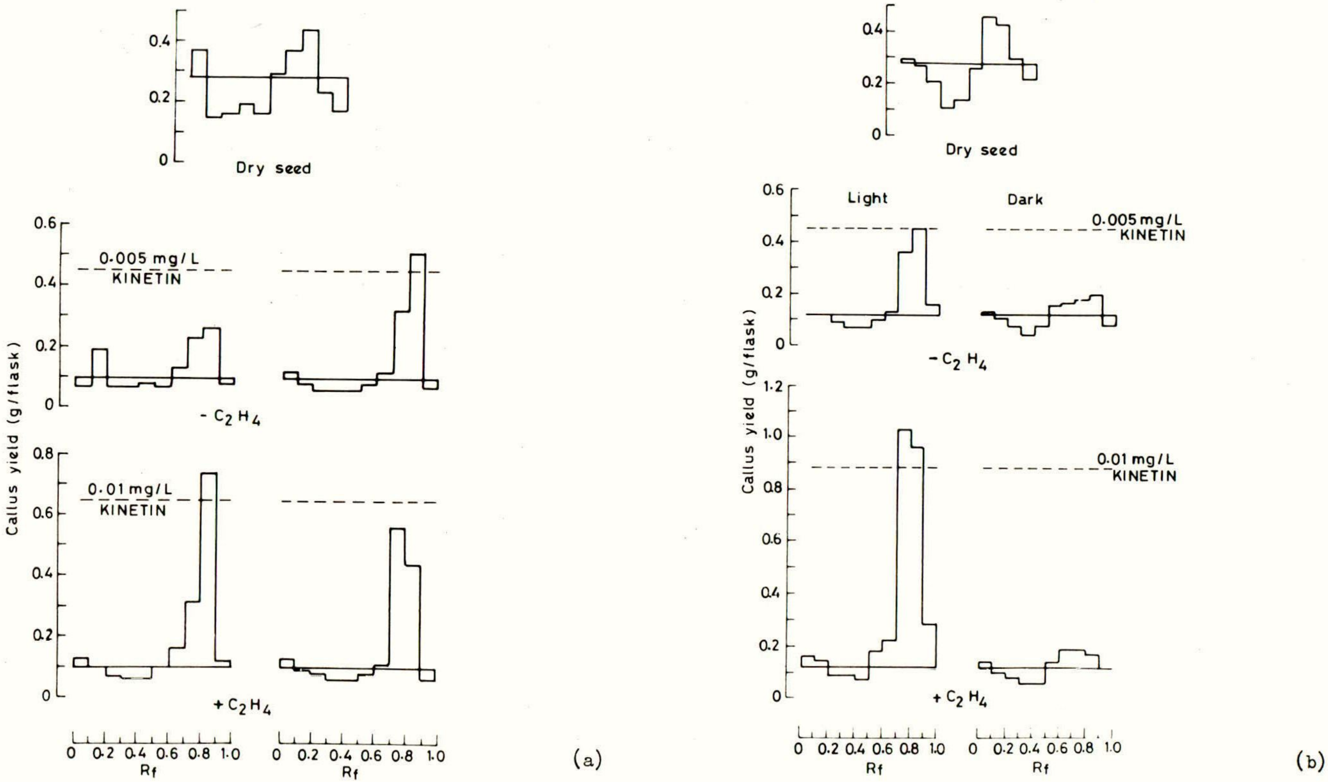

Fig. 3 Soybean callus assays of paper chromatograms loaded with either n-butanol (a) or aqueous (b) extracts from *Spergula* seed. Five grams dry weight equivalent chromatographed on Whatman No. 3MM in water-saturated sec-butanol. Treatments are as shown. Seed was extracted 2 days after imbibition.

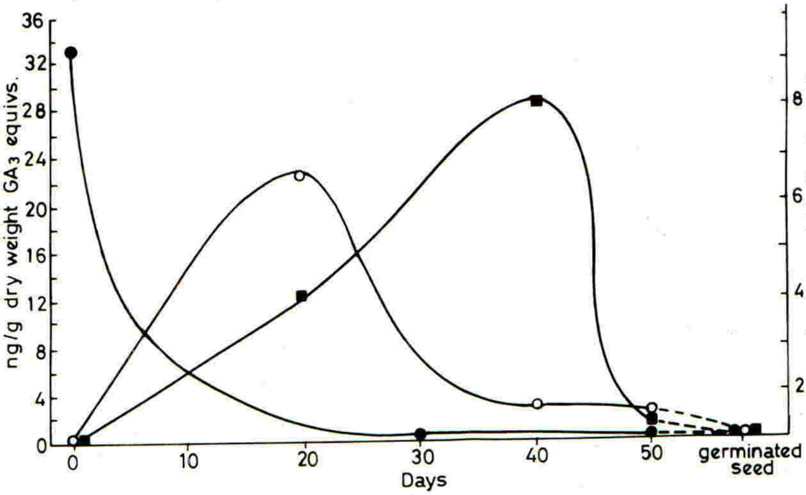

Fig. 4. Changes in levels of endogenous growth regulators during stratification of Acer seed. ●=abscisic acid; O=kinetin equivalents; =GA_3 equivalents.

occur during stratification of this seed are shown in Fig. 4. The first effect observable is a fall in the level of abscisic acid in the seed; this is followed by a rise in extractable cytokinin activity followed in turn by a fall and a concomitant rise in endogenous gibberellin levels. At this point the seed will germinate normally if it is transferred to optimum conditions. It is interesting that in this case we have the converse situation to that found in Spergula arvensis and Rumex obtusifolius; that is, whereas inductive conditions in all three cases result in fluctuations in gibberellin and cytokinin levels, in Acer, cytokinins will break dormancy whereas gibberellins will not (Webb & Wareing, 1972), and vice versa in the other two species. The implication of abscisic acid in the work with Acer also emphasizes the point made by a number of workers that growth promoter/inhibitor interactions may be important in the breaking of dormancy in a number of species (see for example Webb & Wareing, 1972). One final word is appropriate here concerning endogenous levels of growth regulators. Gutterman (1972) has shown that the environmental conditions under which the parent plant is grown have a marked effect on the dormancy of the progeny and this is correlated with endogenous hormone levels in the seed. Thus it is important in any studies on seeds to be certain that the material used is derived from plants grown under comparable conditions lest the results be complicated by differing hormone levels within the seed.

From this brief discussion it must be obvious that we still have a long way to go before a comprehensive picture emerges of the changes which may occur in endogenous levels of growth hormones prior to germination andof the respective contributions to the breaking of dormancy. Nevertheless, such studies as have already been made can contribute a good deal to the search for an effective means of weed control. Taking Spergula as an example - unless we appreciate that light as well as ethylene controls dormancy then application of some ethylene releasing chemical such as CEPA to the soil will only result in the germination of the seeds near to the surface i.e. those exposed to light. However, if the treatment is made after ploughing when a larger number of seeds have been exposed to light then the results will accordingly be more effective. Again, our results would indicate that such a treatment would be more likely to succeed immediately after seeding has taken place i.e. when the seeds are most responsive to ethylene; this is even more true of species such as Hypochaeris radicata where the ethylene effect is more transitory than in Spergula.

What then can be said in conclusion? Some years ago at another of these conferences the distinguished plant physiologist J. van Overbeek suggested that only by elucidating the mode of action of growth hormones can we rationalize work directed at producing synthetic substances for use in weed control. The suggestion that I would like to make is similar in kind but different in extent and related specifically to weed control via manipulation of dormancy mechanisms. It is that we must first identify precisely the nature of the signals initiated by the environmental conditions triggering germination, and since the weight of evidence indicates that hormones are usually involved it is the nature and the levels of these that we need to characterise. In the second place we must determine the nature of the hormonal effects and by this I would include not only their mode and site of action but in addition a determination of the extent of their interactions and the possible implication of sequential effects. Armed with this information - which admittedly will involve many years of work and development of new techniques - comprehensive weed control may become a reality.

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Fig. 3 taken from J.van Staden, S.T. Olatoye and M.A. Hall (1972) Effect of light and ethylene upon endogenous cytokinin levels in seed of *Spergula arvensis*. *J. exp. Bot.* (in press)

Fig. 4 taken from D.P. Webb, J. van Staden and P.F. Wareing (1972) Seed dormancy in *Acer*: changes in endogenous cytokinin, gibberellin and germination inhibitors during the breaking of dormancy in *Acer saccharum* Marsh. *J. exp. Bot.* (in press).