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WEED CONTROL PRACTICES AMONG SMALL SCALE FARMERS IN GUYANA

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Summary A survey was made to discover the problems of small-scale rice and food-crop farmers in Guyana. In rice farms weed problems and their control were found to be interrelated with water control and cultivation techniques; herbicides are used, but are in short supply. Food-crop farms rely on mixed cropping and family labour to control weeds. Lack of foreign exchange to acquire imported inputs is the major restriction to chemical weed control.

INTRODUCTION

The constant battle against weeds is a major concern of Guyanese 'peasant' farmers, who would gladly employ the armoury of herbicides and new technology that has been developed to assist them. However, shortages of supply of herbicides and related inputs are severely reducing the farmers productivity and income.

There has been a lack of documentary evidence about the everyday problems of these farmers, so a survey of the small-scale farming systems was made to help to elucidate these problems. This paper reports some of the results of this survey.

METHOD AND AREA OF SURVEY

The purpose of the survey was to examine the farming systems from the farmer's perspective. The author lived with a family of farmers in the Corentyne region of Guyana for twelve months during 1979 and 1980, and carried out the survey with the assistance of two local schoolteachers, using observation and an interview schedule.

The farmers interviewed were randomly selected from each of the five study areas, the locations of which are indicated on the map of Figure 1:

1. Pioneer farms along the Corentyne river, being cleared from forest by slash and burn methods, growing food-crops only;
2. Yakusari, a section of a 12,400 hectare land settlement scheme, cultivated since 1960, growing rice and food-crops, with a good irrigation system;
3. No. 52 Village, an established village with a good drainage and irrigation system, growing rice and food-crops;
4. No. 48 Village, an established village without a drainage and irrigation system, growing rice and food-crops;
5. Letter Kenny, an established village near a sugar cane estate with small plots of rice grown by 'traditional' methods, without a drainage and irrigation system.

Figure 1 : Map of Corentyne Region of Guyana to show areas of Study

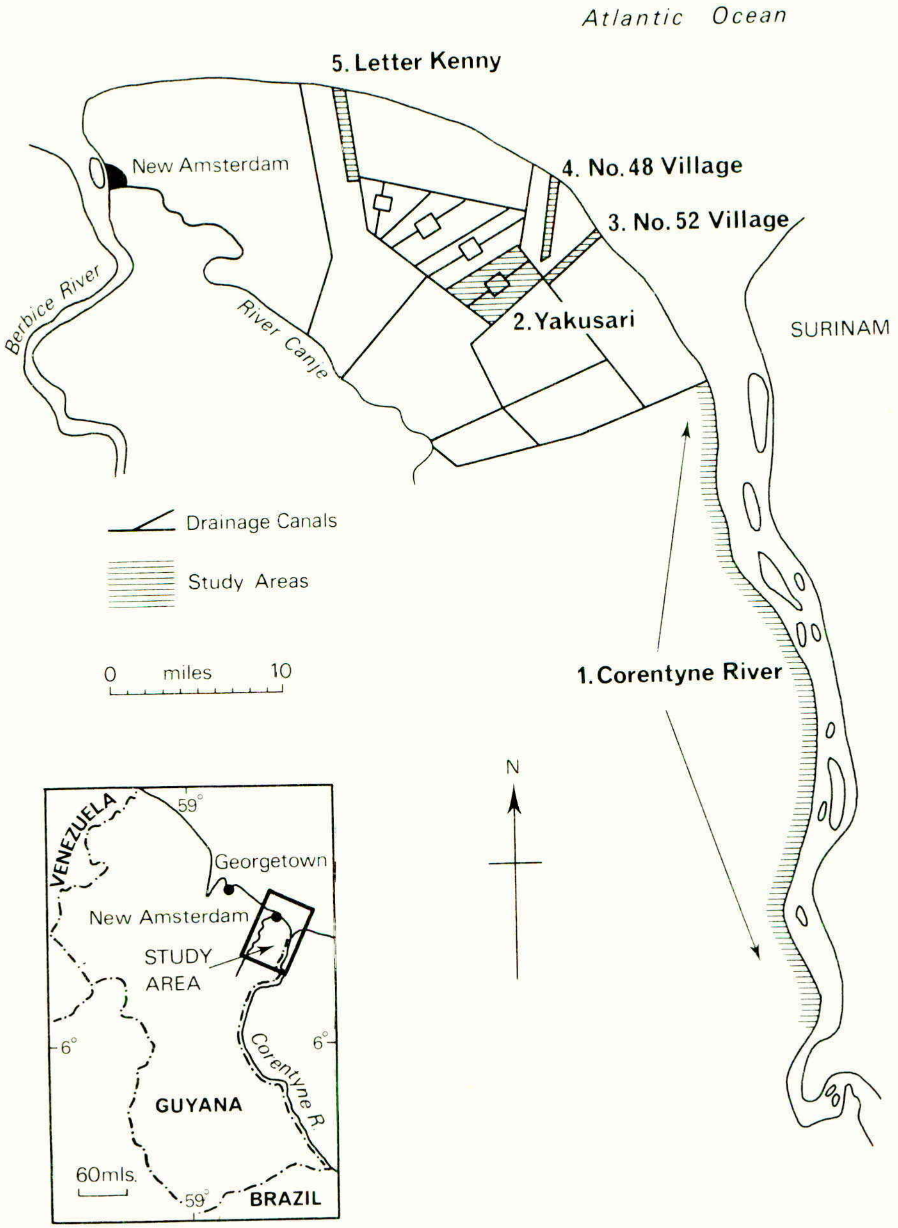

Table 1

Rice Farming Practices

	No drainage and irrigation		Drainage and irrigation	
	Letter Kenny	48 Village	52 Village	Yakusari
Growth of Starbonnet (%)	0	39	100	100
Growth of traditional varieties (%)	100	61	0	0
Sowing pre-germinated seed on flooded land (%)	6	50	100	100
Sowing dry seed on dry land (%)	17	50	0	0
Transplanting seedlings (%)	83	0	0	0
Size of rice holding (ha)	1.0	2.3	4.5	6.0
Average yield of paddy (t/ha)	2.9	1.8	2.1	2.3

Table 2

Rice farms (%) with weed problems

	No drainage and irrigation		Drainage and irrigation		
	Letter Kenny	48 Village	52 Village	Yakusari	Mean
Muraina Grass	56	69	61	83	68
Flower Grass	61	0	6	11	20
Casbinia	78	6	24	0	23
All grass weeds	83	72	71	89	79
Bisi Bisi	89	11	0	0	25
Jhussia	83	44	53	72	63
All reeds and sedges	89	44	53	72	65
Soap Bush	17	0	12	0	9
Duck Weed	72	39	24	56	48
All broad leaf weeds					

Table 3

Factors influencing weed control

	No drainage and irrigation		Drainage and irrigation		
	Letter Kenny	48 Village	52 Village	Yakusari	Mean
Average size of rice holding (ha)	1.0	2.3	4.5	6.0	3.4
Farmers (%)					
with own tractor	6	28	68	56	39
with difficulty to hire tractor	78	56	22	39	49
reporting increase of weeds due to water shortage	17*	39*	33	78	42

* Lower figures than expected because farmers anticipate water shortage and associated weed problems.

Table 4

Rice farms (%) with weed problems and using herbicides

	No drainage and irrigation		Drainage and irrigation		
	Letter Kenny	48 Village	52 Village	Yakusari	Mean
Grass weeds	83	72	71	81	79
Propanil usage	0	44	47	72	41
Reeds and sedges	89	44	53	72	65
2,4 - D usage	83	44	47	77	63
Broad leaf weeds	72	39	24	56	48
Propanil and 2,4 - D usage	0	11	29	56	24
Experience of herbicide supply problems	44*	96	100	100	85

* Less problems at Letter Kenny, since farms are small and can be weeded by hand.

Table 5

Farming practices of foodcrop farms

	Corentyne River	Yakusari	52 Village	48 Village	Letter Kenny
Foodcrop growing farms (%)	100	95	85	70	30
Average area planted (ha)	2.63	0.81	0.53	1.25	0.24
Time spent weeding (d/p.a.)	176	21	15	24	9
Use of cutlass for weeding (%)	100	100	100	85	100
Use of hoe for weeding (%)	0	94	80	85	50
Farms (%) with					
tree crops	100	95	79	29	83
root crops	86	26	36	36	50
vegetable crops	71	95	100	93	67

RESULTS AND DISCUSSION

In Guyana, as in other tropical underdeveloped countries, the 'peasant' farmers have evolved farming systems designed to ensure their families' supply of basic foodstuffs despite the problems posed by an uncertain environment - seasonal drought and flooding, attacks by insects and wild animals, and the encroachment of weeds. Rice is grown on the swampy savannas, where flood water can suppress weed growth, while on the drier sand reefs near the villages, and on the river and canal banks, mixed cropping of other food plants is practised, so that rapidly growing plants such as bananas can suppress weeds by natural competition, giving root and green vegetables a chance to grow.

From this subsistence base, rice and foodcrops have been developed into cash crops, with rice an export crop accounting for ten per cent of export earnings, and both marketing and supply of inputs controlled by a monopoly government corporation, while other food crops remain small-scale, unregulated and subject to the gluts and scarcities of a small domestic market.

Rice Farming

Since the Second World War, rice farming has been transformed and expanded; the traditional, slow methods of ploughing with oxen and hand-harvesting with family labour have given place to mechanised cultivation and harvesting of larger plots of land. The introduction from the U.S.A. of earlier maturing varieties of rice, in 1970, made it possible to grow two crops of rice per year in areas with drainage and irrigation; of these, the variety Starbonnet in particular has been rapidly adopted by farmers.

Table 1 shows the complete acceptance of Starbonnet by farmers in the two survey areas with good drainage and irrigation. In the areas without water control, the use of traditional varieties, and traditional labour-intensive methods continues in Letter Kenny, where the size of holdings is small, and the purpose of farming subsistence; but the farmers in No.48 Village, who grow rice as a cash crop, have adopted a mixed system, because lack of drainage and irrigation makes it difficult to grow Starbonnet as successfully as their neighbours, and the rice lands are considered to be too large to use the labour intensive methods.

With the increasing use of hybrid varieties, fertilizers and double-cropping, the problem of weeds has also increased. 100 per cent of farmers reported an increase in weeds during the last ten years. The main weed problems experienced by farmers in the survey are shown in Table 2. Of these the greatest threat is considered by farmers to be Muraina Grass (Ischaemum rugosum), a very competitive grass weed, which has appeared only in the last five to six years, and is difficult to discern from rice in the early stages of growth.

Cultivation practices are the main method of weed control. Ideally the burning of crop residues is followed by thorough ploughing during the dry season, and a system of under-water cultivation; the land is irrigated to allow weed seeds to grow, then 'puddled' by a tractor fitted with cage wheels, to bury the weeds in mud. After the mud has settled, pre-germinated seeds are shied onto the flooded land, and the seedlings grow through 10 to 15 cm of water for one week; then the land is partly drained for two to three days to encourage the growth of roots, and re-irrigated.

This method of weed control requires a reliable supply of irrigation water, and a moderately high powered tractor suitably equipped for the purpose. Table 1 shows that 100 per cent of farmers in areas with irrigation practise this method of cultivation/ weed control.

However, the weather was exceptionally dry during the survey period, and since this was compounded by mechanical failure of the pumps, irrigation supplies at Yakusari were inadequate; Table 3 shows the consequent failure to control weeds by the wet cultivation method. It also indicates that the problem of obtaining tractor services is associated with the size of plots and quality of water control. This problem is increased by a lack of spare parts, which are not imported because of foreign exchange shortages. Farmers experiencing this problem reported that cultivation by hired tractors was inadequate to control weeds.

Herbicides are used to control weeds that have survived cultivation. Propanil is the only grass herbicide used in rice cultivation and is used when the crop is at the 2, 3 and 4 - leaf stage of development. The land is drained before spraying and re-flooded two or three days later. For the control of reeds and sedges and broad leaf weeds, 2,4-D and a mixture of 2,4-D and propanil respectively are applied 3 weeks after sowing, with 5-8 cm water in the field. The mixture of 2,4-D and propanil is recommended for the control of Soap Bush, but is also used for Duck Weed, since the relevant recommended treatment, the sodium salt of pentachlorophenol (PCP-Na), is not available.

It is difficult for farmers without irrigation to control grassweeds with propanil (for which the land must be drained) because they need to conserve water in their fields. Table 4 shows the percentage of farmers using herbicides, and indicates the high proportion using 2,4-D which is cheaper than propanil. The supply of herbicides and other imported supplies has been restricted for the past three years by the shortage of foreign exchange and consequently many farmers have had difficulty in obtaining them, as shown by Table 4. Farmers queue for up to three days at the offices of the Guyana Rice Board to obtain supplies, which are measured from a bulk store into the farmer's own containers.

Hand weeding is practised in the small areas of the rice fields set aside for the production of seed for the next crop, and at Letter Kenny in the fields of less than half a hectare, where the crop is grown for subsistence only. Hand weeding is not considered to be worthwhile in larger farms, growing rice for the market, because of lack of profitability of the crop; 93 per cent of farmers in the survey found that the price they received for their rice did not compensate them for the costs of production. This is because the present rice farming system is dependent upon imported inputs, and particularly since oil prices started to rise sharply in 1973 the government of Guyana has found it increasingly difficult to find foreign exchange to import the tractors, combine harvesters, spare parts, fuel, fertilizers and pesticides on which farmers have come to depend. These inputs are therefore very scarce, and their prices have risen so sharply that the profitability of rice farming has been eroded. Under these circumstances, farmers will not increase their costs by hiring labour to do weeding, and although farmers do not put any cash value on their own labour, they nevertheless regard the extra effort as not being worthwhile.

Although yields of 5.7 t/ha of Starbonnet paddy have been obtained in experimental plots (Madramootoo,1972), and yields of 3.1 t/ha have been achieved by farmers in Yakusari in previous years, the yields during the period of survey fall far below these levels (Table 1). It is believed that the weed problem accounts for much of this difference.

Foodcrop Farming

Compared with mechanised rice monoculture, the growing of other foodcrops is characterised by diversity and family labour. Table 5 shows the varying degrees of involvement in foodcrop farming of the different areas, from the Corentyne River, where it is the sole source of livelihood, to Letter Kenny, where more farmers are involved in other employment.

In the established villages,foodcrops are grown on small plots of land near to the housing areas, and on government land adjacent to drainage canals. The larger average holding in No.48 Village occurs because farmers, despairing of the lack of drainage and irrigation for rice, have concentrated on other crops. In the land settlement scheme, Yakusari, settlers were each allocated one hectare of homestead land for housing and foodcrops. Along the Corentyne River, the land is being cleared from forest by farmers using slash and burn methods, and the only factor limiting the extent of their farms is the amount of labour available to them.

Table 5 shows that the amount of time spent in weeding crops is related to the amount of land planted, as one would expect. However, since these figures are very difficult to calculate, they are an indication of the order of magnitude only. For whereas farmers and their families in the established villages and land settlement scheme will spend a few hours each day at weeding, along the Corentyne River the farmers camp near their land for ten days of every fortnight, and their labour is concentrated.

Table 5 also shows that most of the weeding is done with a cutlass, although well-established plots are hoed. Family labour is sufficient for weeding the small plots of land in the established villages and Yakusari, but acute labour shortage is experienced by all the Corentyne River farmers, since their families usually remain in the town to receive education. Hired labour is reluctant to undertake this arduous work in primitive circumstances.

Unemployment in Guyana, as in other less developed countries, is distressingly high, but impossible to measure, because, in the absence of social security, the unemployed create work to support themselves. Foodcrop farming is one method of self-support which can be expanded, since abundant suitable land is available along the Corentyne River. But, as Doll (1976) suggests of Colombia, " the drudgery of spending 50% or more of your life fighting weeds ", makes farming unappealing. There is an evident need for more efficient weed control. Herbicides would be beneficial to farmers in these circumstances, but they are extremely difficult to obtain, and only seven per cent of Corentyne River farmers used a herbicide (paraquat).

CONCLUSION

The evidence of this survey suggests that small-scale farmers in Guyana are willing to adopt modern techniques, when the advantages can be seen. They both recognize the need for weed control, and are willing to employ all the techniques available to them. Their main problem is that the instruments of modern weed control are not available to them, mainly because of shortages of foreign exchange.

Large sums of money have recently been made available, by the World Bank and other international agencies, to develop a vast drainage and irrigation scheme in the area of the survey; but without the comparatively small amount of imported tools and herbicides required by the farmers, the high hopes that increased production will result from the investment, are doomed to failure. If production and productivity are to be increased, the farmers need the weapons to fight the weeds.

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NOTES

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LIVE MULCH : A NEW APPROACH TO WEED CONTROL AND CROP PRODUCTION IN THE TROPICS

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Summary Live mulch is a crop production technique in which a food crop is planted directly in a living cover of an established cover crop without tillage or destruction of the fallow vegetation. The effect of several established legume covers on weed competition, fertilizer requirement and yield of maize was studied in the field at the International Institute of Tropical Agriculture. Weed infestation was heaviest in unweeded conventionally tilled and no-tillage plots, but very low in unweeded Centrosema pubescens and Psophocarpus palustris plots. Consequently, maize yield was reduced in all ground covers where weed infestation was heavy but not in the covers that effectively suppressed weeds. Maize yield was significantly higher in the live mulch plots that received no fertilizer than in similarly treated conventionally tilled and no-tillage plots. When 60 kg/ha each of N, P_2O_5 and K_2O was applied to all ground covers, maize yield was either equal or better in the live mulch plots than in the conventionally tilled and no-tillage plots.

INTRODUCTION

Crop production by smallholder farmers of the humid and sub-humid tropics is at the subsistence level. In the past, this was a stable system characterized by low human population densities, intercropping systems, and prolonged fallow periods that stabilized soil fertility and kept hard-to-kill weeds in check. Under the traditional shifting cultivation and bush fallow which are the predominant farming systems in the tropics (Allan, 1965; Greenland, 1974; 1975; Watters, 1971) farmers usually abandon cultivated lands to revert to bush fallow partly because of declining fertility (Nye and Greenland, 1960) and partly because of increasing weed infestation (Concklin, 1957; Emerson, 1953).

While the long fallow periods lasted, hoe weeding was an effective additional weed control method used by farmers. This system has become destabilized in recent times as a result of increasing population pressure on limited areas of land, which in turn has reduced the length of the fallow periods. Excessive weed growth in the cropped short-term fallow has increased the frequency of weeding to such an extent that weeding has become the highest cost item in the production of practically all crops in the tropics. It is also one of the main drudgery items in farming in this region.

In West Africa and other parts of the tropics, fallow period has become considerably shortened to the point that nutrient deficiency symptoms are evident in such crops as maize in newly cleared lands. Consequently yield has dropped below levels ordinarily associated with poor crop husbandary. Some of the soil conservation methods that have been identified as suitable for crop production in the tropics include no-tillage and mulching (Akobundu, 1977; Lal, 1975). Unfortunately some of these conservation measures require higher rates of fertilizer than when conventional tillage is used, especially for such crops as maize.

Furthermore, smallholder tropical farmers are not used to investing in fertilizer as a crop production input. In Nigeria where fertilizers are highly subsidized, distribution problems and uncertainty in supply still limit its use to a few farmers. Other methods of crop and land management are necessary to reduce the cost of weed control and the farmer's dependence on fertilizers. The objective of the present study was to assess the effectiveness of several established legume cover crops in suppressing weeds, sustaining crop yield and contributing to the nitrogen requirement of the maize crop.

METHOD AND MATERIALS

The experiment was carried out in the second season (August-November) of the 1979 growing season in a research farm at the International Institute of Tropical Agriculture, Ibadan, Nigeria. Main plot treatment consisted of ground cover management with a plot size of 5m x 30m. The ground cover treatments were no-tillage, conventional tillage, wild groundnut (*Arachis epens*), centro (*Centrosema pubescens* Benth) and wild winged bean (*Psophocarpus palustris* Desv). Centro and wild winged bean covers were established from seed in 1977, while the wild groundnut was established the same year from stem cuttings.

Each ground cover was randomly located during the initial ground cover establishment. These main plot treatments were replicated three times. The legumes have perennial growth habit and remained green during the five-month dry season. A dense ground cover of each legume was used for this experiment in 1979.

Before planting maize in the legume covers, paraquat (0.5 kg ai/ha) was applied by CP-3 knapsack sprayer set at low pressure to clear 15 cm wide strips across each plot of legume cover. Each strip was 5 m long with an interrow spacing of 75 cm. Maize (cv. TZE 4) was planted in the sprayed strip three days after spraying. Two maize seeds were planted per hill every 25 cm along each strip. The maize was thinned to one stand after germination to give a plant population of 53000 plants/ha. Paraquat (0.5 kg ai/ha) was used for preplant vegetation control in the no-tillage plots. A roto-tiller was used for seedbed preparation in the conventional tillage plots. Maize was planted at 25 cm x 75 cm in all the plots.

In order to assess the effect of weed competition on maize yield, fertilizer was applied uniformly to all ground covers at a rate of 60 kg/ha each of N, P_2O_5 and K_2O two weeks after maize emergence. Subplot treatments were made up of plots that were weeded once, kept weedfree or left unweeded until crop harvest. Data on weed species distribution and weed biomass were recorded at crop harvest from three 0.5 m^2 quadrats randomly selected from each of the subplots.

The effect of fertilizer application on crop response to various ground covers was also investigated. Fertilizer was applied two weeks after maize emergence to all ground covers at three levels (0 kg/ha NPK; 60 kg/ha each of N, P_2O_5 and K_2O and 120 kg/ha N, plus 60 kg/ha each for P_2O_5 and K_2O). All plots were kept weedfree to minimize interference from weeds. All treatments were replicated three times.

Preliminary experiments had shown that it was impossible to grow any crop in established cover of either centro or wild winged bean because these climbing legumes tended to smother the crop. In order to prevent the legumes from climbing on the maize a growth retardant (CGA 47283) was applied three days after maize emergence as a broadcast spray over maize and legume covers at a rate of 2.0 kg ai/ha using a knapsack sprayer calibrated to deliver 200 l/ha spray volume. Visual observations and plant height data were recorded five weeks after planting for possible injury to maize by the growth retardant.

RESULTS

Weed interference due to uncontrolled weed growth caused significant reductions in maize yield relative to the weedfree plots in both no-tillage and conventionally tilled plots but not in the live mulch plots (Table 1). Weed dry weight in the unweeded conventionally tilled plot was about eight times more than the weed weight in the unweeded plots of either centro or wild winged bean. There were marked differences in weed flora distribution between the live mulches and conventionally tilled plots. While 32% of all weeds in the latter were broadleaves and 68% were grasses, the reverse was true of the live mulch plots.

Maize response to fertilizer differed with the type of ground cover. Maize grain yield was significantly higher in the live mulch plots that did not receive any fertilizer than in the no-tillage plots that received no fertilizer (Table 1). Maize yield was similar in all ground covers when 60 kg/ha of NPK was applied. Maize yield increased with increase in nitrogen level in the conventionally tilled and no-tillage plots but not in the live mulch plots. Increasing the nitrogen level above 60 kg/ha had a depressing effect on grain yield in the centro and wild winged bean plots.

There was a marked difference in earthworm activities in the conventionally tilled and live mulch plots. Both the number and dry weight of earthworm casts were higher in live mulch plots and very low in conventional and no-tillage plots (Fig. 1). The high earthworm activity is an indication of a highly favourable soil environment for the soil fauna. Increased earthworm activity in mulched maize plots had earlier been reported by Lal (1975). The growth retardant CGR 47283 did not have any adverse effect on maize growth and grain yield, but was effective in suppressing vine growth in the legumes for ten weeks after treatment.

DISCUSSION

No-tillage crop production and use of organic mulch have already been shown to minimize erosion, reduce loss of organic matter and maintain good water infiltration (Lal, 1975). While the logistics of obtaining mulch cover at a rate of over 4 t/ha limits the general adoption of this package, the high dependence of no-tillage on good chemical weed control may hamper its universal adoption at the smallholder farmer level in the tropics.

Live mulch crop production incorporates the soil conservation features of organic mulch and no-tillage but has the added advantage of smothering weeds. This study has shown that weeding was not necessary in the centro and wild winged bean plots. In the latter, maize yield from the unweeded plots was identical to that from the weedfree plot. The low weed weight observed in the live mulch plots is due to the permanent cover provided by the live mulch. Smothering weeds is a known characteristic of mulch covers. This characteristic of the centro and wild winged bean covers are best exploited when their climbing tendency is controlled with growth retardants such as CGA 47283 used in this study. Farmers in the humid tropics spend about 50% of their time fighting weeds. A weed management practice that reduces this high labor input has a chance to reduce the cost of producing the crop.

Results of this study show that the live mulch contributes to the nitrogen needs of the maize crop. Leaves of six-week-old maize showed nitrogen deficiency symptoms in the conventional and no-tillage plots that received no fertilizer while identical treatments in the live mulch plots did not.

Table 1

Grain yield of maize (t/ha) as affected by weed competition and fertiliser and ground cover in live mulch crop production systems

	Effect of weed competition 1)				Effect of amount of nitrogen (kg/ha)			
Ground Cover	Weeded once	Weed free	Unweeded	Mean	0	60	120	Mean
No tillage	950	0	1600	-				
	2.51	2.78	1.61	2.30	0.68	2.78	3.47	2.31
Conventional tillage	690	0	2890	-				
	2.71	3.04	2.27	2.68	1.48	3.04	3.11	2.54
Arachis	180	0	610	-				
	3.00	2.98	2.47	2.82	2.03	2.98	3.32	2.78
Centrosema	80	0	360	-				
	3.39	3.51	2.65	3.18	1.97	3.51	2.54	2.67
Psophocarpus	0	0	360	-				
	2.93	3.00	2.83	2.92	2.15	3.00	2.62	2.59

Least significant difference (P=5%) between means:		
within type of ground cover	0.58	0.91
between different types of cover	1.04	0.90
Coefficient of variation:		
within type of ground cover	12.0%	20.6%
between different types of cover	30.7%	18.5%

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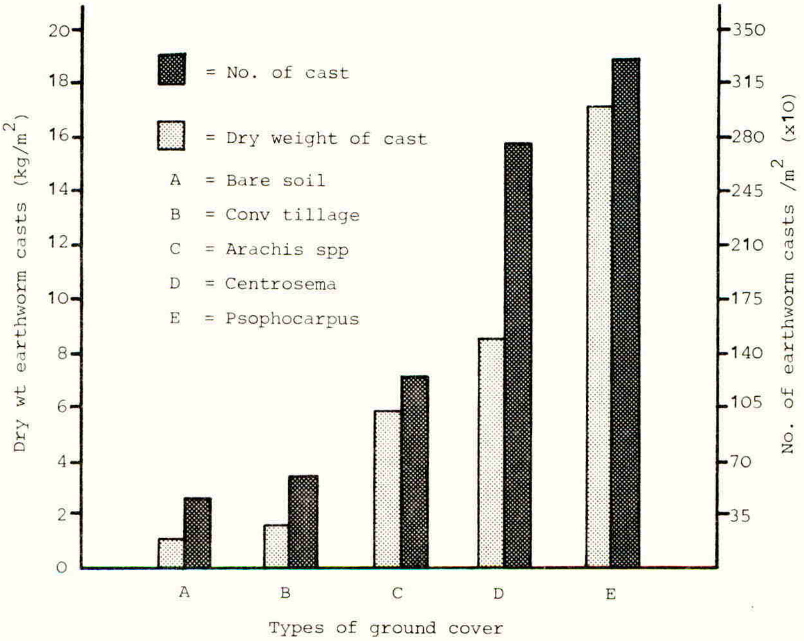
1) Weeds were sampled at crop harvest and their dry weight (kg/ha) is shown in the top line opposite each type of ground cover.

Fig. 1

Earthworm activity under selected ground covers



The nitrogen-fixing ability of centrosema and other tropical legumes have been known for several years but little or no effort has been made to tap this natural source of nitrogen directly for crop production. Bruce (1967) reported that centro fixed 100 kg N/ha in the top 15 cm of soil in North Queensland, Australia. In Hawaii, Whitney et al (1967) showed that in a volcanic soil, centro fixed 268 kg N/ha in pure stand and 121 kg N/ha in mixed grass sward. Centro was also shown to transfer up to 11% of the 123 kg N/ha it fixed to associated grass when grown in a grass mixture. The significantly better performance of maize in the live mulch without fertilizer is an indication that the maize benefited from the nitrogen fixed by the legume. Poor crop performances observed in the conventionally tilled and no-tillage plots that received no fertilizer are typical of those in farmers field in the humid tropical areas where population pressure has reduced the bush fallow period to about three years. Since the live mulch contributes to the nitrogen needs of the crop, this production system offers the opportunity for improving soil fertility, crop yield and reducing weed interference in otherwise impoverished soils of the humid tropics.

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REDUCED PLANT SPACING FOR WEED SUPPRESSION IN TRANSPLANTED RICE

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Summary Transplanting rice at a 10 x 10 cm spacing led to a significant reduction in weed weight compared to a 20 x 20 cm plant spacing in herbicide-treated and untreated plots but not in the hand weeded plots. A significant reduction in grain yield due to weed competition occurred at the wider plant spacing but not at the closer plant spacing. The highest net returns were obtained from the plot in which the rice was transplanted at a 10 x 10 cm plant spacing and weeded once. A farmer may be reluctant though to transplant rice at the closer plant spacing due to the lower cost/benefit ratio compared to rice that is planted at a wider spacing and weeded chemically or by hand.

INTRODUCTION

Bleasdale (1966) reported that if a crop is grown at a range of plant densities it is generally assumed that the total dry matter yield per unit area will increase with increasing density until a level of yield is reached which is rarely exceeded as density increases further. This constant yield over a wide range of high densities represents the maximum fixation of energy that a crop can achieve in the time between sowing and harvest.

In transplanted rice culture, plant density is determined by the number of seedlings per hill and the number of hills per unit area. Yamada et al (1961) reported that the final dry weight per unit area was approximately constant, irrespective of differences in planting density. Akamatsu (1968) found that the number of panicles per m^2 was about the same for four different plant densities. Ghosh et al (1979) reported that the highest grain yield was obtained at 15 x 15 cm spacing at 50 kg N/ha and at 20 x 20 cm spacing at 100 kg N/ha. Choubey et al (1967) found that there was no significant difference in yield between plant spacings even though tiller number increased as plant spacing increased.

Plant spacing also affects weed growth. Ghosh and Sarkar (1975) reported that the best weed control was achieved at a 10 x 10 cm plant spacing. Estorninos and Moody (1976) also observed that the closer rice is transplanted, the more competitive it is against weeds.

The objectives of this experiment were to study the effect of plant spacing and weed control treatments on weed weight and grain yield of transplanted rice and to determine the net benefits due to weed control.

METHOD AND MATERIALS

The experiment was conducted at the end of the 1978 wet season on a Maahas clay soil at the International Rice Research Institute. The field was ploughed once and harrowed three times at 7 to 10 day intervals. The final harrowing was done 1 day before transplanting to level the field and incorporate the basal dose of fertiliser. 80 kg N/ha was applied in three equal splits, prior to transplanting, at maximum tillering and at panicle initiation while 40 kg P_2O_5/ha and 40 kg K_2O/ha were applied prior to transplanting.

A randomised complete block design with three replications was used. The herbicide treatments were applied 4 days after transplanting and are listed in Table 1. No weeding and hand weeding (once at 25 days after transplanting) 'controls' were also included. The plant spacings used were 10 x 10 cm and 20 x 20 cm and 2-3 20-day-old seedlings of IR36 were transplanted per hill.

Weeds were sampled at rice heading from two quadrats each 0.5 m x 0.5 m per plot. For rice, leaf area index and the number of panicles per unit area were determined at rice heading. Yields adjusted to 14% moisture were determined from a 5 m^2 sample area per plot.

A partial budgeting analysis was used to determine the benefits to weed control and decreased plant spacing. The benefit/cost ratios of both these practices alone and in combination were also determined.

RESULTS AND DISCUSSION

The most important weeds present in the field at rice heading were *Monochoria vaginalis* (Burm.f.) Presl. and *Scirpus maritimus* L.

Significantly greater weed weights were harvested from the rice planted at the 20 x 20 cm spacing than the 10 x 10 cm spacing when herbicides were applied or the plots were not weeded while no significant differences were observed in the hand weeded plots (Table 1). Significantly higher weed weights were harvested from the unweeded plot than the hand weeded plot at the 20 x 20 cm spacing while no differences were observed at the 10 x 10 cm spacing.

Table 1

Weed weight at heading of transplanted IR36 rice as affected by weed control treatment and plant spacing

Treatment	Rate (kg ai/ha)	Plant spacing (cm)		
		20 x 20	10 x 10	Difference
2,4-D	0.6	103^{b}	42^{a}	61**
Thiobencarb-2,4-D	0.75-0.38	75^{b}	41^{a}	34*
Butachlor	1.0	92^{b}	31^{ab}	61**
Hand weeding	-	29^{c}	20^{b}	9^{NS}
No weeding	-	221^{a}	39^{a}	182**

In a column, means with common superscripts are not significantly different at the 5% level.

** Significant at the 1% level. *Significant at the 5% level. NS-Not significant.

The herbicides performed equally well in controlling weeds at both plant spacings. At the wider plant spacing, significantly less weeds were obtained from the plots where herbicide was applied than from the unweeded plots. At the closer plant spacing, however, there was no significant difference in weed weights between the herbicide-treated and the unweeded plots. Hand weeding was generally superior to herbicide use in controlling weeds. Thus, weed competition against transplanted rice can be overcome to a great extent by the use of decreased plant spacing or by a weed control practice.

Within each plant spacing no significant differences in leaf area index or number of panicles per unit area were observed between weeding treatments (Table 2). A significantly greater leaf area index and number of panicles was obtained at the 10 x 10 cm plant spacing than at the 20 x 20 cm plant spacing.

Table 2

Leaf area index, number of panicles and grain yield of transplanted rice as affected by plant spacing and weed control treatment

Treatment	Herbicide rate (kg ai/ha)	Plant spacing (cm)	Leaf area index	No. of panicles m^2	Grain yield (t/ha)
2,4-D	0.6	10 x 10	4.1^{ab}	572^{a}	4.5^{ab}
	0.6	20 x 20	3.2^{bc}	317^{b}	3.7^{ab}
Thiobencarb-2,4-D	0.75-0.38	10 x 10	4.7^{a}	528^{a}	4.6^{a}
	0.75-0.38	20 x 20	2.9^{c}	359^{b}	3.7^{ab}
Butachlor	1.0	10 x 10	5.1^{a}	550^{a}	4.1^{ab}
	1.0	20 x 20	3.2^{bc}	323^{b}	3.6^{b}
Hand weeding	-	10 x 10	4.4^{ab}	483^{a}	4.6^{a}
	-	20 x 20	2.4^{c}	282^{b}	3.6^{b}
No weeding	-	10 x 10	4.8^{a}	505^{a}	4.1^{ab}
	-	20 x 20	2.6^{c}	275^{b}	2.5^{c}

In a column, means with common superscripts are not significantly different at the 5% level.

There was no significant difference in grain yield between the herbicide-treated plots and the hand weeded plots for each plant spacing. Yields were lower in the plots with the wider plant spacing but differences were only significant in the hand weeded and unweeded plots. The grain yield was reduced significantly by weed competition at the 20 x 20 cm plant spacing but not at the 10 x 10 cm plant spacing. This result implies that weeding was not needed at the 10 x 10 cm plant spacing whereas at the 20 x 20 cm plant spacing weeding either by hand or herbicide was needed to achieve maximum yields.

There was a high negative correlation between grain yield and weed weight at rice heading ($y = 4.62 - 0.0108x$, $r = - 0.878^{**}$). Based on this equation, a yield reduction of 23% could be expected from competition of 100 g weeds/m^2. 50% yield reduction would result from 214 g/m^2.

The costs associated with the weeding and plant operations are given in Table 3. Based on this information the costs and net benefits of weed control were computed (Table 4).

Table 3

Cost association with the planting and weeding operations

Operation	Cost ($)
1. Seed cost	
20 x 20 cm (60 kg/ha)	9.00
10 x 10 cm (240 kg/ha)	36.00
2. Transplanting	
20 x 20 cm	22.10
10 x 10 cm	88.40
3. Hand weeding	
20 x 20 cm (12.5 man-days)	18.80
10 x 10 cm (6.25 man-days)	9.40
4. Herbicide application[1]	
2,4-D	7.70
Thiobencarb-2,4-D	12.10
Butachlor	17.00

[1] Including cost of application.

Table 4

Costs and net benefits of the different weed control practices

	Plant spacing (cm)	Yield (t/ha)	Output ($)	Total cost ($)	Net benefit ($)
2,4-D	10 x 10	4.5	678.10	132.10	546.00
	20 x 20	3.7	557.60	38.80	518.80
Thiobencarb-2,4-D	10 x 10	4.6	693.20	137.50	555.70
	20 x 20	3.7	557.60	42.20	514.40
Butachlor	10 x 10	4.1	617.80	141.40	476.40
	20 x 20	3.6	542.50	48.10	494.40
No weeding	10 x 10	4.1	617.80	124.40	493.40
	20 x 20	2.5	376.70	31.10	345.60
Hand weeding	10 x 10	4.6	693.20	133.80	559.40
	20 x 20	3.6	542.50	49.90	492.60

In all cases except where butachlor was applied, the net benefits were greater at the 10 x 10 cm plant spacing than the 20 x 20 cm plant spacing with the greatest benefit to reduced plant spacing occurring in the unweeded plots. At the 10 x 10 cm spacing, the highest net benefits were obtained from the plot that was hand weeded once and the lowest net benefits were obtained from the plot to which butachlor had been applied. At the wider spacing the lowest net benefit was obtained from the unweeded plots while the greatest benefit was obtained when 2,4-D was applied.

The return to weeding was greater at the 20 x 20 cm plant spacing than at the 10 x 10 cm plant spacing averaging $159.20 at the wider spacing and $40.98 at the closer spacing. At the wider spacing, there is little difference in the returns obtained from the various weed control treatments, 2,4-D and thiobencarb-2,4-D being slightly superior to butachlor and hand weeding. On the basis of the benefit/cost ratio, 2,4-D was superior to the other methods of weed control (Table 5). At the closer spacing where returns to weeding were less than at the wider spacing, the returns to using butachlor were inferior to those of the other treatments. In terms of benefit/cost ratio, 2,4-D was again superior.

Table 5

Benefits, costs and benefit-cost ratio for weed control and reduced plant spacing in transplanted rice

Weed control treatment	Benefit ($)	Cost ($)	B/C ratio
Benefit to weeding, 20 x 20 cm plant spacing			
2,4-D	173.20	7.70	22.49
Thiobencarb-2,4-D	167.80	12.10	13.87
Butachlor	148.80	17.00	8.75
Hand weeding	147.00	18.80	7.82
Benefit to weeding, 10 x 10 cm plant spacing			
2,4-D	52.60	7.70	6.83
Thiobencarb-2,4-D	62.30	12.10	5.15
Butachlor	- 17.00	17.00	- 1.00
Hand weeding	66.00	18.80	3.51
Benefit to decreased plant spacing			
2,4-D	27.20	93.30	0.29
Thiobencarb-2,4-D	41.30	93.30	0.44
Butachlor	- 18.00	93.30	- 0.19
Hand weeding	66.80	93.30	0.72
No weeding	147.80	93.30	1.58
Benefit to weed control and decreased plant spacing			
2,4-D	200.4	101.0	1.98
Thiobencarb-2,4-D	209.1	105.4	1.98
Butachlor	130.8	110.3	1.19
Hand weeding	213.8	112.1	1.91

The benefit/cost ratio for decreased plant spacing except for the no weeding plot which had a value of 1.58 averaged only 0.32. While the benefit/cost ratio for decreased plant spacing and weed control was 1.98 or less.

Based on the above figures it is more likely that the farmer would opt for the wider plant spacing with some form of weed control than for the closer plant spacing with or without weed control.

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THE IMPORTANCE OF RELATIVE HUMIDITY AND TEMPERATURE ON THE UPTAKE, TRANSLOCATION AND ACTIVITY OF ASULAM, DALAPON ALONE AND IN A MIXTURE ON ALANG-ALANG (IMPERATA CYLINDRICA (L.) BEAUV.)

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Summary A mixture of asulam and dalapon containing 6 kg total a.i./ha produced a marked synergistic effect in preventing regrowth of *Imperata cylindrica* (L.) Beauv. under high relative humidity (75-92%), compared with 4 kg a.i./ha asulam or 8 kg a.i./ha dalapon. Increasing the relative humidity from 40 to 95% at 30°C increased the control of regrowth by the mixture from 71 to 100%. The influence of temperature was not as critical as relative humidity (r.h.). At 30°C there was a seven-fold increase in initial uptake of ring labelled ^{14}C-asulam and a five-fold increase in subsequent translocation to rhizomes at 95% r.h. compared to 40% r.h. When applied with dalapon at 95% r.h., the initial uptake of asulam-ring ^{14}C was greater (74%) than when applied alone (55%). These results support the development of an asulam/dalapon mixture for control of *Imperata cylindrica* in humid tropical regions.

Résumé Un mélange d'asulame et de dalapon contenant au total 6 kg m.a./ha, a montré un sensible résultat synergique en empêchant la répousse de *Imperata cylindrica* (L.) Beauv. sous les conditions d'une haute humidite relative (75-92%) comparativement à 4 kg m.a./ha d'asulame ou 8 kg m.a./ha de dalapon. Un accroissement de 40% jusqu'à 95% de l'humidité relative à 30°C a augmenté le niveau de contrôle de la répousse, par le mélange, de 71% jusqu'à 100%. L'influence de la température était moins importante que celle de l'humidité relative (h.r.). A 30°C il-y-avait un augmentation de sept fois dans l'absorption initiale de l'asulame marqué au ^{14}C sur le noyau et de cinq fois dans la translocation aux rhizomes à 95% h.r. en comparison avec celle à 40% h.r. L'absorption initiale de l'asulame ^{14}C était plus élevée (74%) en application avec le dalapon à 95% h.r. qu'en application seul (55%). Ces résultats soutiennent le développement d'un mélange d'asulame et de dalapon pour la butte contre l'*Imperata cylindrica* dans les régions tropicales et humides.

INTRODUCTION

Alang-alang (*Imperata cylindrica* (L.) Beauv.) is a troublesome perennial grass weed of the tropics and sub-tropics, occurring in perennial crops such as rubber, tea, oil palm, teak, coconut and cinchona. In Malaysia two million ha of rubber has been estimated to be seriously infested with this weed and in Indonesia about 15-30 million ha of perennial crops were infested with an annual encroachment rate of 150,000 ha (Holm *et al*, 1977). Its aggressive, and extensive rhizomes with great regenerative power make mechanical eradication by hand or by cultivation difficult and costly (Eussen & Soerjani, 1975). Chemical control with translocated herbicides which move to the underground rhizomes either killing all viable buds or at least preventing them forming new aerial shoots is proving to be the most efficient method of eradication. Dalapon (2,2-dichloropropionic acid) is used on a large scale in rubber plantations of Malaysia (Seth, 1970) and Indonesia (Staalduine, 1974) and glyphosate (N-(phosphonomethyl)glycine) is also showing promise (Mangoensoekarjo & Kadnan, 1975). In field trials, carried out in Malaysia, control of Imperata by asulam (methyl (4-amino-benzenesulphonyl)carbamate) was comparable with that achieved by the conventional treatment of dalapon, but best control was given by asulam/dalapon mixture suggesting a synergistic interaction between two chemicals (Hill & Ingram, 1980). This synergistic interaction was not evident in normal greenhouse conditions (Gore, 1979 personal communication), but if synergism was confirmed a mixture of asulam/dalapon might have potential for long-term control of Imperata.

The efficacy of several phloem mobile herbicides, in particular water soluble herbicides such as dalapon, glyphosate and asulam are greatly influenced by environmental factors; especially relative humidity. Studies with ^{14}C-labelled dalapon, glyphosate and asulam on several perennial weeds showed that the absorption through the foliage and subsequent translocation to the rhizomes was markedly enhanced under high relative humidity (Prasad et al, 1967; Veerasekaran et al, 1977; Chase & Appleby, 1979 and Whitwell et al, 1980). These results suggest that the performance of these herbicides would reach their peak when used under humid tropical conditions as prevalent throughout the year in Malaysia and Indonesia. This could explain the anomaly between greenhouse and field results with asulam/dalapon mixtures. The present report deals with the studies carried out under greenhouse and controlled environmental cabinets to examine the synergistic interaction of an asulam/dalapon mixture, the conditions under which a desirable interaction occurs and the basis of such an interaction.

METHOD AND MATERIALS

Imperata cylindrica plants were grown in the greenhouse with a 14 h illumination from rhizome segments in 13 cm diameter plastic pots containing John Innes Compost No. 1 until they had a well developed and uniform rhizome system. 20 week old plants were clipped 10 cm above the soil surface and grown for another six weeks. The main shoot had 5-6 leaves when treated. The herbicides - 4 kg a.i./ha asulam; 8 kg a.i./ha dalapon; 6 or 12 kg a.i./ha asulam/dalapon mixtures - were sprayed at a volume rate of 800 l/ha using a Teejet 8008 fitted to the laboratory sprayer. All the spray solutions contained 0.1% w/v Arylan S90 as a wetter.

Greenhouse studies

One half of the treated plants were transferred to a polythene tent erected in the greenhouse to provide high relative humidity (75-92% r.h.) and the rest placed in the greenhouse under 38-50% r.h. The temperature in the greenhouse ranged from 15-35°C whilst the temperature inside the tent was always 2-3°C higher than the greenhouse. Three weeks after treatment, the shoots were clipped (5 cm above soil level) and fresh weight reductions were assessed. Each treatment had six replicate pots and three pots were assessed for regrowth 1 and 2 months after clipping.

Environmental cabinet studies

Two separate experiments were conducted in environmental cabinets (Fisons Scientific Apparatus, Pat.No. 812417) to determine the effect of temperature and humidity on the performance of asulam/dalapon. Three days prior to treatment, uniform plants grown in the tent inside a greenhouse at the growth stage described previously, were conditioned in growth cabinets at either 20 or 30°C and 40 or 95% r.h. with 14 h illumination. The plants were treated as described for greenhouse studies and transferred to growth cabinets and maintained at the appropriate environmental conditions for 3 weeks, then the shoots were clipped and all the pots were moved to the greenhouse. The activities were compared by assessing shoot fresh weight reductions after 3 weeks and regrowth one month after clipping. Data were analysed using Duncan's multiple F and range test.

The interaction of dalapon and humidity on the uptake and translocation of ring labelled ^{14}C-asulam was studied under controlled environmental conditions. Two solutions of ^{14}C-asulam, one containing asulam alone (20 mg/ml) and the other containing asulam/dalapon (60 mg/ml) with similar specific activity (40 µCi/ml) were prepared. Both solutions contained 0.1 w/v Arylan S90 as a wetter. The youngest fully expanded leaf of Imperata cylindrica plants at the growth stage described before, was treated with ^{14}C-solutions as 7, one ul droplets (0.25 µCi), distributed uniformly on the adaxial surface of the leaf blade. The treated plants were maintained in growth cabinets at 30°C and at either 40 or 95% r.h. with 14 h illumination. From each treatment 3 plants were harvested after 1 and 7 days. The ^{14}C-activity remaining on the surface was washed from the detached leaves in 25 ml of water containing 0.1% wetter (Ethylan BCP). The distribution of ^{14}C in the treated leaves, the remainder of the shoot and rhizome plus roots was determined by autoradiography, oxygen combustion of dried samples and liquid scintillation assaying.

RESULTS

The efficacy of asulam, dalapon and asulam/dalapon was significantly increased when the treated plants were maintained in the polythene tent to provide high relative humidity (75-92%) rather than in the greenhouse. Asulam alone (4 kg a.i./ha) failed to produce a satisfactory control of regrowth in the greenhouse, but at high humidity conditions, asulam (4 kg a.i./ha) or dalapon (8 kg a.i./ha) produced about 75% control of regrowth after 2 months. The mixture of asulam/dalapon (6 kg a.i./ha) produced a synergistic effect in the reduction of fresh weight and suppression of regrowth when the treated plants were maintained in the tent. This mixture produced complete control of regrowth assessed after 2 months. Visual effects are manifested as a gradual wilting and yellowing of the treated plants which advanced to complete browning, deterioration of plant tissue and ultimate decomposition of rhizomes and roots. A higher rate of asulam/dalapon (12 kg a.i./ha) gave good control of regrowth both in the greenhouse and in the tent, but 100% control was only achieved in the tent.

Table 1

Effect of asulam, dalapon and mixtures on the control of *Imperata cylindrica* in the greenhouse/tent at 15-35°C

(Untreated control = 0)

Treatments kg a.i./ha	Greenhouse (38-50% r.h.) Fr. Wt reduction* %	% suppression of regrowth † 1	2	Tent (75-92% r.h.) Fr. wt reduction %	% suppression of regrowth 1	2
Asulam 4	31.1^{a}	73.0^{a}	62.7^{a}	56.6^{a}	84.3^{a}	74.8^{a}
Dalapon 8	65.0^{c}	81.1^{b}	70.5^{b}	73.4^{b}	85.4^{a}	76.8^{a}
Asulam/Dalapon 6	39.9^{b}	81.6^{b}	77.5^{c}	57.8^{a}	100.0^{b}	99.3^{b}
Asulam/Dalapon 12	70.5^{d}	90.3^{c}	91.8^{d}	91.1^{c}	100.0^{b}	100.0^{b}

* % fresh weight reductions were assessed 3 weeks after treatment.

† % shoot regrowth was assessed 1 and 2 months after clipping.

In each column, means followed by same letter postscripts are not significantly different at P = 5%.

The influence of temperature and relative humidity on the efficacy of asulam, dalapon and the mixtures on *Imperata* studied in growth cabinets indicated that the treated plants maintained for 3 weeks under high relative humidity (95%) either at 20°C or 30°C showed significant increase in activity for all the treatments as compared to plants maintained under low humidity (40%) (Table 2). Asulam/dalapon mixture (6 kg a.i./ha) showed poor control of regrowth at low relative humidity irrespective of temperature, but significant synergistic effect was observed at 95% r.h. both at 20 and 30°C. The influence of high (30°C) and low temperature (20°C) was not as critical as relative humidity. Even at the high rate of asulam/dalapon mixture (12 kg a.i./ha) complete control of regrowth was achieved only at 95% relative humidity.

Table 2

The effect of temperature and humidity on the efficacy of asulam/dalapon mixtures in growth cabinets

(Untreated control = 0)

	% Fr. wt reduction*				% Suppression of regrowth †			
Treatments	Temp. 20°C		Temp. 30°C		Temp. 20°C		Temp. 30°C	
kg a.i./ha	40% r.h.	95% r.h.	40% r.h.	95% r.h.	40% r.h.	95% r.h.	40% r.h.	95% r.h.
Asulam 4	29.0^{a}	46.0^{a}	34.7^{a}	59.8^{a}	37.3^{a}	83.6^{a}	59.2^{a}	83.1^{a}
Dalapon 8	50.0^{b}	61.2^{b}	45.7^{b}	63.2^{a}	67.2^{b}	81.7^{a}	71.1^{b}	82.9^{a}
Asulam/ Dalapon 6	63.2^{c}	71.7^{c}	62.6^{c}	74.3^{b}	67.7^{b}	96.0^{b}	71.1^{b}	98.2^{b}
Asulam/ Dalapon 12	75.9^{d}	88.4^{d}	75.5^{d}	93.5^{c}	83.6^{c}	100.0^{b}	84.0^{c}	100.0^{b}

*Fresh weight reductions 3 weeks after treatments.
†Regrowth assessed one month after clipping.

In each column, means followed by same letter postscripts are not significantly different at P = 5%.

The uptake and translocation of ^{14}C-asulam or its metabolites was markedly influenced by relative humidity (Table 3). An increase from 40 to 95% r.h. resulted in a seven to eight-fold increase in uptake during 24 h when ^{14}C-asulam was applied to the leaves either with or without dalapon. When ^{14}C-asulam was applied with dalapon at 95% r.h. 30°C, the initial uptake of ^{14}C during 24 h was more rapid (74.2%) than for ^{14}C-asulam applied alone (54.6%). After 7 days, the translocation of ^{14}C into the underground rhizome and roots and aerial shoots from the leaves treated with ^{14}C-asulam alone or with dalapon was increased more than five-fold when humidity was increased from 40 to 95% at 30°C. Though the presence of dalapon in the mixture increased uptake of ^{14}C at 95% r.h., it did not enhance the translocation; in fact a slight decrease in translocation was observed. At 40% r.h. most of the applied activity remained on the surface of the treated leaves; above 74% of applied activity remained on the surface after 7 days showing very low penetration into the leaves and limited translocation into the rhizomes.

Table 3

The effect of relative humidity and the addition of dalapon on the uptake and translocation of ^{14}C, 1 and 7 days following application of ^{14}C-asulam at 30°C (Mean of 3 plants)

Treatments	Relative humidity at 30°C (%)	Days	^{14}C-distribution (% of applied activity)					
						Translocation		
			Surface residue	Total uptake	Treated leaf	Shoot	Rhizomes & roots	Recovery
1. ^{14}C-asulam	95	1	30.3	54.6	32.3	14.3	8.0	94.9
		7	16.1	80.3	37.5	26.1	16.7	96.4
2. ^{14}C-asulam	40	1	89.0	7.0	5.6	0.9	0.5	96.0
		7	79.4	17.1	10.1	3.9	3.1	96.5
3. ^{14}C-asulam/ dalapon	95	1	23.2	74.2	53.6	12.9	7.7	97.4
		7	7.6	88.3	54.7	17.7	15.9	95.9
4. ^{14}C-asulam/ dalapon	40	1	89.6	8.7	8.0	0.5	0.2	97.7
		7	74.2	21.8	14.8	4.1	2.9	96.0

DISCUSSION

The relative humidity inside the tent in which treated plants were exposed was considerably higher (75-92%) than in the greenhouse (38-50%) and it significantly increased the activity of asulam, dalapon and the mixture. The asulam/dalapon mixture at the lower rate of 6 kg a.i./ha showed a synergistic interaction in terms of increase in control of regrowth; complete suppression of regrowth for up to 2 months was achieved under high relative humidity (Table 1). The importance of high humidity in producing a synergistic interaction between asulam and dalapon was further confirmed by the growth cabinet experiments. At 95% r.h. effective control of regrowth was achieved irrespective of variation in temperature indicating that toxicity was primarily affected by relative humidity. However, the influence of a wider range of temperature below 20°C and above 30°C has to be tested to study the influence of temperature on the activity of asulam/dalapon mixture.

The ability of foliage applied herbicides to control perennial weeds may be attributed to their ability to penetrate the foliage and translocate to the sites of action. Greater uptake of asulam and the maximum translocation into the underground rhizome buds of bracken was only achieved at high relative humidity (Veerasekaran *et al*, 1977). The uptake of ^{14}C-dalapon and translocation into the rhizomes of *Cynodon dactylon* and *Sorghum halepense* was markedly enhanced at high relative humidity (Prasad *et al*, 1967; McWhorter & Jordon, 1976). It is believed that high relative humidity enhances uptake through the leaves by hydrating the cuticle. In *Imperata* under high relative humidity, uptake of ^{14}C-asulam increased seven to eight-fold during 24 h and translocation increased five-fold after seven days (Table 3). These results suggest that under high humidity a marked increase in herbicidal activity of asulam or asulam/dalapon mixture is directly related to the enhanced uptake and translocation of asulam. Under low humidity the failure of a synergistic interaction of asulam/dalapon could be attributed mainly due to the poor penetration of both compounds and very limited translocation to the sites of action.

The mechanisms by which herbicides interact in mixtures are complicated and mostly unknown (Putnam & Penner, 1974). The herbicides in the mixture may affect each other by interfering with the pattern of penetration, translocation or metabolism exhibited by any single herbicide. The mixtures may also affect herbicidal activity at the sites of action within the plant cells or tissues by interferring with physiological and biochemical processes. The interaction may be influenced by environmental conditions, solvents or additives used in the formulation of the mixtures. In the present studies, the interaction of asulam and dalapon resulted in greater uptake of ^{14}C-asulam during first 24 h of treatment than ^{14}C-asulam applied alone. It is possible that asulam in the mixture may interact to increase the uptake and translocation of dalapon, but this was not studied. High humidity apparently favours the accumulation of both asulam and dalapon at the sites of action where they interact to produce a synergistic effect.

Other factors such as soil moisture and shade may also influence the efficacy of asulam/dalapon mixture on *Imperata*. It was reported that control of *Imperata* by glyphosate was increased with increase in soil moisture and shade (Moosavi-Nia & Dore, 1977 a, b). Dalapon in combination with shade produced a better control of *Imperata* than dalapon in combination with normal light (Sukartaamadja & Siregar, 1971). High soil moisture and shade conditions have often been associated with high humid conditions (Hammerton, 1968). An investigation to examine the influence of soil moisture and shade on the activity of asulam/dalapon mixture would be worthwhile

Under tropical humid condition, dalapon is being used to a large extent at 10-15 kg/ha to control *Imperata*, but sprayings at frequent intervals are necessary to kill the shoots emerging from escaped rhizomes and to prevent new rhizomes being formed (Staalduine, 1974). To improve the control of *Imperata*, mixtures of dalapon with paraquat and glyphosate have been suggested (Mangoensoekarjo & Kadnan, 1975). The present results suggest that reliable control of *Imperata* should be possible with an asulam/dalapon mixture in areas where the humidity is high all the year around, as the mixture showed a synergistic interaction under humid conditions in the temperature range of 20-30°C. A mixture of asulam/dalapon is now commercially available in Malaysia for this purpose following two years of successful field trials (Hill & Ingram, 1980).

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ASULAM BASED MIXTURES FOR WEED CONTROL IN TROPICAL PLANTATION CROPS

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Summary Formulations of asulam/paraquat (ARD 13/26) and asulam/dalapon (ARD 13/30 and 13/31) showed enhanced activity over paraquat and dalapon alone, by broadening the weed control spectra and prolonging the persistence of activity. In several crops ARD 13/26 (4-7 l/ha) had greater persistence and weed spectrum than the standard materials, paraquat and dalapon/diuron, when used at their recommended rates. In sugar cane ARD 13/30 (7.5 kg/ha) widened the weed control spectrum, to include two difficult-to-control weeds *Dactyloctenium aegyptium* and *Chloris* spp. compared to the standard herbicide asulam (3.5 l/ha), when they were both applied in combination with ioxynil/2,4-D (1.25 l/ha). In plantation crops ARD 13/31 (13.5-18.0 kg/ha) exhibited excellent control of the noxious weed *Imperata cylindrica*, demonstrating a higher level of control than dalapon and greater reliability than glyphosate at their normal rates of use. All three exhibited excellent selectivity in all the crops tested.

Résumé L'asulame en formulation avec le paraquat (ARD 13/26) ou le dalapon (ARD 13/30, 13/31) était plus persistant et supprimait un spectre plus large de mauvaises herbes que les deux produits utilizes seules. Sur plusiers cultures ARD 13/26 (4-7 l/ha) était plus persistant et supprimait plus d'éspeces de mauvaises herbes que le paraquat ou le dalapon/diuron pulverisé a leur dose recommandée. ARD 13/30 (7.5 l/ha) utilisé sur la canne a sucre en association de lioxynil/2,4-D (1.25 l/ha) faisait preuve d'un specte d'activité plus large que l'association d l'asulame plus l'ioxynil/2,4-D et supprimait les deux mauvaises herbes difficiles, *Dactyloctenium aegyptium* et *Chloris* spp. Utilisé dans les plantations ARD 13/31 (13.5-18.0 kg/ha) faisait preuve d'une éfficité sûre et éxcellente contre la mauvaise herbe nuisible *Imperata cylindrica*, avec un niveau de controle supérieur an dalapon et plus sur que le glyphosate a leur dose d'emploi normal. Les trois formulation aucun indice de phytotoxicité.

INTRODUCTION

Asulam alone or in mixtures with atrazine or diuron is firmly established as a pre- or early post-emergence herbicide for sugar cane and other plantation crops. The continuous development of asulam, directed towards specific weed problems associated with certain crops or "hard to kill" weeds has now led to three new herbicide combinations which are presented in this paper. Veerasekaran (1980) has shown that mixtures of asulam and dalapon have produced a marked synergistic effect under laboratory conditions in preventing the regrowth of *Imperata cylindrica*. Field results are presented that confirm that mixtures of asulam with paraquat and dalapon enhances the persistence and weed control spectra of paraquat and dalapon.

METHOD AND MATERIALS

The chemicals and formulations used in this study were ARD 13/26 (36.8% aqueous solution asulam + paraquat), ARD 13/30 (65.0% s.p. asulam + dalapon), ARD 13/31 (63.5% s.p. asulam + dalapon), paraquat (20% aqueous solution), glyphosate (36% aqueous solution), dalapon (85% sp.) and 'Actril DS' (70% e.c. ioxynil/2,4-D).

Treatments were applied by knapsack sprayer at volumes of approximately 400 l /ha in coffee, sugar cane and bananas and up to 880 l/ha in oil palm and rubber.

Sites varied from randomised, non-replicated (ARD 13/26 in West Indies, Equador and Brazil) to randomised three replicate layouts (ARD 13/30 and ARD 13/31 in Thailand and Malaysia), depending upon country and crop.

Weed control was assessed either by the EWRC 1-9 scale (1 = complete control, 9 = no effect) or by percentage ground cover. Crop condition was assessed either using the EWRC 1-9 scale or on a 0-10 scale. In both cases the high figure represented crop kill.

RESULTS AND DISCUSSION

ARD 13/26 (asulam/paraquat mixture)

This mixture has been extensively tested in the West Indies, Equador and Brazil and has shown a wide spectrum of activity, on both broad-leaved weeds and grasses and has given a longer persistence of effect than standard materials such as paraquat alone or dalapon/diuron mixtures as shown in Table 1 and 2. The speed of action is not as rapid as paraquat alone, taking up to 21 days for full activity to show, however the slower speed contributes to greater longevity of effect.

The persistence of effect of ARD 13/26 varies from 45 to 100 days, usually approximately 75 days, compared with paraquat which has a persistence of 14 to 35 days before re-treatment is necessary. Dalapon/diuron is comparable to ARD 13/26 on sensitive species but the spectrum of activity is more restricted.

ARD 13/26 has shown excellent crop tolerance, in bananas, oil palm, cocoa, plantains and coffee, when used as a directed spray, at the doses required for weed control (4-7 l/ha).

Table 1

Comparative persistence of weed control with ARD 13/26 and standards in West Indies, Equador and Brazil (1978-80)

Species	Occurrence (No. of sites)	Number of days of acceptable weed control obtained by treatment with		
		ARD 13/26 (4-7 l/ha)	paraquat (approx. 3 l/ha)	dalapon/diuron (6 + 2 kg/ha)
Achyranthes indica	1	95	R	
Ageratum conyzoides	1	<45	-	
Amaranthus dubius	1	50	<50	
Bidens pilosa	1	>90	-	
Borreria spp.	2	95	R	
Chloris spp.	2	>50	-	
Cleome ciliata	2	<56	<56	
Commelina elegans	4	<49	18	
Cyperus spp.	3	<84	50	
Digitaria spp.	3	>99	<50	
Eleusine indica	6	>99	42	
Euphorbia hypericifolia	4	>99	<50	
Ipomea spp.	1	>84	>90	
Panicum fasciculatum	8	>99	-	
P. maximum	5	<14	<14	42
Paspalum paniculatum	4	>99	<50	
Portulaca oleracea	1	>90	>90	
Pteridium aquilinum	3	>98	-	<71
Setaria barbata	3	95	42	
Sida sp.	2	95	42	

R = weed resistant. Results are means from 8 sites

Treatments applied in established crops in partial or full shade conditions.

Table 2

Comparative persistence and rate of activity (EWRC score) between ARD 13/26 and paraquat. West Indies 1978-80

Treatment	Weeks post spraying		
	1	9	17
ARD 13/26 (7 l/ha)	6.0	3.7	4.7
Paraquat (2.8 l/ha)	3.6	5.7	6.7

ARD 13/30 (asulam/dalapon mixture)

ARD 13/30 has extended the spectrum of weeds controlled to include those species which are normally resistant to asulam, e.g. *Dactyloctenium aegyptium* and *Chloris* spp. (Table 3). The trials were carried out using mixtures of ARD 13/30 and asulam with ioxynil/2,4-D as the objective was complete weed control and the formulations are designed to complement each other. The tolerance of the sugar cane, in terms of both height and numbers of tillers, has been excellent to ARD 13/30 + ioxynil/2,4-D at up to two times the dosage of ARD 13/30 and is comparable to the selectivity of asulam (Table 4).

Table 3

Weeds controlled with ARD 13/30 in sugar cane - Thailand 1978-80

Species	Occurrence (No. of sites)	ARD 13/30 + ioxynil/2,4-D (7.5 kg/ha + 1.25 l/ha)	asulam + ioxynil/ 2,4-D (3.5 kg/ha + 1.25 l/ha
Achyranthes indica	3	MS	MS
Acranchne racemosa	2	S	-
Ageratum conyzoides	2	S	MS-S
Alysicarpus vaginalis	1	S	-
Borreria articulatus	1	S	-
Brachiaria sp.	3	MS*-S	MR
Cenchrus echinatus	1	MS*-S	R
Chloris barbata	3	MS*-S	R
Cleome viscosa	1	S	-
Corchorus aestuans	2	S	-
Cynodon dactylon	1	MS	MR
Cyperus compressus	1	R	-
C. iria	1	S	-
Dactyloctenium aegyptium	9	MS*-S	MR-R
Echinochloa colonum	4	S	MS
Eleusine indica	5	S	S
Euphorbia geniculata	5	S	S
Ipomea aquatica	1	S	-
Leptochloa chinensis	4	S	MS
Pennisetum pedicellatum	3	S	MS-S
P. polystachyon	3	S	MS
Rottboellia exaltata	1	S	-

* Large weeds at flowering stage.
S = susceptible MS = moderate susceptible MR = moderately resistant
R = resistant - = no data.

Results are means from 9 sites assessed 28-45 days post-spray.

Table 4

Tolerance of sugar cane to ARD 13/30. Thailand 1978-80

Treatment	Dose rate/ha	Tillers Height (cm)	Tillers Numbers
ARD 13/30 + ioxynil/2,4-D	7.5 kg + 1.25 l	34.9	3.1
" " "	15.0 kg + 1.25 l	32.1	2.9
Asulam	3.5 kg + 1.25 l	34.5	2.6
Hand weeded control	-	32.6	3.0
Unsprayed control	-	22.2	1.5

Results are means of 5 sites assessed 42 days post-spray.

ARD 13/31 (asulam/dalapon mixture)

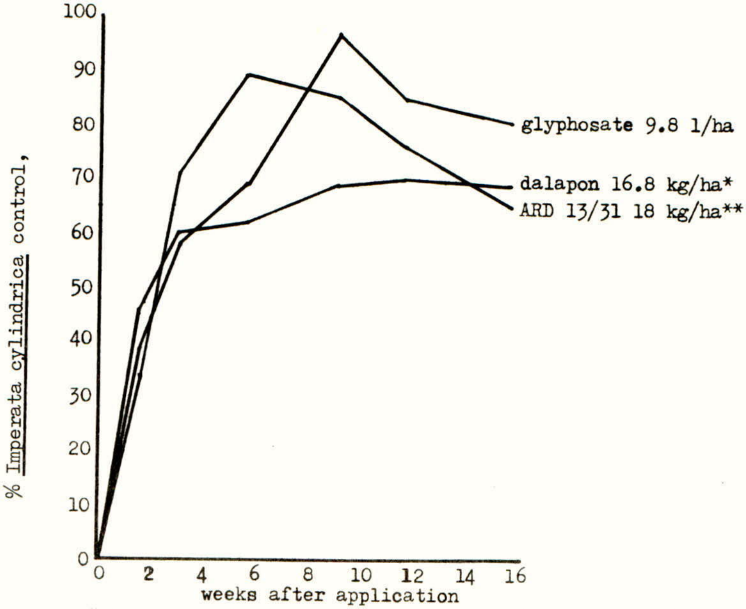
ARD 13/31 has been extensively tested in Malaysia during 1978-1980, and also at a few non-crop locations in Africa and the West Indies. The product when applied at 13.5 to 18.0 kg/ha (13.5 kg in >30% shade and 18.0 kg/ha in 0-30% shade) has shown good control of a wide range of weed species including Cynodon dactylon, Digitaria sanguinalis, Eleusine indica, Eupatorium odoratum, Mikania cordata, Ottachloa nodosa, Panicum maximum and Paspalum sp.

The prime target in Malaysia was the noxious weed Alang-alang (Imperata cylindrica (L.) Beauv.) present in rubber and oil palm plantations. ARD 13/31 at 18.0 kg/ha in conditions of less than 30% shade and 13.5 kg/ha in more than 30% shade has given good control of Imperata cylindrica. The level of control achieved in the shorter term (up to 50 days) with ARD 13/31 was superior to dalapon alone (either single dose in 30+% shade or dual dosage in 0-30% shade) and it gave more consistent control than glyphosate (Table 6). The longer term results (102-182 days post-spraying), which were only recorded from sites which had had no other management, e.g. slashing, burning and had been retained because of the general level of efficacy of all treatments including the standards, showed that ARD 13/31 was still giving a satisfactory level of control (Table 6). Overall it was found that glyphosate was capable of giving excellent control of Imperata but there was a significant number of failures, whilst ARD 13/31 was more consistent in its generally high level of efficacy. It was also found that ARD 13/31, particularly in 0-30% shade, produced the quickest kill of Imperata (Figure 1a and 1b). Dalapon was consistently outperformed by both glyphosate and ARD 13/31.

The crop tolerance of the major varieties of rubber (seedling to >3 years), oil palm (>2 year old), coconut (seedling to >3 year) and established mangoes, to directed sprays of ARD 13/31, avoiding foliar contact, has been excellent. Even where young volunteer coconut palms and rubber have been oversprayed, only initial yellowing of the coconut fronds has occurred, but these subsequently recovered to normal health. Studies on uptake by roots from the soil have shown no ill effects.

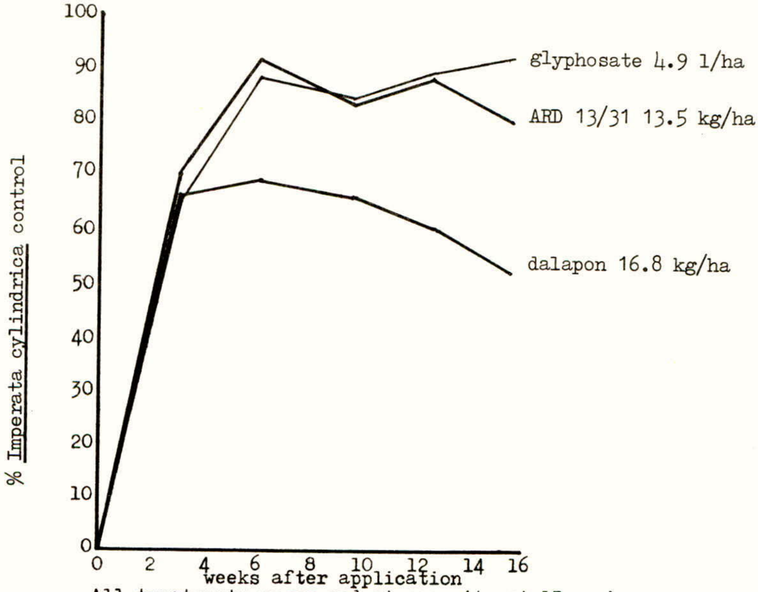
Summary of results from _Imperata cylindrica_ trials. Malaysia 1979-80

Fig. 1a
0-30% shade



* dalapon - touch-up application of 5-6 kg/ha at 5-6 weeks
** ARD 13/31 18 kg/ha touch-up at 7 weeks
means of 5-10 sites

Fig. 1b
>30% shade



All treatments resprayed at one site at 13 weeks
Means of 3-5 sites.

Table 6

Control of Imperata cylindrica with ARD 13/31. Malaysia 1979-1980

Treatment	dose rate/ha	No. of sites with % weed control (I = 0-30%, II = >30% shade) 100-85		84-70		<70	
		I**	II$^+$	I**	II$^+$	I**	II$^+$
1. Assessments 35-50 days post-spraying							
ARD 13/31	18.0 kg	8	4	2	1	0	0
"	13.5 kg	2	5	6	0	1	0
"	9.0 kg	-	2	-	3	-	0
Dalapon	16.8 + 5.4 kg*	1	-	5	-	4	-
"	16.8	-	0	-	3	-	2
glyphosate	9.8 l	6	-	0	-	4	-
"	4.9 l	-	3	-	2	-	0
2. Assessments 102-182 days post-spraying							
ARD 13/31	18.0 kg	4	1	1	4	6	0
"	13.5 kg	0	3	1	1	8	1
"	9.0 kg	-	1	-	1	-	3
Dalapon	16.8 + 5.4 kg*	0	-	3	-	8	-
"	16.8 kg	-	1	-	0	-	4
Glyphosate	9.8 l	6	-	3	-	2	-
"	4.9 l	-	5	-	0	-	0

* 5.4 kg/ha dalapon applied at all sites approximately 42 days after first spray.

** ARD 13/31 18.0 kg and 13.5 kg resprayed by spot treatment on 2 sites at 77 days after spraying.

\+ All treatments resprayed at one site at 89 days after spraying.

All treatments applied from fully emerged to flowering growth stages of I. cylindrica.

CONCLUSIONS

The results show that with mixtures of asulam it is possible to enhance the activity of paraquat and dalapon in a wide range of plantation crops.

ARD 13/26 (asulam/paraquat) has shown an increased weed spectrum and persistence compared with the standard herbicides in bananas, oil palm, cocoa, plantains and coffee. With ARD 13/30 (asulam/dalapon) it is possible to control a wider range of weeds than with asulam alone, when applied in mixtures with ioxynil/2,4-D. ARD 13/31 (asulam/dalapon) has given more reliable control of Imperata cylindrica than the standard herbicides dalapon and glyphosate. These results support the laboratory work of Veerasekaran (1980) who showed synergism between asulam and dalapon in the control of I. cylindrica.

Acknowledgement

We are indebted to our colleagues in May & Baker Ltd. and Rhone-Poulenc Agrochimie. We are also especially indebted to F. Polius of Winban St. Lucia for his trials work with our products in St. Lucia and Dominica.

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NOTES

AGRICULTURAL DEVELOPMENT AND ADVISORY SERVICE/WEED RESEARCH ORGANIZATION AVENA FATUA CASE STUDIES

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Summary Some 30 fields in six regions were monitored by ADAS to study the trends in *Avena fatua* populations over a number of years in relation to control methods and cropping and cultivation policies under commercial conditions.

In the majority of fields the chemical control measures over 4 years or so were remarkably successful particularly when combined with break crops. However the very low populations of *A. fatua* remaining after treatment are proving difficult to eradicate and reinfestation of apparently clean fields has occurred. Eradication was achieved in one field.

Farmers emphasised the importance of continuous vigilance to avoid reinfestation and a flexible approach in removing survivors by hand roguing and the occasional use of specific wild-oat herbicides.

Other annual grass weeds are sometimes a problem in winter cereals. The use of herbicides primarily intended for *Alopecurus myosuroides* but with useful activity against *A. fatua*, should be sufficient to control the low levels of *A. fatua* remaining after a well conducted control programme.

INTRODUCTION

In 1973 the ADAS/WRO Liaison Group agreed to organise surveys, on a field basis. These were to study trends in *A. fatua* populations, the remedial treatments undertaken, the cropping and cultivation policy and comments on the field situation by the farmer and ADAS assessor. The prime object was to study the effectiveness of commercial control measures and common factors leading to possible eradication. The project was originally co-ordinated by A. Phillipson and J. Holroyd and currently B.J. Wilson of WRO. This report is an interim review of the situation in 29 fields which have been studied for a number of years. Those fields which have been recently introduced or cover only a few years are excluded leaving 16 fields reviewed.(Table 1) Primary cultivations are also excluded from the table as these were of less importance than cropping and herbicides.

METHOD AND MATERIALS

Fields were selected with a previous *A. fatua* history. Each year *A. fatua* panicles were assessed on a common transect line at five or more equidistant points between 25 and 50 metres apart along the line. At each point, panicles were counted in a 2 metre wide strip, of length varying according to *A. fatua* density, and the number of panicles/m^2 derived. In some cases instead of using a transect, panicles were counted in a fixed quadrat of 10 m x 10 m. These records together with information on the previous *A. fatua* history, cropping, herbicides used and cultivations were sent by the surveyors to WRO for collation.

Table 1

Fields surveyed, code numbers, and areas of fields reported on

Region	Site	Field No.	Area (ha) of reported fields only
Northern	Heighington	3600	1.2
Yorks/Lancs	Malton	129	6.5
		143	3.6
		128N	10.1
		128S	10.1
	Burton Pidsea	34	19.4
		43	6.9
		20	13.8
	High Mowthorpe E.H.F.	12	
		164	
	Churchtown	1572	
	Simonswood	196	
Wales	St. Athan	2862	5.7
	Llantwit Major	6063	2.8
	Rudbaxton	239	2.8
		52	3.2
		67	4.9
	Mostyn	648	
		649	
	Usk	277	8.1
		332	
E. Midlands	E. Haddon	79	10.9
	Brooksby	44	8.9
	Sapperton	63	
		67	
	Stainton	42	
		45	
W. Midlands	Drayton E.H.F.	10	
		11	

Comments on the fields (see Table 2)

Field 129. Infestation up to over 100/m^2 by 1970 was reduced to nil in 4 years by barban and benzoylprop-ethyl treatments in cereals, and by a root break. Infestations were maintained at nil or very low levels for the next 5 years by herbicide control in cereals (benzoylprop-ethyl, barban and tri-allate) and by root breaks. There was no recurrence of the infestation in 1979.

Field 143. Heavy infestations from pre 1970 were reduced to nil by 1974 by barban and benzoylprop-ethyl in cereals and by root breaks. These were kept at nil by a combination of sprays (benzoylprop-ethyl, tri-allate, barban) and by root breaks for the next 4 years. There was no control in the last 2 cereal crops (separated by a root break), and in both these crops A. fatua re-appeared and had to be rogued.

Field 128N. Infestation up to 761/100 m^2 by 1971 had apparently been reduced to nil by one root break and barban spraying in the next cereal crop. A small re-infestation in 1974 when no herbicide was used should have been rogued. Thereafter zero levels were maintained, by barban and tri-allate in cereals and root or legume breaks, for 5 years. A few were seen again in the pea crop in 1979, and were rogued. The farmer reported fewer A. fatua after direct drilling wheat in 1978.

Field 3600. A. fatua built up to 225/100 m^2 in successive spring barley crops before 1974. Two years of poor control by barban and into grass 1976.

Field 128S. Infestation was up to 187/100 m^2 by 1970 and numbers increased in the first 2 years of cereals in spite of tri-allate and barban sprays. A following potato crop led to a decline of A. fatua in the next two cereal crops. Thereafter numbers were kept at zero levels for 4 years by cereal sprays and root breaks though there were still a few to rogue in 1979. The farmer reported fewer A. fatua after direct drilling in 1978.

Field 34. There had been a long history of A. fatua since the late 1940's. There was an apparent immediate reduction to easily roguable numbers by tri-allate in 1972 with an opportunity (not taken) to eliminate by roguing at this stage. Very low levels were maintained for the next 2 years by tri-allate and a legume break. No control for next 3 years with a grass ley in the second year probably prevented re-infestation. Thereafter elimination was maintained by herbicide and by a legume break.

Field 43. There had been a long history of A. fatua since late 1940's. A massive infestation of 5000/100 m^2 was reduced to 175/100 m^2 in 4 years by using tri-allate in cereals and one legume break. There was apparently an increase in spring oats before going into a 3 year grass ley.

Field 20. Another long A. fatua history since late 1940's. 156/100 m^2 in 1971 were reduced to a roguable level (but were not rogued) by tri-allate in 1973. Immediately numbers built up again (211/100 m^2) when control ceased in the fourth year. A 2 year ley left the following cereal crop clean with no control but thereafter benzoylprop-ethyl and tri-allate were required to maintain zero levels.

Field 2862. A long A. fatua history (1930's) built up rapidly in the 4-5 years prior to 1973 to very heavy infestations. Drastic reduction from 320/100 m^2 to 31/100 m^2 was achieved by 3 years' use of tri-allate in spring barley. None were seen in potatoes in the fourth year.

Field 239. A clean field in 1972 after 4-5 years grass. There was no control used in 3 cereal crops. An initial infestation appeared in the fourth cereal. This was eliminated in fifth and sixth years by roguing.

Field 52. A build-up (from 1970 with no control in successive spring barleys) to a light infestation (33/100 m^2) was checked by one spray (tri-allate) in 1974 and hand roguing in the following year prior to a grass ley.

Field 79. A history of A. fatua since 1963. Good results were obtained with tri-allate and barban between 1968 and 1972 and a root break in 1973 brought populations down to low levels. These were smothered out by rape in 1977.

Field 44. No control in the first cereal following a root break resulted in A. fatua levels of 1100/100 m^2. These were not controlled in the second cereal in spite of a double herbicide treatment, nor by a root break with no herbicide control in the

Table 2

Details of cropping, herbicide use and A. fatua population changes

Field No.	Year	Crop	Herbicide	A. fatua panicles /100 m^2
129	1970	S. beet	Barban	over 100
	71	S. barley	Barban	308
	72	W. Wheat	Benzoylprop-ethyl	554
	73	Potatoes	Paraquat	Nil
	74	W. wheat	Benzoylprop-ethyl	Nil
	75	S. beet	Tri-allate	9
	76	S. barley	Tri-allate	Nil
	77	W. wheat	Barban	Nil
	78	Potatoes	Nil	Nil
	79	W. wheat	Nil	Nil
143	1970	S. barley	Barban	
	71	Potatoes	Paraquat	112
	72	W. wheat	Benzoylprop-ethyl	161
	73	S. beet	Tri-allate	22
	74	S. barley	Tri-allate	Nil
	75	W. wheat	Benzoylprop-ethyl	Nil
	76	Potatoes	Paraquat	Nil
	77	W. wheat	Nil	Nil
	78	S. beet	Tri-allate	Nil
	79	S. barley	Nil	10
128N	1971	S. barley	Barban	761
	72	Turnips	Nil	Nil
	73	S. barley	Barban	Nil
	74	W. wheat	Nil	14
	75	S. barley	Barban	Nil
	76	S. beet	Tri-allate	Nil
	77	S. barley	Tri-allate	Nil
	78	W. wheat	Paraquat	Nil
	79	Peas	Paraquat	Nil
3600	1974	S. barley	Barban	750
	75	S. barley	Barban	1200
	76	Grass	Nil	73
128S	1971	S. barley	Tri-allate	187
	72	S. barley	Barban	377
	73	Potatoes	Paraquat	Nil
	74	W. wheat	Nil	73
	75	S. barley	Barban	1
	76	S. beet	Tri-allate	Nil
	77	S. barley	Tri-allate	Nil
	78	W. wheat	Paraquat	Nil
	79	Potatoes	Paraquat	Nil
34	1971	S. barley	Tri-allate	108
	72	S. barley	Tri-allate	1
	73	Peas	Tri-allate	8
	74	W. wheat	Tri-allate	3
	75	S. oats	Nil	8
	76	Ley	Nil	Nil
	77	W. wheat	Nil	Nil
	78	Peas	Tri-allate	2
	79	W. wheat	Benzoylprop-ethyl	Nil
43	1971	W. wheat	Tri-allate	5000
	72	W. wheat	Nil	3000
	73	Peas	Tri-allate	438
	74	W. wheat	Tri-allate	207
	75	S. barley	Tri-allate	175
	76	S. oats	Nil	3000
	77	Ley	Nil	Nil
	78	Ley	Nil	Nil
	79	Ley	Nil	Nil

Table 2 cont.

Field No.	Year	Crop	Herbicide	A. fatua panicles /100 m^2
20	1971	Peas	Tri-allate	156
	72	W. wheat	Tri-allate	66
	73	S. barley	Tri-allate	11
	74	S. barley	Nil	211
	75	Ley	Nil	Nil
	76	Ley	Nil	Nil
	77	W. wheat	Nil	Nil
	78	W. wheat	Benzoylprop-ethyl	Nil
	79	Beans	Tri-allate	Nil
2862	1973	W. wheat	Tri-allate	n.a.
	74	S. barley	Tri-allate	320
	75	S. barley	Tri-allate	10
	76	S. barley	Tri-allate	31
	77	Potatoes	Monolinuron	Nil
239	1972	W. barley	Nil	Nil
	73	S. barley	Nil	Nil
	74	W. oats	Nil	Nil
	75	S. barley	Nil	20
	76	S. barley	Nil	Nil
	77	W. barley	Nil	Nil
52	1973	S. barley	Nil	33
	74	S. barley	Tri-allate	10
	75	Oats & barley	Nil	3
52+67 fields joined	76	Ley	Nil	Nil
	77	Ley	Nil	Nil
79	1968	S. barley	Nil	3600
	69	S. barley)	Tri-allate	
	70	S. barley)	or	
	71	S. barley)	Barban	
	72	S. barley	Nil	200
	73	Turnips	Dalapon	
	74	W. wheat	Tri-allate	11
	75	S. barley	Barban	14
	76	S. barley	Barban	Nil
	77	Oilseed rape	Dalapon	Nil
44	1973	W. wheat	Nil	1100
	74	W. wheat	Tri-allate + Benzoylprop-ethyl	420
	75	S. beet		
	76	Maize	Atrazine	Nil
277	1975	Maize	Atrazine	
	76	W. wheat	Tri-allate	9
	77	Peas	Tri-allate	130
6063	1973	Swedes	Paraquat	
	74	S. barley	Tri-allate	360
	75	S. barley	Tri-allate	27
	76	W. wheat	Tri-allate	28
	77	S. barley	Nil	370

third year. A maize crop treated with atrazine in the fourth year eliminated panicles.

Field 277. A fatua history since 1965. Assessment was not possible in maize in 1975. A fatua built up the following two years (wheat and peas) despite the use of tri-allate.

Field 6063. A fatua had been present since 1930's, became very bad in early 1970's. A 1973 root break was very effective, followed by 3 years of tri-allate which reduced the population. However numbers increased in the absence of herbicide in 1977.

DISCUSSION

Herbicide performance

Herbicide performance records which are available over a long period show that herbicides have apparently achieved impressive population reductions over a relatively short time (Table 3).

Table 3

Fields showing reductions in A. fatua achieved with herbicides

Field	Population reduction/100 m^2	% reduction	Years treated
3600	750 - 73	90	3
129	100 - Nil	100	3
143	112 - Nil	100	3
128N	761 - Nil	100	2
128S	187 - 1	99	4
34	108 - 1	99	1
43	5000 - 175	96	4
20	136 - 11	92	2
79	3600 - 200	94	4

However after initial rapid declines the surviving A. fatua were very difficult to eradicate and tended to re-appear after a period of zero recording (Fields 128N, 128S, 34, 143 and 129). This suggests a latent population of dormant seeds in the soil.

The results show a good performance from the old established herbicides barban and tri-allate. There were however some failures (Field 3600 - barban, 128S - barban, 277 - tri-allate) where infestations increased after treatment, probably as a result of crop damage and reduced competition. The herbicide benzoylprop-ethyl has been used in more recent years with somewhat mixed results, successful in 34, 143, 20 but poor control in individual years in Fields 143, 129 and 44. It was recorded that benzoylprop-ethyl resulted in panicles below the crop canopy. Partial failures are a danger signal for maintaining control measures in future crops.

Only in one field (52) was eradication achieved by herbicides and roguing alone and here the initial infestation was light.

The influence of break crops and rotation

Arable crops. The rapid reductions in A. fatua populations noted in this study were undoubtedly assisted in many cases by the root breaks, particularly as many pre- and succeeding crops were winter cereals where herbicide control is more difficult.

Herbicides alone were obviously successful but required a longer period for the same effect.

Break crops had an obvious immediate effect in reducing populations as in Fields 129 potatoes, 128N turnips, 128S potatoes, 43 peas, 79 turnips. However break crops grown early in the control programme still show the importance of vigilance in following cereals although in Field 128N an 'early' turnip crop enabled populations to be contained in the following crops. With break crops sown later in the control programme A. fatua were easily contained or eliminated (Fields 79, 128S, 2862). Forage maize and winter oilseed rape also allow very effective A. fatua control by chemical means.

Grass leys. The study demonstrated the value of grass leys in A. fatua seed decline but as is well known a surprisingly high number of dormant seeds may germinate following soil disturbance for the first cereal crop (Fields 34, 20). Every effort should be made to prevent re-seeding and re-infestation at this stage.

Cultivations

No obvious cultivations benefits show up in the study but there may have been some via the break crops in terms of different times of sowing relative to cereals, e.g. - later sowing of root crops and more thorough cultivations. Similarly, alternating winter and spring cereals has been shown to prevent A. fatua building up when no herbicides were used (Roebuck and Field 1978) over 8 years.

Direct drilling in 128N and 128S was reported by the farmer as being beneficial, probably because of seed decline on the soil surface as reported by Wilson 1972.

Straw disposal as a factor in A. fatua control was not included in the study.

Eradication of light infestations

Light populations re-appearing in apparently clean crops were dealt with effectively, providing action was prompt, e.g. Field 239 by roguing.

When can spraying stop?

Eradication was achieved in Field 52 but in other fields omitting control measures too early in the programme (in the fourth year) led to an immediate flush of A. fatua forcing resumption of spraying (Fields 128S, 128N, 20, 79, 6063). Spraying was also necessary in some cases after recording nil levels, or after omitting control measures for a few years or after a ley (Fields 34, 20) showing the need for continued vigilance.

Although the results from the study are optimistic in terms of commercial success with A. fatua control the eradication of survivors and prevention of re-infestation remain as dominant problems. Removal of survivors by hand roguing for the purpose of eradication is likely to take considerable time but farmers' opinions suggest that this is a cheaper policy than chemical control as these very low populations are unlikely to repay the cost of chemicals by yield response. But the picture may change with increasingly dominant winter cereal rotations and early drilling.

In those fields with very ligh infestations the use of specific A. fatua herbicides at reduced rates or in alternate years may help to reduce costs. Alternatively a number of wide spectrum herbicides (e.g. chlortoluron, isoproturon) will cope with low levels of A. fatua and also control other annual grass weeds (particularly A. myosuroides) which are now more serious than A. fatua (National Survey of Wild Oats and other Grass Weeds, 1977).

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THE PREDICTION OF WEED INFESTATIONS AND COST OF DIFFERING CONTROL STRATEGIES.

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Summary Two mathematical models are introduced for the calculation of the rates of change of the size of weed infestations. The utility of these models is examined in the case of *Avena fatua* and *Agropyron repens* and an approach to the evaluation of the costs of weed containment or eradication illustrated.

INTRODUCTION

For the majority of cereal crops grown today in the Western Hemisphere a range of effective measures, herbicidal and cultural, are available for weed control. However, the cereal farmer is faced with a complex decision making problem in an economic environment of fluctuating financial returns and often increasing agrochemical costs. First he must decide upon a strategy of weed control and second, within that strategy, what level of control to aim for in any particular growing season. Viewed in the long term, clearly the most desirable solution is the one which by reducing weed infestation maximises the monetary value of the crop over as many seasons as possible, for the monetary investment made in weed control measures. Such a solution may be achieved either by a deliberate policy of containment of the weed to low levels of infestation, or one of attempting ultimate eradication of the weed.

Assessment of these two options demands detailed knowledge on the one hand of the population biology of the weed and on the other of the finances of crop production including the various costs of the weed control measures available. This paper explores the problem of relating the regulation of weed infestations to the associated costs of controlling them.

THE APPROACH

In broad terms, the task of formulating an equation relating the cost of control and the amount of regulation achieved, requires three fundamental questions to be answered.

1. In any given cropping environment, how fast is the weed population growing in the absence of a proposed control measure?

2. How much of the proposed control is required to either

   (a) contain the weed infestation at its present size

   or (b) force the population into a decline (induce a negative growth rate) so as to cause ultimate eradication?

3. What is the best way of optimising costs - namely achieving the level of control required for the lowest cost?

In order to determine whether either containment or ultimate eradication is the best option, it is necessary to previously know the rate of change of the size of the weed population under a particular crop management in the light of the economics of the control measure. This rate of change may be measured by the net reproductive rate or finite rate of change and is the product of the survivorship of the individuals in the population and their fecundity. Since weed infestations in general rely on the presence of a reserve of innoculum, mainly in the form of buried seeds or buds on rhizomes, any calculation of net reproductive rate must take into account all the components of which the weed population consists; namely seeds, buds, seedlings and adults as appropriate. The first step in obtaining a measurement of the rate of population change is the conceptual organisation of the dynamics of the particular weed species into a flux diagram (Sagar and Mortimer, 1976). In the case of annual species such as Avena fatua, this is not hampered by the overlapping of adult generations which will occur in perennial weeds such as Agropyron repens. The measurement of the fluxes (rates of change) within the conceptualised life cycle of the weed can then be incorporated into a mathematical model (Mortimer, et al., 1978) by which the net reproductive rate may be calculated. These models provide a framework to test the effects of control practices upon the subsequent sizes of weed populations by computer simulation (Mortimer, et al., 1978). They may furthermore be used to evaluate the control required to contain or eradicate an infestation. This approach is illustrated below for Avena fatua and for Agropyron repens.

A MODEL FOR AN ANNUAL WEED - Avena fatua

Avena fatua is a semelparous weed; within the time span of one year seeds germinate to establish adult plants which then set seeds and die. Seeds germinate either in autumn or spring yet seed dissemination from adult plants occurs largely concurrently in late summer. A population of wild oats may be envisaged as a series of cohorts (a group of seedlings which emerge during a short period of time, e.g. one week), (Fig. 1.A), in which the fates of individual plants may be measured by their probability of survivorship to maturity, p_i, and their fecundities as the average seed number, F_i, (Fig. 1.B). The dynamics of this population may be developed as follows, where $n_{i,t}$ is the number of seeds germinating in the 'i' th cohort in year t, and N_t and N_{t+1} are total seed populations at the start of the year t and t+1 respectively.

In the absence of a seed bank,

$$N_{t+1} = n_{1,t}\, p_1\, F_1 + n_{2,t}\, p_2\, F_2 \dots\dots\dots + n_{z,t}\, p_z\, F_z$$

In the presence of a seed bank,

$$N_{t+1} = n_{1,t}\, p_1\, F_1 + n_{2,t}\, p_2\, F_2 \dots\dots\dots + n_{z,t}\, p_z\, F_z + B$$

where B is the number of seeds remaining in the bank. Now, if k_i is the proportion of seeds germinating in the ith subunit of time then $k_i = \frac{n_{i,t}}{N_t}$

and if b is the proportion of seeds that remain in the seed bank, $\frac{B}{N_t}$,

then

$$N_{t+1} = k_1\, N_t\, p_1\, F_1 + k_2\, N_t\, p_2\, F_2 \dots\dots\dots + k_z\, N_t\, p_z F_z + bN_t$$

with the constraint that $1 \geqslant \sum_{i=1}^{z} K_i + b$. The rate, λ, at which the population is increasing ($\lambda > 1$) or decreasing ($\lambda < 1$) is $\lambda = N_{t+1}/N_t = \sum_{i=1}^{z} K_i\, p_i\, F_i + b \dots\dots\dots 1.$

To express the dynamics of the population experiencing the weed control we must introduce a term θ_{ii} into the equation. θ_{ii} is the proportion of individuals in the ith cohort that survive weed control measures in the ith subunit of time. Thus for the ith cohort, $\prod_{j=1}^{z} \theta_{ij}$ is the proportion that survive to set seed and $1 - \prod_{j=i}^{z} \theta_{ij}$ is the proportion that are killed. Introducing this into our model, 1, we have

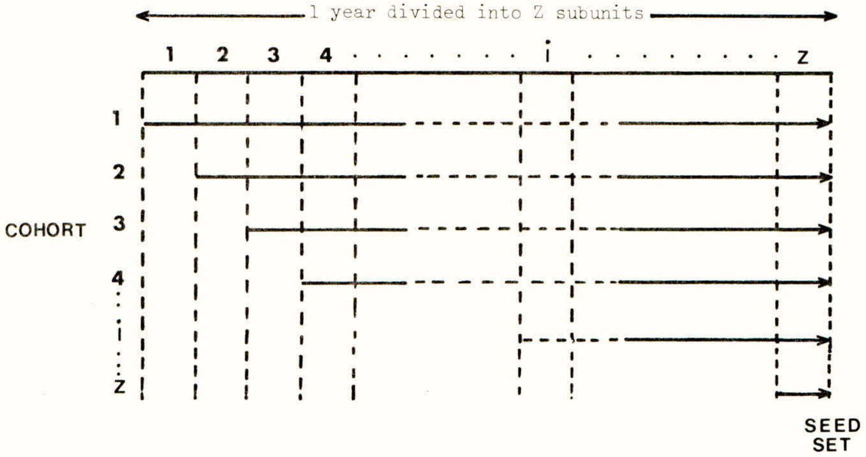
$$N_{t+1} = N_t \left[\sum_{i=1}^{z} K_i\, p_i\, F_i \left(\prod_{j=i}^{z} \theta_{ij} \right) + b \right]$$

and thus the rate under weed control, $\lambda_c = \sum_{i=1}^{z} K_i\, p_i\, F_i \left(\prod_{i=j}^{z} \theta_{ij} \right) + b \dots\dots\dots 2.$

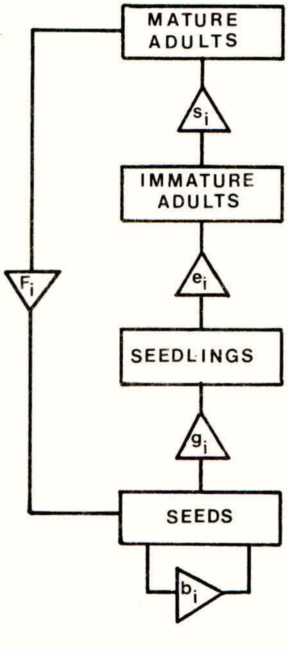
The utility of this model may be seen by examining the data of Chancellor and Peters (1972) on the growth of Avena fatua in spring barley (Table 1). Using 1 and with the assumption that the probability of a seed remaining viable in the seed

Fig. 1

A. Visualisation of the dynamics of an annual plant species - a series of cohorts.



B. Life-history of Avena fatua for the i^{th} cohort.



F_i = total adult fecundity (number of seeds) subsuming all tillers per plant.

p_i — the probability of a seed surviving to become a mature flowering adult = $g_i . s_i . e_i$

Constraints:-

$$0 \leqslant p_i \leqslant 1$$

$$0 \leqslant g_i \leqslant 1$$

$$0 \leqslant s_i \leqslant 1$$

$$0 \leqslant e_i \leqslant 1$$

$$g_i + b_i \leqslant 1$$

TABLE 1. THE DYNAMICS OF A POPULATION OF AVENA FATUA IN SPRING BARLEY UNDER NORMAL FARM MANAGEMENT. FROM CHANCELLOR & PETERS, 1972, (BAMPTON SITE).

COHORT	EMERGENCE PERIOD (days after crop drilling)	Proportion Emerging, k_i	Probability of Plant Surviving to set seed, p_i	Mean No. Seeds per Plant, F_i	$k_i p_i F_i$
1	1 - 10	0.015	0.03	117	0.053
2	11 - 20	0.090	0.15	117	1.580
3	21 - 30	0.150	0.40	117	7.020
4	31 - 40	0.125	0.60	40	3.000
5	41 - 50	0.080	0.80	6	0.384
6	51 - 60	0.035	0.86	4	0.120
7	61 - 70	0.015	0.90	4	0.054

$$\sum_{i=1}^{7} K_i p_i F_i = 12.211$$

Proportion of seed remaining viable in seed bank, b = ... 0.25

From Equ. 1 Finite rate of growth, λ = ... 12.461

ASSUMPTIONS:-

1) All plants of *A. fatua* present prior to crop drilling are killed.
2) All plants of *A. fatua* set seed at the same time.
3) The probability of a seed germinating and producing a seedling is 0.5 for all cohorts.

bank, b, is 0.25, the net reproductive rate, λ , is 12.461 (see Table 1 for means of calculation). In other words the *Avena fatua* population has increased by approximately $12\frac{1}{2}$ fold in one year. The final column in Table 1 indicates the relative contributions of each cohort to the rate of population increase and furthermore that the plants that germinated from seed in the period 21-30 days after crop drilling contribute the greatest. With these contributions in mind the effectiveness of a control measure may be evaluated.

Fig. 2 demonstrates the relationship between mortality and plant age for a dose of a herbicide. For convenience subunits of time in Fig. 2 are the same as in Table 1. The response is entirely hypothetical but is chosen to illustrate a situation in which the most effective kill is achieved on the youngest plants. The resulting schedule of survivorship for cohorts is given in Table 2 together with the rates of growth, λ_c , of the wild oat population calculated from equation 2. It is immediately apparent that the most effective regulation of infestation rate occurs if this hypothetical herbicide is applied 31-40 days after crop drilling since this is precisely the time when the optimal number of wild oats most susceptible to the herbicide occurs. The final step in the usage of this model is to equate the reduction in growth rate achieved to the fixed and variable costs involved in the use of the herbicide.

A MODEL FOR A PERENNIAL WEED - *Agropyron repens*

The life history of *A. repens* is demographically complex. Adult tillering shoot systems (hereafter referred to as 'adults') may live for several years and annually contribute both buds and seeds to banks of propagules from which new adults may arise. The life history of *A. repens* is illustrated in Fig. 3 which shows the fluxes that may occur in one complete year, starting in July. A more detailed description of the acquisition of these data is given in McMahon and Mortimer (The prediction of couch infestations - a modelling approach) in these Proceedings. The growth of this population may be modelled using a matrix approach (Sarukhan & Gadgil, 1974; Mortimer *et al.* 1978) in which the dynamics of the population are summarised in a transition matrix of survivorship and fecundities (Table 3) and from which it is possible to calculate the net reproductive rate, λ (Usher 1972). For a population of couch grown at the Botanic Gardens of the University of Liverpool, that is illustrated in Fig. 3, this rate was found to be 2.96. Since a population with a net reproductive rate of unity is static in size, the yearly level of weed control to contain the size of this couch population will be on average$((\lambda-1)/\lambda)$.100 or 66.2%. Annual control in excess of this figure will result in a decline in the size of the couch infestation.

The transition matrix may, however, be utilised in a further way to predict the levels of control required to achieve consistent declines in the weed population. As a scenario we may envisage an arable crop severely infested with couch which has a potential annual threefold increase, (as in Fig. 3). It is proposed to compare the costs of containment of the couch at its present size of infestation versus the costs of eradication at a rate which halves the infestation every two years, a suitable control measure which kills adult plants only being used. The level of adult mortality needed to be achieved by herbicide application will be different for these two options and may be calculated by a derivative, to be published elsewhere, of a mathematical model already in the literature (Lefkovitch, 1967). Although it does require some knowledge of matrix algebra for detailed comprehension, the underlying principle is straight forward. Given a transition matrix describing the dynamics of the population, it is possible to calculate the level of control of any component(s) of the population (seeds, buds or adults) that is required to achieve a desired rate of decrease and hence ultimate eradication ($\lambda < 1$) or containment ($\lambda = 1$). The poster display previously referred to illustrates the workings of the model and the method of calculation follows Lefkovitch (1967). Using the transition matrix in Table 3, it was found that to contain this couch population 73.7% of all the adults in each age class should be killed annually.

Fig. 2. Hypothetical activity response of a particular dose of herbicide in relation to plant age.

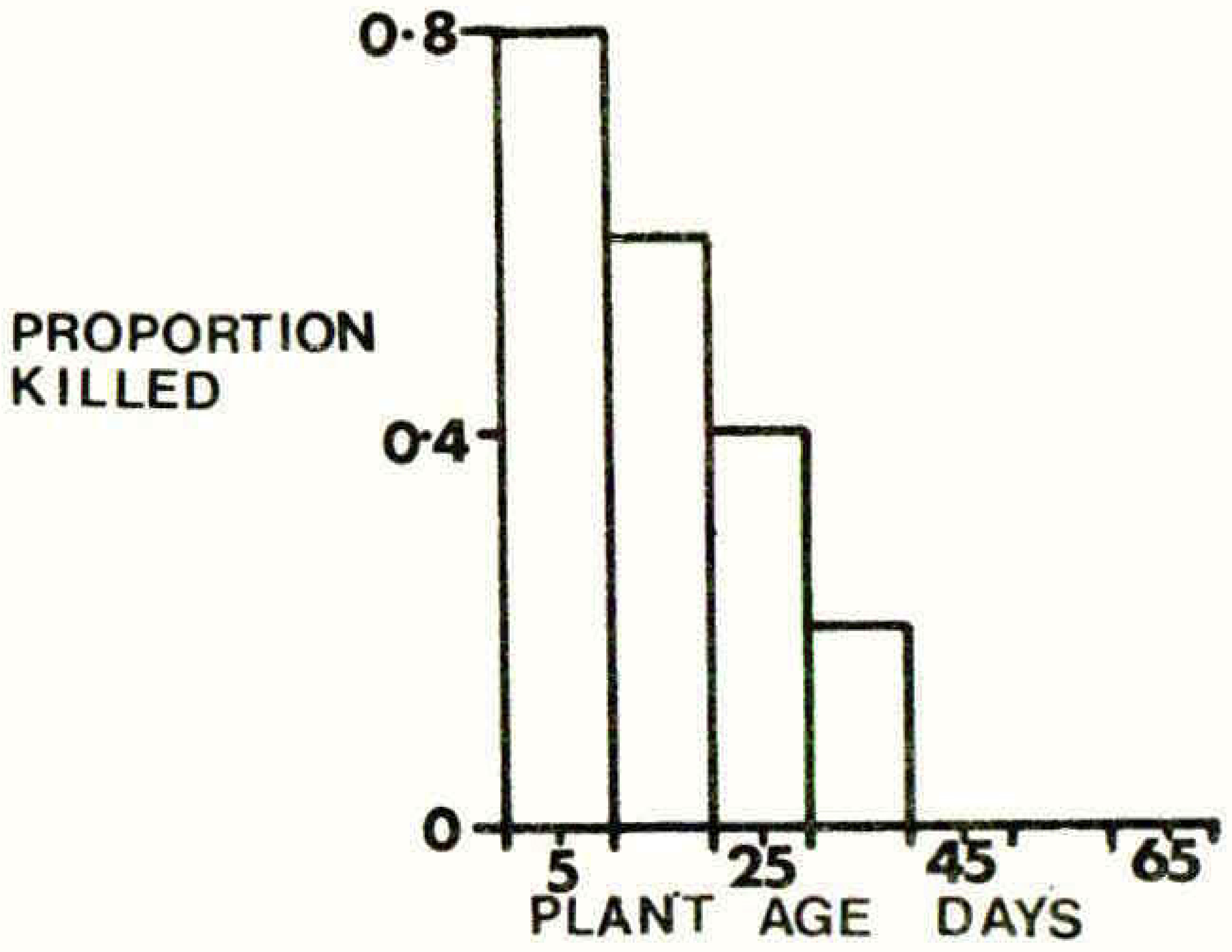
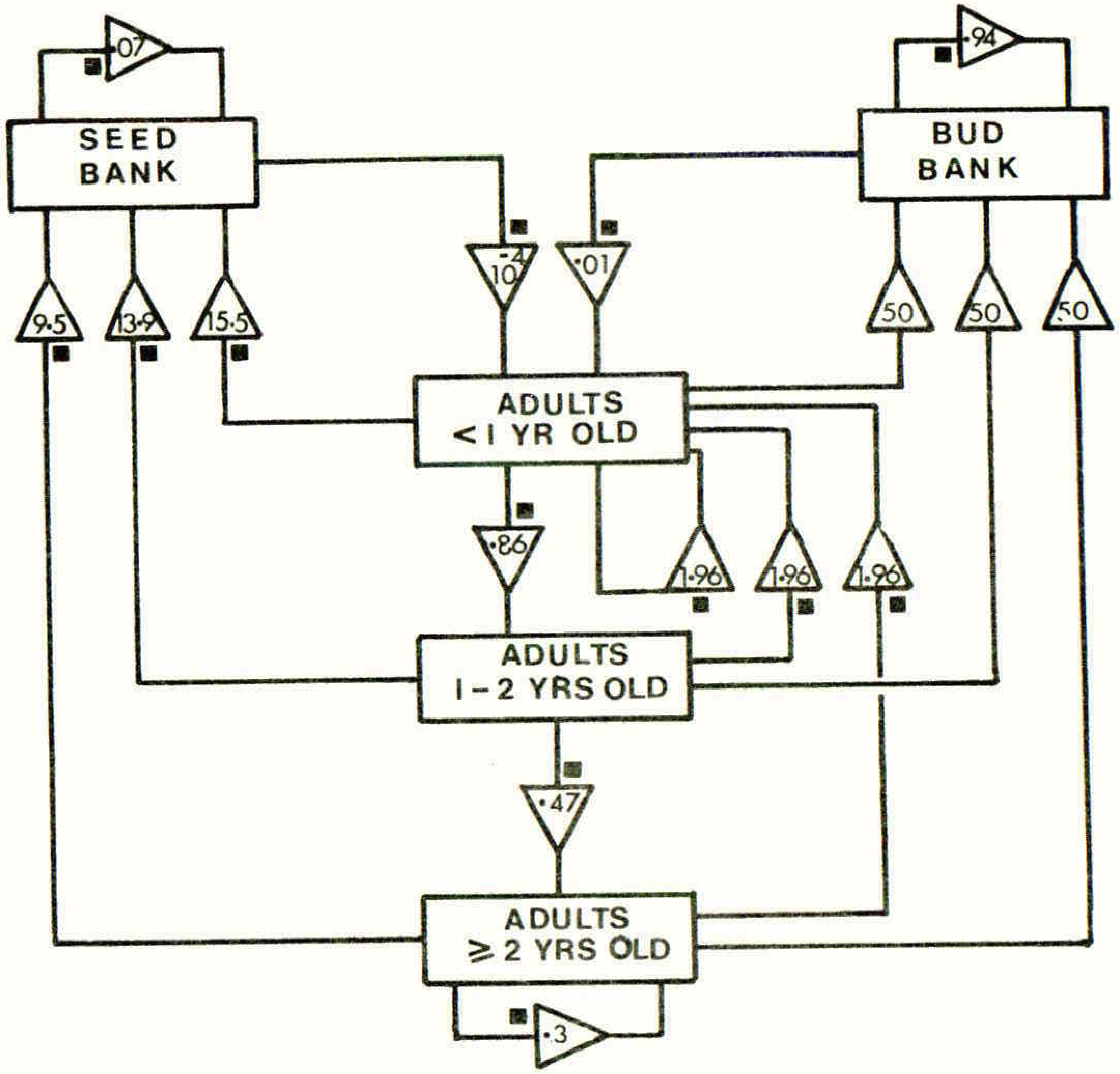


Table 2. Schedules of survivorship (ϑ_{ij}) for a wild oat population in response to herbicide activity as in Fig. 2. (see text for explanation).

	TIME PERIOD (DAYS) DURING WHICH HERBICIDE APPLIED						
	1-10	11-20	21-30	31-40	41-50	51-60	61-70
Cohort 1	0.2	0.4	0.6	0.8	1.0	1.0	1.0
2	1.0	0.2	0.4	0.6	0.8	1.0	1.0
3	1.0	1.0	0.2	0.4	0.6	0.8	1.0
4	1.0	1.0	1.0	0.2	0.4	0.6	0.8
5	1.0	1.0	1.0	1.0	0.2	0.4	0.6
6	1.0	1.0	1.0	1.0	1.0	0.2	0.4
7	1.0	1.0	1.0	1.0	1.0	1.0	0.2
λ_c	12.41	11.17	5.88	5.11	7.23	8.63	11.59

Fig. 3. A diagrammatic life table for *Agropyron repens*.



TRANSITION PROBABILITIES AND FECUNDITIES MARKED ■ ARE OBTAINED FROM FIELD MEASUREMENTS IN A REGULATED POPULATION SUCH AS MIGHT OCCUR IN AN INFESTED ARABLE CROP UNDER MINIMUM TILLAGE. OTHER FLUXES ARE OBTAINED FROM EXPERIMENTAL AND LITERATURE SOURCES. THE TIME SCALE IS 1 YEAR STARTING IN JULY.

TABLE 3. TRANSITION MATRIX FOR A POPULATION OF AGROPYRON REPENS AS ENVISAGED IN FIGURE 3

	SEED	ADULTS ≤1 YR	ADULTS 1 - 2YRS	ADULTS ≥2 YRS	BUDS
SEED	0.07	9.52	13.90	15.50	0
ADULTS ≤1 YR	0.0001	1.96	1.96	1.96	0.01
ADULTS 1-2 YRS	0	0.86	0	0	0
ADULTS ≥2 YRS	0	0	0.47	0.30	0
BUDS	0	50	50	50	0.94

To enable eradication however, calculation showed that this mortality rate should be increased to 99.2% per annum. It may appear surprising that the level of control for containment is as high as 73.7% when 99% mortality of adults is needed for the programme of eradication. This results from a feature of the population being modelled. Recruitment over one year to the youngest age class from all adult classes through rhizome tip development contributes in relative terms more to the population growth rate than the contributions from bud and seed banks. Eradication involves ultimate destruction of these banks and hence the additional level of control over and above that for containment is not high, although the progress of eradication may be protracted.

The predicted levels of adult mortality required for the two control options are clearly attainable in the field. Costs of two in comparison may be widely different and their assessment, knowing the desired level of control, is the province of the farm economist. Within this scenario however, the containment option is economically favourable if the size of the weed infestation is such that the costs incurred through crop losses due to the presence of the weed exceed the costs of containment. Similarly for eradication, the long term financial expectation of increased yield returns must be equated against the costs of regular herbicide application over a period of a number of years, depending on the size of the original infestation.

DISCUSSION

The two approaches taken above illustrate the means by which population growth rates may be calculated; the timing of a control measure, and hence its cost effectiveness, evaluated; and the levels of weed control required for containment or eradication of the infestation evaluated. No attempt has been made to predict actual costs for proprietary herbicides or for cultural measures, although given the available data a linear programming solution could easily be taken to optimise costs to the farmer.

Application of either of these two approaches in the agricultural industry requires long term experimentation and monitoring of weed populations. Such experimental work need not take longer than 3 years - D.J. McMahon obtained the data for *A. Repens* in this time. Yet is is probably desirable to gather data over a longer period to account for climatic heterogeneity. Data do however need to be acquired for a variety of crop management regimes and soil environments. It is only then that alternative and integrated control procedures may be examined since there is no theoretical restriction to the sequential alteration of survivorship and fecundity terms in the model for the calculation of rates of population change. Increased realism and precision may be attained by allowing these terms to be intraspecifically regulated and for proportions of the individuals in the weed population to show herbicide resistance. Such sophistications are perfectly possible.

An additional feature of the matrix approach is that it enables the feasibility of a proposed eradication programme to be assessed. Whilst a particular herbicide may in trials offer the promise of eradication by mortality to a weed species, this does not *per se* imply its success as an eradicant. If for instance the rate of mortality required for the eradication programme in the couch scenario had exceeded 100% of all adults per annum, additional control measures besides the herbicide would have to be adopted or the speed of eradication lessened. The model may of course be used in reverse. For a given financial budget and efficiency of proposed control measures, the rate of population decline and hence speed of eradication may be calculated and assessed in relation to its costs.

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FOLLOW-UP TREATMENTS FOR CONTROL OF PTERIDIUM AQUILINUM

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Summary The reinfestation of hill pastures in the West of Scotland by *Pteridium aquilinum* (bracken) following successful control by spraying with asulam can be delayed by the presence of grazing cattle. Repeated annual applications of the herbicide reduce frond numbers to a very low level but are impractical as a means of eradication.

Changes in the grazing pattern which can minimise *Pteridium aquilinum* regrowth are dependent on improvements in sward quantity and quality. In some cases, marked yield increases can be obtained by frond clearance alone and it may be difficult to justify follow-up treatments.

Where follow-up treatments are being considered, they must be related to the soil and vegetation type and also the level of management which can be given to the pasture. The first aim must be containment of reinfestation and if this can be carried out successfully, eradication may be possible because rhizome reserves available for regrowth have been reduced to a very low level.

INTRODUCTION

The infestation of pastures with *Pteridium aquilinum* is usually an indicator of a grazing system based on set-stocking with sheep. Control is primarily an economic problem but changes in management are required if reinfestation is not to occur. These can be an important factor in determining the amount of control achieved in the long term. While the eradication of *Pteridium aquilinum* is always possible in enclosed pastures because of the degree of grazing control which can be exercised, the cost of new fencing on an open hill may be unacceptably high in relation to the increase in output which may be expected. The eradication of *Pteridium aquilinum* where close control of grazing is not possible is more difficult to achieve and requires manipulation of stocking rates to an extent which cannot be met on the majority of hill farms in the West of Scotland because of their shortage of land suitable for forage conservation for winter keep. The aim must then be to slow down the rate at which *Pteridium aquilinum* recolonises in order to postpone repeat control measures for as long as possible.

Almost all control of *Pteridium aquilinum* on hill grazings is now carried out by spraying with asulam. This paper considers, in terms of increased sward output, various treatments which may be carried out after the initial frond control has been achieved.

METHOD AND MATERIALS

Trials were set up between 1973 and 1976 to study various factors related to the control of *Pteridium aquilinum* with asulam. The experimental sites were at Callander, Perthshire; Dalry, Kirkcudbrightshire; Dunscore, Dumfriesshire; Gatehouse of Fleet, Kirkcudbrightshire; Glen Douglas, Dunbartonshire and Glespin, Lanarkshire. Initial spraying at 4.5 kg/ha a.i. in 400 l/ha water was followed by assessments of the rate of frond regeneration, the production of indigenous grasses, the possibilities of eradicating *Pteridium aquilinum* by repeated treatments with asulam and the effect of fertiliser application.

RESULTS

A. The effect of stock on frond regeneration

It has been observed that even in the absence of any follow-up treatment after spraying, the type of stock grazing can have a marked effect on the rate of recolonisation by fronds of *Pteridium aquilinum*. Table 1 shows regeneration rates at the various trial sites.

Table 1

The effect of type of stocking on frond regeneration

		Frond nos. (% of control)				
Years after spraying		1	2	3	4	5
A. Sites grazed by sheep						
Callander		1.2	1.8	14.7	24.9	46.2
Glen Douglas		2.4	6.5	20.4	35.1	71.3
Glespin		1.6	4.3	17.3	28.1	51.6
	Mean	1.7	4.2	17.5	29.4	56.4
	SE ±	0.41	2.13	3.80	5.62	6.44
B. Sites grazed by cattle and sheep						
Dalry		0.9	0.4	2.1	2.1	3.4
Dunscore		2.2	2.8	5.2	10.8	14.9
Gatehouse of Fleet		1.3	1.8	1.0	3.2	2.6
	Mean	1.5	1.7	2.8	5.4	7.0
	SE ±	0.37	0.42	2.01	4.59	5.72

The presence of even a small suckler herd of cattle has reduced *Pteridium aquilinum* regrowth and has substantially delayed the necessity for respraying.

B. The effect of frond clearance on sward output

The increase in sward production which results from frond clearance will depend very much on the density of the original *Pteridium aquilinum* infestation and the amount of ground which is covered with litter. In the West of Scotland, a frond cover which is not sufficient to produce any appreciable amount of litter on the ground in July normally has a sward beneath it composed largely of *Agrostis tenuis* and *A. canina*, with lesser amounts of *Festuca rubra* and *Anthoxanthum odoratum*. As the amount of frond cover increases, *Holcus mollis* becomes more important and the area of ground which is covered with litter also increases.

Spectacular percentage increases in sward yield will obviously be obtained if a dense stand of *Pteridium aquilinum* is cleared, but recolonisation of litter by indigenous species may be slow and weed species may become established more rapidly than those which are of use. Table 2 shows the average production of four species of hill grasses at Dunscore. Five 1 m^2 grazing cages were set up over pure stands of each grass and assessments made of dry matter yield in mid-July and mid-September, 1974 and 1975.

Table 2

Production of hill grasses

	Dry Matter (t/ha)
Festuca rubra	2.6
Deschampsia flexuosa	1.5
Holcus mollis	4.6*
Agrostis tenuis	4.1
SE ±	0.38

*1974 figures only. Negligible growth in 1975.

In the moist climate of the West of Scotland, recolonisation of litter-covered areas is fairly rapid except in the densest infestations and although asulam causes an initial reduction in the proportion of *Agrostis* and *Holcus* (Williams, 1977), its use can give appreciable increases in the quantity of vegetation produced. The results in Table 3 have been taken from Williams & Fraser (1979) and show the effect of frond clearance on sward output at Callander.

Table 3

Effect of asulam on sward production

Years afer spraying	1	2	3
Yield (t/ha dry matter)	1.49	1.95	2.15
Increase over control (t/ha DM)	0.19	0.75	1.02

At present, asulam spraying alone does not qualify for grant aid and the improvements shown must be set against a cost of approximately £150/ha for aerial spraying in 1980.

C. The effect of follow-up herbicide treatments

While asulam spraying gives excellent control of *Pteridium aquilinum*, some frond regrowth occurs in the following year. Apart from areas which show poor control because of uneven spray distribution, some fronds are produced from rhizome apices which did not produce a frond in the previous year. The effect of annual follow-up spraying at 2.0 kg/ha a.i. for 3 years was investigated at Dunscore to find out whether eradication was possible using asulam alone, and the results are shown in Table 4.

Table 4

The effect of follow-up asulam spraying on *Pteridium aquilinum* regrowth

	Frond nos./1000 m^2			
Years after initial treatment	1	2	3	4
Resprayed annually	423	104	56	4.5
No respraying	386	1031	2128	5729
SE±	56	230	384	426

The treatment reduced frond numbers to a mean of 4.5 per 1000 m^2 trials plot but there was increased damage to the pasture and the cost was prohibitive. While these disadvantages could be overcome by using spot treatment, this presents difficulties in extensive areas of hill country. It therefore appears that eradication by herbicide use alone is impossible in practice.

D. The effect of fertiliser treatments

The minimum follow-up treatment specified by DAFS before the cost of bracken clearance will be grant-aided is 300 kg/ha of ground mineral phosphate, which adds about £100/ha to the gross cost of improvement. In western Scotland, where the pH of soils in bracken-infested areas is normally between 4.0 and 4.5, there is no evidence that this application has more than a marginal effect on sward production (Williams & Fraser, 1979). This contrasts markedly with results obtained in other parts of the world, where low application rates of phosphate fertiliser have given appreciable increases in production and the difference appears to be one of soil pH.

Nitrogenous fertilisers are not usually recommended in open hill situations because they are rapidly leached under conditions of high rainfall and also because the indigenous grasses often do not show a response which justifies the cost involved. Table 5, however, shows the effect of an application of nitrogenous fertiliser on the recolonisation of ground covered with litter after bracken removal. Asulam was applied at Gatehouse of Fleet in August 1974 and followed by 60 kg/ha N as nitrochalk in May 1975. Assessment of the percentage of ground covered by litter were made in August 1975, 1976 and 1977.

Table 5

Effect of N on litter recolonisation

	% litter-covered ground		
	1975	1976	1977
Control	43.6	21.4	3.2
Nitrochalk	19.7	2.2	0
S.E. ±	6.0	4.1	0.8

Most of the recolonisation was by *Holcus mollis* and in view of its behaviour under close cutting (Table 2), it may not persist under hard grazing. Grazing of this order would almost certainly provide enough increase in soil fertility from deposition of dung and urine to allow other beneficial species to become established and more rapid colonisation of litter-covered areas by grass reduces the chance of weed species becoming established. Further work is required to determine how much grass cover and which species need to be present initially to make this type of follow-up treatment worthwhile, and whether soil conditions or other factors also have an effect.

DISCUSSION

Although the establishment of *Pteridium aquilinum* from spores is extremely rare in the field and the plant must therefore rely heavily on its rhizome system for persistence and spread, eradication by herbicide use alone is not feasible. If *Pteridium aquilinum* is to be eradicated, control measures must be followed by the adoption of grazing management techniques which ensure that re-establishment does not occur. The development of new methods of fencing which are considerably cheaper than the traditional post and wire will encourage the enclosure of hill pastures, giving a degree of grazing control which should ensure that *Pteridium aquilinum* does not become a problem again. It has already been pointed out, however, that adoption of such techniques may not be possible and many schemes for the control of *Pteridium aquilinum* on the open hill will still be undertaken.

Where eradication is not feasible the aim must be to reduce frond regrowth and to delay for as long as possible the necessity for respraying. A major factor in the suppression of *Pteridium aquilinum* recolonisation is the presence of cattle but while the removal of fronds minimises the danger of poisoning, there is still a problem of providing sufficient feed, especially during the winter months.

The greatest potential production in unfertilised hill swards comes from *Agrostis* and *Holcus* and the aim of follow-up treatment must either be to increase the proportion of these species present or to replace them with species of better quality such as *Festuca rubra* or *Trifolium repens*. Both *Agrostis* and *Holcus* are adversely affected by asulam spraying but recover relatively rapidly in the moist climate. Rapid colonisation of litter by grasses is important to reduce the likelihood of weed species establishment and to obtain as great a sward output as soon as possible after frond clearance.

In some cases, a marked improvement in pasture output can be obtained from *Pteridium aquilinum* clearance alone and this may be sufficient for the extra stock which can be provided from available capital. Ground mineral phosphate applied alone to very acid soils makes no appreciable difference to sward productivity or composition and it can be argued that on these very acid soils, lime application will be of more benefit than phosphate in that it will at least increase the proportion of *Agrostis* and *Festuca* (Robertson & Nicholson, 1961). The difficulty is that the quantity of lime required cannot be applied from the air and much bracken land is too steep or rocky to be treated from the ground. It would seem to be preferable to apply lime to those areas which were accessible, however, rather than give an overall application of dubious value of ground mineral phosphate. On less acid soils, lime and phosphate applications can be used to improve sward quality and promote the growth of *Trifolium repens*.

The type of follow-up treatment must therefore be considered in relation to soil and vegetation type, and also to the level of management which can subsequently be given to the pasture. The first aim must be containment of reinfestation and if this can be carried out successfully, eradication may be possible because the rhizome reserves available for regrowth have been reduced to a very low level. The decision as to whether containment or eradication of *Pteridium aquilinum* is feasible is unfluenced greatly be economic factors. The restoration of confidence in hill farming will stimulate more interest in clearance schemes, the extent of which will depend on how much money is available.

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PLANNED GRASS WEED CONTROL WITH FLUAZIFOP-BUTYL IN BROAD-LEAVED CROPS

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Summary Strategic planning of weed control in the 1980's requires herbicides that are consistent, flexible, cost-effective and which simplify management. This paper presents field data from the United Kingdom on the use of fluazifop-butyl as a post-emergence annual and perennial grass killer in broad-leaved arable crops. The compound has given consistently excellent weed control over varying crop/weed growth stages and environmental conditions, without crop phytotoxicity. Fluazifop-butyl effectively controlled *Agropyron repens*, *Agrostis* spp, *Alopecurus myosuroides*, *Avena fatua*, *Lolium perenne* and volunteer barley in arable crops at rates from 0.25 -1.0 kg ai/ha.

This potential flexibility of use makes fluazifop-butyl particularly suitable for the opportunist control of grass weeds at the optimum time for cost-effective crop production. Examples include weed control in sugar beet and potatoes, the control of volunteer barley early in winter oilseed rape and the control of spring barley sown to protect sugar beet from wind erosion on blowing soils.

Résumé La prévision optimale des traitements herbicides dans les années 80 n'est possible qu'avec des produits qui apportent un haut niveau d'efficacité, une grande régularité d'action, un maximum de flexibilité, un bon rapport qualité-prix, et donc une simplification de l'organisation. Cette communication présente des résultats obtenus en plein champ avec le fluazifop-butyl utilisé comme herbicide de post-émergence sur graminées adventices annuelles et vivaces dans des cultures de dicotylédones. Cette matière active a donné régulièrement une excellente efficacité à divers stades de croissance des mauvaises herbes ou des cultures, dans des conditions d'environnement très différentes, et ce sans aucune phytotoxicité. Le fluazifop-butyl détruit *Agropyron repens*, *Agrostis* spp, *Alopecurus myosuroides*, *Avena fatua*, *Lolium perenne* ainsi que les repousses d'orge dans différentes cultures, à des doses variant de 250 à 1000 g m.a./ha.

La grand souplesse d'emploi du fluazifop-butyl le rend particulièrement bien adapté à une destruction des graminées au moment le plus opportun. Parmi les divers exemples fournis figurent des résultats relatifs au désherbage de la betterave, de la pomme de terre, et au contrôle des repoussses d'orge dans du colza d'hiver. Des résultats destruction d'orge de printemps semmée pour protéger des betteraves sucrières de dégâts dûs a l'érosion éolienne en la concezmant sol léger sont également inclus.

INTRODUCTION

The relationship between herbicide use and crop management is interactive; just as the introduction of a new herbicide with novel properties can lead to significant changes in management practice, so changes in management practice can necessitate a change in herbicide use. Good historical examples within our own company, Imperial Chemical Industries Ltd., are the discovery and introduction of growth-regulator herbicides in the 1940's and the bipyridyls in the 1960's. The control of broad-leaved weeds by the growth-regulator herbicides, previously achieved by careful husbandry, seed-bed preparation and crop rotation, permitted the development of arable farming as we know it today, with continuous cereals and high fertilizer usage. The introduction of the bipyridyls encouraged the development of 'zero' and reduced tillage systems which, by improving the speed and timeliness of operations including drilling, led to an increase in the acreage of winter-sown cereals.

Weed control strategy in the 1980's is based upon a battery of existing herbicides used in increasingly complex mixtures and programmes. Economic considerations are critical; attention is focused upon maximising the cost-effectiveness of crop production, including weed management, rather than the single-minded pursuit of maximising crop yield or achieving technically excellent weed control. In this respect, the use of effective post-emergence herbicides must become increasingly important to the farmer; they allow him the flexibility to select the components of his weed control programme and the timing of their applications according to the weed populations in individual fields and their competitiveness; they avoid the need for incorporation of some herbicides and the wide variation in performance of pre-emergence herbicides depending upon soil moisture and soil type.

The success of a new herbicide depends ultimately upon its potential to improve the cost-effectiveness of crop production. This may result either from a direct improvement in weed control or, more often, from a simplification in management practice. It is particularly desirable that a new compound can be used flexibly over a range of crop/weed situations, growth stages and environmental conditions. This paper describes such characteristics for the new herbicide fluazifop-butyl, previously coded PP009 or TF1169 (Plowman et al, 1980), when used for the control of annual and perennial grasses in temperate broad-leaved crops.

METHOD AND MATERIALS

The results quoted in this paper have been selected from fully replicated trials conducted in the United Kingdom during 1979 and 1980. The trials were designed to study the rate-response characteristics of fluazifop-butyl when used to control grass weeds in sugar beet, potatoes and oilseed rape.

The experiments consisted of four randomised blocks of 10 - 14 treatments. The plot size was either 2.5m x 10m or (for potatoes) 5 rows x 8m. Treatments were applied in 200 l water/ha using a hand-held CO_2-powered boom fitted with TeeJet and operated at 2.1 bar. In these trials, fluazifop-butyl was formulated as a 25% e.c. to which a wetter ('Agral' 90) was added at 0.1% v/v of the final spray. The following standards were used : paraquat; paraquat/monolinuron; alloxydim-sodium; diclofop-methyl; propyzamide and carbetamide. The trials programme covered a range of soil types, varieties and sites; details are given in Table 1.

Assessments : Weed counts were made 4-6 weeks after spraying in potatoes and sugar beet. In oilseed rape, the weed counts were made in December and March. Weeds were counted using ten 0.09 m^2 or 0.16 m^2 quadrats per plot though, in some of the row crops, 8m lengths of inter-row were counted. The results from each trial were analysed using Duncan's multiple range test.

Broad-leaf Weed Control : In sugar beet, chloridazon, metamitron and phenmedipham were used as recommended. In oilseed rape, a benazolin/3,6-dichloropicolinic acid mixture was used.

Table 1

Site Details

Site	Address	Spray dates	Variety	Soil type
		SUGAR BEET		
A3/79	Littleport, Cambs	15/5, 7/6	Monotri	Fen(26%o.m)
A4/80	Littleport, Cambs	25/5	Bush Mono G	Fen(28%o.m)
A5/79	Combs, Suffolk	31/5	Bush Mono G	Heavy Loam
A1/80	Combs, Suffolk	24/5	Monotri	Med. Loam
A1/79	Norton, Suffolk	30/5, 22/6	Monotri	Med. Loam
A2/80	Norton, Suffolk	2/6	Monotri	Heavy Loam
A8/80	Bricklehampton, Worcs	28/5	Bush Mono G	Heavy Loam
A9/80	Ipsden, Oxon	23/5	Vytomo	Heavy Loam
A8/79	Twyning, Gloucs	8/6	Nomo	Light Loam
A9/79	Hindlip, Worcs	18/6	Monotri	Heavy Loam
A5/80	Wick, Worcs	18/6	Vytomo	Med. Loam
C6/80	Barnham, Suffolk	19/5	Nomo	Light Loam
		POTATOES		
B1/80	West Clandon, Surrey	21/5, 12/6	Desiree	Light Loam
B2/80	Kineton, Warwicks	4/6, 2/7	King Edwards	Med. Loam
A2/79	Sunningdale, Berks	22/6, 26/7	Pentland Crown	Light Loam
A1/80	Sunningdale, Berks	29/5, 12/6	Pentland Crown	Light Loam
B1/79	Poole Keynes, Gloucs	4/6, 2/7	Pentland Crown	Heavy Loam
A3/80	Porters Mill, Worcs	30/5, 23/6	King Edward	Med. Loam
A4/80	Toddington, Gloucs	21/5, 18/6	King Edward	Med. Loam
		OILSEED RAPE		
A4/79-80	Rede, Suffolk	19/11, 17/12	Jet Neuf	Heavy Loam
A5/79-80	Hawsted, Suffolk	17/10, 20/11	Jet Neuf	Heavy Loam
A6/79-80	Lidgate, Suffolk	2/11, 17/12	Jet Neuf	Heavy Loam
A9/79-80	Hook, Hampshire	4/9, 27/10	Jet Neuf	Med. Loam

RESULTS

Field work to evaluate the performance of fluazifop-butyl in arable rotations has been conducted in the United Kingdom since 1978. The compound has been shown to be very selective post-emergence at rates up to 2kg ai/ha in all the important broad-leaved crops. In the United Kingdom, sugar beet, potatoes and oilseed rape are the most important cereal break crops. Data for the three crops from a selection of diverse sites are given in Tables 2, 3 and 4 respectively.

Sugar beet : In each of two very different years, fluazifop-butyl consistently gave greater than 90% control of *Avena fatua*, *Alopecurus myosuroides* and *Agropyron repens* from post-emergence applications at growth stages ranging from two leaves to six tillers for annual grasses and from two-three leaves to four-five leaves (well tillered) for perennial grasses. Our experience shows that the compound was most effective when the grasses were in an active state of growth. The crop growth stages ranged from cotyledon to eight leaves; no crop phytotoxicity was observed.

Table 2

Grass Weed Control in Sugar Beet 1979 and 1980 % Reduction in weed populations (4-6 weeks post-spray)

Site	Crop growth stage (leaves)	Weed growth stage (leaves)	Treatments (kg ai/ha) Fluazifop-butyl 0.25	Fluazifop-butyl 0.5	Fluazifop-butyl 1.0	Alloxydim-sodium 0.94	Alloxydim-sodium 1.88	Diclofop-methyl 0.7	Control (No/m^2)
					AVENA FATUA				(No. plants)
A3/79	C	2-3	-	97a	98a	-	-	-	(50)b
	8	4-5	-	99a	100a	-	*100a	-	(50)b
A1/80	4-6	3	98	99	99	95	99	97	(94)
A4/80	4	4-5	-	98	100	99	100	97	(45)
A2/80	0-4	6 tillers	92a	86a	94a	0c	53b	1c	(64)c
A8/80	0	4 tillers	99a	99a	100a	55b	96a	53b	(17)c
					ALOPECURUS MYOSUROIDES				(No. plants)
A1/79	2-4	2-3	94a	100a	99a	-	-	-	(4)b
A5/79	2-4	2-3	93a	97a	99a	-	-	-	(3)b
A1/80	4-6	3	98b	100ab	99ab	99ab	100ab	72c	(32)d
A9/80	C-2	6 tillers	100a	100a	100a	96b	100a	14c	(92)c
					AGROPYRON REPENS				(No. tillers)
A2/79	C-2	2-3	-	92b	97a	-	-	-	(194)c
A8/79	4	4-5	-	95ab	98a	-	*84b	-	(46)c
A9/79	4	4-5	-	94a	98a	-	*63b	-	(63)c
A5/80	2-6	4-5	93b	98ab	99a	-	98a	-	(475)c
A4/80	4	4-5	-	96a	100a	-	97a	-	(29)b
A2/80	0-4	3	74ab	95a	84a	-	76ab	-	(42)c

C = Cotyledon

* In these trials alloxydim-sodium was applied at 1.5 kg ai/ha tank mixed with 5 l. 'ACTIPRON'.

Statistics : Within each trial treatment means not followed by the same letter are significantly different (P=0.05).

Table 3

Grass Weed Control in Potatoes 1979 and 1980

% Reduction in weed population (6 weeks post-spray)

Site	Species	First* spray only	Second spray** Fluazifop-butyl (kg/ha) 0.5	1.0	Control (No/m^2)
A2/79	*Agropyron repens*	A 81b	98a	99a	(78)+
A2/79	*Agrostis spp*	A 88b	99a	99a	(57)+
B1/79	*Agropyron repens*	B 80b	98a	99a	(74)+
A1/80	*Agropyron repens*	A 71b	97a	99a	(435)
A3/80	*Agrostis stolonifera*	A 17b	93a	99a	(438)
A4/80	*Lolium perenne*	A 29b	99a	100a	(43)
B1/80	*Agropyron repens*	B 79b	100a	100a	(53)
B2/80	*Avena fatua*	B 48b	89a	97a	(2)

* First spray either (A) paraquat or) applied at 10-40% emergence.
(B) paraquat/monolinuron)

** Second spray, fluazifop-butyl applied at 40-60% ground cover.

\+ Assessed before first spray.

Table 4

Control of Alopecurus myosuroides in Oilseed Rape 1979/80

% Reduction in population (March 1980)

			Treatments (kg ai/ha)					
Site	Crop growth stage (leaves)	Weed growth stage (leaves)	Fluazifop-butyl			Carbet-amide	Propyz-amide	Control (No/m^2)
			0.25	0.5	1.0	2.1	0.7	
A4/79-80	2-3	2-3	99a	99a	100a			(151)d
	4-5	3 tillers	99ab	99ab	100a	86c	99a	
A5/79-80	2-3	2-3	98ab	99ab	99ab			(223)d
	4-5	3 tillers	99a	100a	100a	83c	99bc	
A6/79-80	2-3	2	100a	100a	100a			(493)e
	4	3 tillers	84d	97b	100a	80d	93c	

Statistics : Within each trial treatment means not followed by same letter are significantly different (P=0.05).

Potatoes : The paraquat or paraquat/monolinuron treatments gave good suppression of Agropyron repens and Agrostis spp, particularly in the drier conditions of 1979. However, the second spray with fluazifop-butyl gave excellent long term control of late germinating Lolium perenne and Avena fatua and regrowth of Agropyron repens and Agrostis spp in both years, without crop damage.

Oilseed Rape : When used in the autumn, fluazifop-butyl gave excellent control of Alopecurus myosuroides at both times of application, without crop damage.

The flexibility of use associated with these characteristics make fluazifop-butyl particularly suitable for the timely control of grass weeds before they are damaging to crop development. This is well illustrated by the control of volunteer barley in autumn-sown oilseed rape.

The trend in the rape crop is for earlier sowing using either direct drilling or minimum cultivation techniques on barley stubbles. In these circumstances, the shed barley is left on or near the surface after drilling and can be a serious crop competitor which cannot be treated by the standard products until the crop 3-4 leaf stage. The results presented (Table 5) show that even in the very dry autumn of 1979, early application of fluazifop-butyl released the crop from the severe early weed competition with a resultant long-term improvement in crop condition and flowering. Later sprays gave equal or better final weed control but were too late to prevent some crop loss; strategically and in terms of cost-effectiveness, early application was superior. Work done by ADAS (Proctor and Finch 1976) has shown that early release from weed competition in rape will result in a marked yield increase. This has also been shown for sugar beet (Scott et al, 1979).

A further example of this type of use for fluazifop-butyl is for the removal of spring barley sown to protect sugar beet from wind damage on the blowing sand and fen soils of East Anglia (Table 6). In using the Breckland spring barley technique to protect his crop from wind erosion, the farmer is choosing to encourage the cover crop during the critical early stages of crop establishment and then removing it before competition becomes too severe.

DISCUSSION

If a farmer's weed control policy is dictated by each crop in isolation without consideration for the rest of the rotation (Bray 1976), then weed control strategy will depend on the likelihood of the weed populations causing crop loss. Where weed populations are high, it is easy to justify control measures because of the effect of the weed competition on the growing crop. In low density weed populations, the cost/benefit evaluation may need to consider the indirect effects of the weeds on crop quality or cost of harvesting and other operations in order to determine the level of weed control that is most cost-effective.

The effect of the weed population upon the rotation must also be considered. This is particularly important for weeds that will be difficult or expensive to control in the following crops. At the present time, the proliferation of annual and perennial grass weeds in cereals has meant that farmers are, once more, looking to use profitable arable break crops as cleaning crops. The elimination of grasses in the break crop will produce a benefit in the following crop by reducing the grass weed problem.

In this way, weed control strategy can be planned and costed in advance, just as crop rotation is planned. The farmer may be prepared to tolerate low levels of weeds (or weed seed production) that will be easy to control in the following crop but must eradicate weeds that will be both difficult to control and highly competitive in them. Consequently, he may need to extend his cost/benefit evaluation over a number of crops and consider the long term implications of his weed control programme.

Table 5

Volunteer Barley Suppression and Eradication in Oilseed Rape (A9/79-80)

Chemical	Rate (kg/ha)	Crop growth stage (leaves)	Barley % control 28/11/79	Crop* condition 28/11/79	Barley % Control 25/3/80	Early* flowering score 25/4/80
Fluazifop-butyl	0.25	C-1	71b	6.50b	80c	2.91ab
Fluazifop-butyl	0.5	C-1	95a	7.37a	98b	3.19a
Fluazifop-butyl	1.0	C-1	97a	7.75a	100ab	3.25a
Fluazifop-butyl	0.25	4-5	**	5.75bc	100ab	2.94ab
Fluazifop-butyl	0.5	4-5	**	5.25cd	100ab	2.78ab
Fluazifop-butyl	1.0	4-5	**	5.62c	100a	2.87ab
Carbetamide	2.1	4-5	**	5.00d	100ab	2.44b
Propyzamide	0.7	4-5	**	5.37cd	100a	2.47b
Control (No/m^2)			(323)c	4.75d	(196)d	2.47b

* Crop condition and flowering assessments were done on a 0-10 visual scale where 10 represents an excellent crop or complete flowering.

** Control not assessable in December because of late application.

Table 6

Breckland Spring Barley Technique to Prevent Wind Erosion in Sugar Beet (C6/80)

	Treatments (kg a.i./ha)*		
Assessment	Fluazifop-butyl		Alloxydim-sodium
	0.25	0.5	0.94
Days after treatment	% CONTROL OF BARLEY		
11	48b	65a	3c
22	90b	99a	10c
36	100	100	8
	% GROUND COVER OF SUGAR BEET		
53	63a	67a	35b

* Barley 15cm high and well tillered at spraying, crop at 6 leaves.

Statistics : Treatment means not followed by the same letter are significantly different (P=0.05).

In either case, the use of fluazifop-butyl to control grass weeds in broad-leaved arable crops (Plowman et al, 1980) allows the optimum strategic course to be followed. The compound is particularly suitable for early post-emergence application to release seedling crops from severe grass weed infestations, but is sufficiently flexible to be applied later in the post-emergence weed control programme. This allows the farmer more time to judge his particular weed spectrum and both the present and future crops' requirements.

Work is continuing to extend these basic principles into other uses and other crops such as market and fodder brassicae, vegetables, legumes, soft fruit and other non-graminaceous crops, both in the United Kingdom and world wide. Application methods are also being evaluated; fluazifop-butyl has proved effective at very low volumes of application through the 'Electrodyn' system.

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CONTROL OF COUCH GRASS (AGROPYRON REPENS) IN AN ARABLE ROTATION WITH ALLOXYDIM-SODIUM

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Summary User trials were set up in 1979 to confirm the efficacy of alloxydim-sodium for the control of *Agropyron repens* in sugar beet, turnips and peas under practical farm conditions. The sites of these trials were reassessed in 1980 to verify the persistence of control in succeeding crops.

In 1979, alloxydim-sodium at 1.5 or 1.9 kg a.i./ha gave season-long control of *Agropyron repens* although the higher rate was more effective, particularly in sugar beet. Control was also good in succeeding cereal crops in 1980, the level of control being better at some sites than in 1979 probably because of mortality of treated rhizomes following cultivations.

Alloxydim-sodium controls *Agropyron repens* in many broad-leaved arable crops; the persistence of effect obviates the need for control measures before drilling succeeding cereal crops, making this a highly cost-effective strategy.

Résumé Des essais étaient réalisés en 1979 sous des conditions pratiques d'élevage commercial chez des exploitants agricoles pour confirmer l'efficacité de l'alloxydim-sodium dans le contrôle de *l'Agropyron repens* à propos de betteraves à sucre, de navets et de petits pois. La lecture des résultats a été refait sur l'emplacement de ces essais en 1980 pour vérifier la continuité de contrôle dans les récoltes successives.

En 1979 L'alloxydim-sodium à 1.5 ou à 1.9 kg ma/ha a contrôlé *Agropyron repens* pour la durée de la saison, quoi que la dose la plus haute était plus efficace, en particulier sur les betteraves à sucre. Le contrôle était aussi bien sur des céréales successives en 1980, le niveau de contrôle étant mieux a quelques emplacements qu'en 1979, probablement dû à la mortalité des rhizomes traités suivant la cultivation de la terre.

L'alloxydim-sodium contrôle *l'Agropyron repens* sur un grand nombre de dicotylédones arables. La continuité d'effet évite la nécessité des mesures de contrôle avant de semer des céréales successives, résultant dans une stratégie très rentable.

INTRODUCTION

The efficacy against Gramineae and high selectivity of alloxydim-sodium in broad-leaved crops has been demonstrated in Europe and the United Kingdom (Quere *et al*., 1977; Beaudoin *et al*., 1977; Vernie, 1977; Salembier & Belien, 1977; Deryche, 1978; Ingram & Turner, 1978; Knott, 1978; Slater & Hirst, 1980).

Twenty-five large plot unreplicated user trials laid down in 1979 confirmed that alloxydim-sodium controlled annual grasses such as *Avena fatua*, *Alopecurus* *myosuroides* and volunteer cereals, and gave season-long control of *Agropyron repens* in sugar beet, peas and turnips. Following these trials, alloxydim-sodium was marketed in these crops in 1980 for the control of annual grasses at 0.94 kg a.i./ha and couch grass at 1.5 kg a.i./ha (peas and turnips) and 1.9 kg a.i./ha (sugar beet and peas).

Couch sites were reassessed in 1980 to measure the persistence of control. At each site the succeeding crop was cereals. Similar assessments could not be made on small plot replicated trial sites because farm cultivations caused redistribution of couch rhizomes.

This paper records the results of these trials and discusses the implications of 'in-crop' couch control on arable rotations.

METHOD AND MATERIALS

Site details are given in Table 1.

Alloxydim-sodium as a 75% w/w soluble powder was applied to 1 ha unreplicated plots in a volume range 200-400 l/ha, using farm equipment. An untreated control area of at least 40 m^2 was present at each site.

Treatments were applied when the couch was growing strongly and had 3-6 leaves, but before shoot extension started.

Assessments

(a) 1979: At sites 1, 2 and 3, 10 x 0.5 m^2 quadrats were taken at random in each plot at spraying, to establish couch shoot numbers and crop growth stage. Visual assessments were made at sites 5, 11 and 12. At sites 4, 7, 8, 9 and 10, 10 x 0.5m^2 fixed quadrats were positioned in the treated areas at spraying.

2-6 weeks, and at most sites 10-15 weeks after spraying, the counts were repeated. At site 6, random quadrats were assessed in treated and untreated plots post-spraying only.

(b) 1980: The number of couch shoots was counted in between 10 and 50, 0.5m^2 random quadrats per plot; higher numbers were taken in patchy infestations. At sites 6 and 7, no untreated areas remained, so control shoot numbers were taken from the final 1979 assessments.

RESULTS AND DISCUSSION

(a) 1979

All sites had a heavy infestation of couch before treatment (Table 1). Table 2 shows that alloxydim-sodium at 1.9 kg a.i./ha gave excellent control of couch shoots in sugar beet and turnips with the exception of sites 4 and 5 where control was moderate.

Control in turnips was also very good at 1.5 kg a.i./ha. This rate was less effective in sugar beet although control was satisfactory. Control was again poorer at site 4, although only a little less than with the higher rate.

Couch control in vining peas (sites 11 and 12) was acceptable although generally inferior to that in sugar beet and turnips. This may be because the smothering ability of peas is less and develops later than that of root crops, although excellent results for couch control in peas have been obtained by Knott (1978).

Table 1

Control of couch grass in sugar beet; Site details

Sugar beet 1979						Succeeding cereal crop 1980		
Site Number & Location	Spraying date	Crop and growth stage (no. of leaves)	Couch shoots per m^2 or % ground cover At spraying	At first assessment	Other herbicide applied in 1979, and timing in relation to alloxydim-sodium	Crop & cultivar	Drilling date	Cultivations & soil type
1. Salhouse, Norfolk	2.6.79	Sugar beet 4-6	35%	58	Metamitron 7 days after	Winter barley Maris Otter	Mid-Jan	Ploughed sand
2. Taversham, Norfolk	18.5.79	Sugar beet 2	38%	59	Chloridazon pre-em Phenmedipham 3 days before	Spring barley Georgie	12.2.80	Ploughed sand
3. Sicklesmere, Suffolk	8.6.79	Sugar beet 2	30%	20	Chloridazon pre-em Phenmedipham 1 day before	Winter wheat Hobbitt	14.11.79	Ploughed, harrowed, clay loam
4. Spalding, Lincolnshire	5.6.79	Sugar beet 2-4	30-50%	-	Chloridazon pre-em	Spring barley Athos	11.4.80	Chisel ploughed, harrowed, disced, silt clay loam 6% o.m.
5. Good Easter, Essex	1.6.79	Sugar beet	32%	33%	-	Spring barley Athos	3.3.80	Ploughed, loam clay
6. Droitwich Worcestershire	11.6.79	Sugar beet 2-4	-	152	lenacil pre-em Phenmedipham post-em (tank-mix)	Spring barley Athos	15.4.80	Ploughed, sand loam

Table 1 continued

Control of couch grass in turnips and vining peas; Site details

Turnips and vining peas 1979						Succeeding cereal crop 1980		
Site Number & Location	Spraying date	Crop and growth stage (no. of leaves)	Couch shoots per m^2 or % ground cover At spraying	Couch shoots per m^2 or % ground cover At first assessment	Other herbicide applied in 1979, and timing in relation to alloxydim-sodium	Crop & cultivar	Drilling date	Cultivations & soil type
7.Abbey-St-Bathans, Berwickshire	29.6.79	Turnips 6	40%	40%	trifluralin pre-em Propachlor post-em 10 days before	Spring barley Midas	28.4.80	Ploughed medium loam
8.Hamilton Lanarkshire	26.6.79	Turnips 6	75%	75%	-	Spring barley Sundance	1.4.80	Ploughed (20cm) medium loam
9.Mickleour Perthshire	9.7.79	Turnips 6	50%	50%	-	Spring barley Golden Promise	14.4.80	Ploughed medium loam
10.Alves, Morayshire	18.6.79	Turnips 6	50%	50%	-	Spring barley Midas	28.4.80	Ploughed sand loam
11.St. Osyth Essex	4.5.79	Vining peas 2-4	80	80	-	Winter barley Maris Otter	Early October	Ploughed harrowed sandy loam
12.Pointon, Lincolnshire	30.5.79	Vining peas 2-5	40-50%	70%	-	Winter wheat Sentry	28.10.79	Ploughed harrowed, silt loam

Table 2

Percentage control of A. repens shoots in 1979 & 1980 following treatment of 1979 crops with alloxydim-sodium

	1979			1980			
Site	Time of assessment weeks after application	% Control of shoot nos. alloxydim-sodium kg/a.i./ha		Time of assessment weeks after application	Control pop. at assessments shoots per m^2 or % ground cover	% Control of shoot nos. alloxydim-sodium kg/a.i./ha	
		1.5	1.9			1.5	1.9
1	5 12	71 78	99 92	62	78	75	86
2	4 15	74 61	92 89	65	91	71	91
3	4	-	90	61	23	-	68
4	6	62	68	56	26	75	83
5	2 8	- -	60 75	66	22	-	75
6	1 2	86 79	92 83	65	134*	-	89
7	4 10	90 85	100 95	57	58	99	-
8	4 10	85 100	95 100	58	2	100	100
9	4 10	95 85	- -	57	66	97	-
10	4	100	-	58	10	-	45
11	15	75	85	69	14	84	88
12	6 12	-	71 77	56	90%*	-	79

* Final, 1979 untreated assessment. Control area not present in 1980.

Assessments made 10-15 weeks after treatment show that control will be maintained throughout the life of the crop. There was a slight decrease in shoot control at most sites indicating re-growth of some plants. Surprisingly, the level of control increased at sites 1 (low rate), 5, 8 and 12, although this was probably due to variability of assessments at sites 1 and 12, where increases were slight.

These results were influenced by the favourable weather conditions in 1979 (Table 3). At the English sites, treatments were made shortly after the end of May, which was wetter than average, leading to active couch growth and therefore good uptake and translocation of alloxydim-sodium. The crop was also able to grow well and, in the case of sugar beet and swedes, smother the couch. June and July were drier than usual and the couch was subjected to moisture stress, thus aiding control. This was particularly evident on the light Norfolk soils (sites 1 and 2, Table 2). The relatively poor control at site 4 may reflect the moisture retaining qualities of the slightly organic soil which may have aided couch survival (Table 1). Treatments were applied later at the Scottish sites (end of June - early July) but they probably still benefitted from the wet spring and dry summer.

Table 3

Metereological Office rainfall figures for May, June and July, expressed as a percentage of the monthly mean.

Region	May	June	July
East Anglia	172	61	32
Midlands	188	61	38
E. Scotland	118	73	81

With the exception of site 12, where a slight discolouration of leaves was noticed 2-3 weeks after application, no crop phytotoxicity was recorded. This suggests that alloxydim-sodium can be safely used following lenacil, chloridazon, trifluralin, phenmedipham and propachlor, before metamitron and in a tank-mix with phenmedipham.

(b) 1980

Control of couch shoots persisted into succeeding cereal crops at all sites at both rates of use. Apart from sites 3 and 10, control was very good; at sites, 2, 4, 7, 9 and 12, control was greater than at the final 1979 assessment.

At site 3 control was inferior to the other sites but still moderate. At site 10, couch numbers were low in the untreated plot in 1979 and 1980 compared with the 50% ground cover recorded overall at spraying in 1979. This has led to a low figure for percent control (45%) despite the low number of shoots recorded in the treated area (6/m^2). If total ground cover is equivalent to approximately 100 shoots/m^2, it is likely that a true figure for control at this site in 1980 would be about 80%.

Site 8 was similar, with a very low couch population in the untreated area, but at this site there was total control in the treated areas following a high infestation (75% ground cover) in 1979.

The improved control recorded at some sites in 1980 is probably because of mortality of treated couch rhizomes during cultivations. Rhizomes from treated plots at site 4 were examined after harvest in 1979 and were found to be considerably smaller than those from the untreated area. Such rhizomes were likely to die during or after cultivations. Similarly, Knott (1978) found that the majority of rhizomes from alloxydim-sodium treated areas in peas were small and not viable.

The greatest increase in the level of control between 1979 and 1980 was achieved at site 4 where the soil was chisel ploughed, disced and harrowed (Table 1) suggesting that, as an aid to rhizome mortality, deep ploughing was unnecessary in that season. This contrasts with the requirements for optimum control of couch with dalapon (Lawson 1962) where rhizomes should be buried as deeply and efficiently as possible.

A further possible reason for the improved control could be the marginal effects of annual grass herbicides applied to cereals during 1980; however, such treatments were only applied at one site (isoproturon and benzoylprop-ethyl, site 3) and this site had the least control of couch in 1980.

No crop phytotoxicity was recorded in succeeding cereal crops. Although alloxydim-sodium is highly active against cereals, the residual activity is of short duration (Ingram & Turner, 1978).

These trials indicate that alloxydim-sodium applied in broad-leaved crops will control couch grass throughout the life of a succeeding cereal crop. This alleviates the need for control measures outside the crop season and the need to allow time for grass weed control before the next crop. This is particularly important in late harvested crops such as sugar beet and turnips, where it is often essential to drill the following cereal crop straight after harvesting. These crops also have the advantage of providing the best conditions for maintenance of couch control by alloxydim-sodium, since they possess a dense smothering foliage which is retained until harvest, by which time the rate of couch growth has slowed down in the cool conditions.

Although the overall level of control was slightly lower in the pea crop, a good, increased level of control was recorded in the following cereals, suggesting that control will persist following early harvested crops. As at sites 11 and 12, it is probably important to cultivate the land well soon after harvest.

Alloxydim-sodium will not eradicate couch, but it will contain infestations for two seasons. The use of alloxydim-sodium for containment will therefore be highly cost-effective where couch has to be controlled in a growing, broad-leaved crop; application will obviate the need for couch control before drilling succeeding cereals.

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