SESSION 7B

WEED CONTROL IN TROPICAL AND SUB-TROPICAL CROPS I

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ECONOMICS OF WEED CONTROL IN THE TROPICS AND SUB-TROPICS

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Summary. The economic, social and political factors affecting agriculture in tropical regions are briefly considered. The concept of dualistic agriculture, in which both large scale commercial farming systems exist side-by-side with small scale peasant farmers, is explained. The economic importance of weed control in the tropics is highlighted and specific examples of the influence of government policy in weed control strategy are given. The economics of weed control requires placing it in a much wider context including the institutional, political and social environment in which it exists. Case studies from Central America are used to show that whilst improved weed control technologies are available, their adoption by small scale peasant farmers is not easy. The need for future weed control technologies to be developed to meet the needs of the peasant farmer is stressed.

INTRODUCTION

The limits of the apparent north and south journey of the sun approximate to the tropical regions of the world. Countries in these regions are generally developing countries. Most are relatively poor and many are short of food. Forty of the forty-three countries designated by the World Food Council as "Food Priority Countries" are located in the tropics and sub-tropics. This area contains 42 of the UN's 45 "Most Seriously Affected" countries, a classification which is based on per capita income and balance of payment deficit (IADS, 1981).

GENERAL BACKGROUND

Agriculture in the tropics and the sub-tropics may be considered to be dualistic; that is, there is a simultaneous existence of both commercial (modern) and peasant (traditional) agricultural production practices. Commercial farms are generally larger, utilise improved production technologies and tend to sell their products in the international market. Peasant farms tend to utlise labour extensively (generally family labour), and produce for home consumption. The occasional surplus is sold through local markets.

In Mexico, for example, large farms are the principal producers of the export crops, coffee, fresh fruits, vegetables, cotton and wheat. Peasant farmers and small farmers on government donated land (the Ejidatarios) predominate in the production of the basic foods - maize, beans and rice (Table 1).

Table 1

Mexico : Value share of agricultural production, 1950 and 1960 (as per cent)

Value Share	Percent							
	Rice	Maize	Beans	Coffee	Sugar	Cotton	Wheat	Cattle
1950								
More than 5 hectares	39	45	52	67	48	59	57	-
Less than 5 hectares	0	15	6	0	4	1	5	-
Small farmers (Ejidos)	61	40	42	33	48	40	38	-
1960								
More than 5 hectares	35	43	46	62	49	66	68	88
Less than 5 hectares	3	10	3	11	3	0	2	2
Small farmers (Ejidos)	62	47	51	27	48	34	30	10

Source : de Janvry, 1981

Production practices within the modern sector of a dualistic agriculture are not materially different from those of commercial agriculture in the developed countries of the world. As in the U.S. and Europe, there has been a substitution of capital for labour. This is justified by the tropical, commercial farmer by the need for timely agricultural practices and the perceived high cost of labour. Statements like the following from Pakistan are common and accepted, "Non availability of credit and high fertilizer cost were the most important constraints identified" to increased sorghum production (Dhanakumar and Perunal, 1982).

As in the developed countries increasing costs of petroleum products have renewed interest in minimum or no-tillage operations on commercial farms. This is coupled with the fact that agricultural chemical prices have increased slower than machinery services (fuel and energy, tractors and other machinery), (Table 2). The data shown are from the U.S., but similar conditions exist in many developing countries. The use of herbicides has increased in recent years. This trend is likely to continue in commercial agriculture (Frost and Sullivan, 1978). A survey (IADS, 1979) estimated world herbicide expenditure to be $4,891 million, compared with $3,716 million in 1978. World herbicide use was expected to increase by 27%. This will be a 4.8% annual rate calculated on a constant dollar basis and nearly half of this increase was projected in the developing world.

In the U.S. and Europe, most herbicides are used on food crops - maize 47%, soybeans 20%, cotton 9%, wheat 5% (1977). In contrast in tropical and sub-tropical areas, most herbicides are used on commercial crops not generally grown by traditional farmers. In Venezuela (according to the U.S. Embassy) 43.5% of herbicides used were on cotton with an additional 28.5% used for rice, which is produced on large, commercial farms. In north-east Brazil, nearly 100% of the herbicides are used on sugar cane plantations where their use threatens traditional employment of agricultural workers.

Table 2

Percentage changes in prices paid by U.S. farmers to December 1980

	Changes from							
	1973 Annual	1974 Annual	1975 Annual	1976 Annual	1977 Annual	1978 Annual	1979 Annual	1980 Annual
Wages	+ 86	+ 62	+ 50	+ 37	+ 27	+ 19	+ 9	+ 1
Fertilizer	+142	+ 48	+ 14	+ 34	+ 36	+ 37	+ 26	+ 2
Agri. chemicals	+ 74	+ 54	+ 14	+ 5	+ 17	+ 24	+ 22	+ 4
Fuels & energy	+236	+145	+120	+108	+ 93	+ 84	+ 41	+ 3
Farm & motor supplies	+ 93	+ 57	+ 38	+ 41	+ 40	+ 35	+ 22	+ 5
Autos & trucks	+115	+ 94	+ 63	+ 47	+ 33	+ 26	+ 14	+ 8
Tractors & S.P. mach.	+146	+109	+ 73	+ 55	+ 42	+ 30	+ 17	+ 4
Other machinery	+143	+113	+ 72	+ 50	+ 37	+ 27	+ 15	+ 4
Buildings & fencing	+105	+ 66	+ 46	+ 40	+ 31	+ 21	+ 11	+ 3
Services & cash rent	+107	+ 70	+ 42	+ 32	+ 22	+ 14	+ 6	0

Source : Agricultural Prices, Crop Reporting Board, ESCS, USDA

The dualism that exists is often an indirect result of government policy concerned with the expansion of foreign exchange and maintenance of cheap food. The need for inexpensive food for the urban population has often been met by:- 1) the development of a commercial or plantation agriculture under the active encouragement of the state, 2) importation of food using preferential credit facilities, or 3) by direct state intervention "in internal pricing via price ceilings, taxes and quotas on exports, consumer rationing, and state marketing monopolies" (de Janvry, 1981). In a similar vein, foreign exchange earnings via agriculture have been encouraged through public subsidies on agricultural inputs and publicly subsidised agricultural research.

The pricing policies have been particularly pervasive. Price levels have been allowed to follow the international price levels for export crops and luxury foods while food crop prices have generally been fixed. This bias has led to an expansion in commercial agriculture while traditional agriculture has stagnated.

"In Brazil, the terms of trade between food products for the domestic market (potatoes, manioc, rice, beans, onions, eggs, pork and milk) and industry increased by 30%, while the terms of trade between agricultural products for the external market and for processing (cotton, soybeans, peanuts, castor oil, tea, coffee, sugar cane, oranges and bananas) and industry increased by 83%" in the same period (de Janvry, 1981). As a result, traditional food crops have stablised while the area planted to export and industrial crop has expanded, i.e., 28% and 58% respectively for export and industrial crops in the State of San Paulo, Brazil.

In Mexico, "state policies have imposed a ruling on both rural and urban prices of the basic food commodities. Although nominal prices of all foods have continued to increase, in real terms, there has been a decline in their prices and particularly that of maize, which fell 33% between 1963 and 1972" (de Janvry, 1981). It is little wonder why Mexico has had a declining maize production during the last 25 years.

The ability to obtain credit also reinforces this price bias. "In Guatemala, 87% of government credit between 1964 and 1973 financed export crops, while rice, maize and beans received 3%" (de Janvry, 1981). Modern inputs were also primarily used on export crops. In Ecuador, the production of sugar cane, coffee and bananas account for 64% of fertilizer consumption.

What emerges from this review is the realisation that policy or action by the government is not neutral. Agriculture is changed as much by governmental action as by physical and biological processes. To understand the economics of weed control requires viewing it in a much broader context including the institutional, political and social environment in which it exists.

WEED CONTROL IN COMMERCIAL AND TRADITIONAL FARMING SITUATIONS

Weeds create major problems in the tropics and sub-tropics. The 76 weeds listed in "The World's Worst Weeds" (Holm, et al., 1977) include 68 which are major weeds in the tropics. Weeds constitute a major constraint to increased agricultural production and weed control (the manner in which it is either practised or ignored) is fundamental to farming systems of both agricultures and of universal concern. Shifts in weed control technology generate ripples of change not only on the farm, but in the rural communities that service agriculture and very quickly to the nation and beyond.

Weed control is an important user of farm inputs. The high labour demand, especially in traditional agriculture, is of social concern. Several studies suggest that weed control on traditional farms commonly absorbs from 20 up to 80% of total crop production labour (Table 3). It is not only the large amount of time it absorbs, but its seasonal uses and potential shortages which are of concern.

Table 3

Average labour for various farm operations in Nigeria (days/ha)

Operation	Savanna	Forest Reservation
Clearing	7	13
Planting	33	13
Weeding	189	256
Harvesting	57	44

As stated by Sanders working in Brazil (Sanders & de Hollanda, 1979) " ... seasonal labour shortages - especially for the necessary weeding after the intense rains - are important in determining cotton yield and area cultivated. By overcoming these constraints, a reasonable internal rate of return of 35% is attained with the purchase of animal cultivation."

Norman (Norman, Newman & Quedraogo, 1981) states that weeding is a primary bottleneck in semi-arid West Africa. Even though the total annual work required appears small, its seasonal distribution creates bottlenecks. During these periods, labour is fully employed. "With only hand labour and indigenous technology, the time and amount of weeding is often considered the most limiting. The weeding bottleneck can be accentuated if the rains are particularly good" (Norman, Newman & Quedraogo, 1981). Both total and seasonal labour demand can reduce production - either through reduced production per hectare or reduction in the number of cultivated hectares.

On the other hand, improved weed control technologies that substitute machinery or chemicals for labour can cause severe social problems in labour-surplus-economics. "The transition from the hoe to herbicides, in developing countries, can reduce labour requirements 20-fold in short cycle crops and up to 35-fold in long cycle crops. Aerial application can reduce labour requirements more than 1,000-fold over traditional methods" (Young, et al., 1978). If the labour has no alternative, a cadre of unemployed can be created with resultant political and social upheaval.

From this dilemma again emerges the important role governments play in the acceptance of weed control systems. As previously shown, the governmental control is often exercised through the control of product prices with the consequent expansion of the export products and the continuation of food purchases.

Governments often try to overcome the adverse effect of low farm prices by subsidising farm inputs, such as herbicides, sometimes with adverse effects. An analysis in El Salvador (Fonollera, 1978) revealed that government intervention through subsidised herbicides, reduced total employment on weed control by 45 to 55% on farms producing basic grains. The group most seriously affected by the reduction in employment was landless labour. The agricultural employment ranged from 73 to 89% below employment levels which would have existed without the subsidies.

Governments also attempt to stimulate production by supporting research. Technological change is imperative to the survival of the community. Briefly stated, technological change overcomes constraints imposed by limited resource supplies. It utlises knowledge (of "new" or different methods) to increase productivity of the fixed resources of land and water. But the technology coming from the research is not neutral. "A common misconception is that increasing farm yields results in increased income to farmers. While this is true, if the increased quantity of product is sufficiently small that it does not alter the price, it often is not, especially if the technology is adopted over large areas. Since the demand for many agriculture products is inelastic (the percentage change in quantity is less than percentage change in price), farm revenue will drop with increased production. Even though farmers do not always gain with increased production, consumers do. Consumers gain through the decreased price of the product" (McCarl, 1981). Several studies have suggested that demand for food in low income countries tends to be more elastic than food demand in high income countries. To the extent that this is true, the reduction in farm income will be smaller than in high income countries.

Governmental action is often contradictory, confusing the issue that it is trying to improve. Since 1976, the International Plant Protection Center (IPPC) has had a team in Costa Rica attempting, in co-operation with the Centro Agronomico Tropical de Investigacion y Ensenanza to develop appropriate weed control for small traditional farms. The team soon identified a labour bottleneck in land preparation which was limiting the amount of maize produced. Where farms had a large population of perennial weeds before planting, farmers generally hand-cut weeds at ground level, followed by applying a mixture of chemicals to the re-growth. Hand-cutting of weeds 20 to 25 days after planting and an application of paraquat then followed 30 to 40 days after planting. Herbicides were applied by back-pack sprayers without a nozzle shield. A total of 19 person-days/ha of weed control labour was required in the farmers' system.

After several years of research, two treatments were identified, tested, and selected by IPPC as being better than the existing system:-

Treatment 1 Weeds are cut before planting followed by the application of 0.4 kg/ha of paraquat. A second and third application of paraquat at 0.3 kg/ha is made 20 and 40 days after planting (DAP). The main difference between this system and the farmer's practice is the use of an inexpensive, home-made spray shield. Its use enables farmers to spray paraquat early (20 DAP) without undue damage to maize, rather than wait until 40 DAP to apply paraquat. The labour requirement is only slightly reduced in comparison to the farmers' practice, 18.5 person-days/has. It does not overcome the preplant labour bottleneck.

Treatment 2 Glyphosate at 1.5 kg/ha is applied 10 to 12 days prior to planting. A heavy mulch is created from the existing vegetation which eliminates post-plant weed control. Two and one half person-days/ha are required in this system.

Research results indicated that the two treatments gave nearly identical yields. However, the costs were different (Table 4). The yield and resulting gross income of both systems were better than the farmers' practice. Treatment 2 was superior to Treatment 1 and to the farmers' practice in net income and eliminated the pre-plant weed control bottleneck. All labour is priced at ¢30/day, the prevalent agricultural wage rate. Traditional farms with available labour may have a cost per day much less than this. In an opportunity context, the farmer (by employing family labour to manually cut the vegetation) is giving up the opportunity of adding additional acreage. This opportunity cost is likely to be equal to, or considerably higher than the charge made here.

As a result of the preliminary evaluation, the researchers held high expectations for farmer adoption of Treatment 2 and a system of monitoring the adoption process was developed. However, government action and the prevailing economic climate frustrated the attempt. Changes in the prices of herbicides and maize, and changes in the exchange rate between June 1978 and August 1978 are shown in Table 5. Maize prices and the exchange rate are set by the government. Herbicide prices are unregulated and their prices reflect the change in the exchange rate and inflation.

Table 4

Gross income (GI), cash costs (CC) and net income (NI) for three weed control systems for three dates in Costa Rica (Colones ¢/ha)

System	GI	CC	NI
		1978	
Farmer	3,584	756	2,828
Paraquat	4,241	820	3,421
Glyphosate	4,241	651	3,590
		December 1981	
Farmer	11,945	1,630	10,315
Paraquat	14,135	1,810	12,325
Glyphosate	14,135	2,886	11,249
		1982	
Farmer	20,307	3,005	17,302
Paraquat	24,030	3,255	20,775
Glyphosate	24,030	4,603	19,472

Source : Project files

Table 5

Prices of inputs, shelled maize, and exchange rate for three dates in Costa Rica (in Colones ¢)

Item	June 1978	December 1981	August 1982
Daily wage	30.0	60.0	120.0
Roundup (glyphosate)/l	138.0	656.0	1,032.0
Gramoxone (paraquat)/l	53.0	140.0	207.0
Shelled maize/kg	1.5	5.0	8.5
Exchange rate (c/$)	8.5	41.0	59.0

Source : Project files (based on partial budgeting)

By the end of 1981, the price of paraquat had increased 164% and glyphosate 373%. The price of maize increased 233% while the wage rate doubled. The modification in wages and prices changed the profitability of the various systems. The paraquat treatment now became superior, in terms of net income, to both the glyphosate and farmers' system.

The same price and wage relationship has continued in 1982. Treatment 1 is still the preferred treatment (based on net income). While it is still an improvement over the farmers' practice, it does not solve the problem of the labour bottleneck at planting, which, in turn, may limit the size of maize plantings per farm and subsequent total production. Thus, while an improved system has been identified, governmental action has seriously limited the likelihood of its adoption.

Risk attitudes of farmers are also important in the acceptance of new technologies. Traditional farmers tend to be more averse to risk than commercial farmers (Moscardi, 1979). Technologies which are more variable in terms of yield are discounted by peasant farms - with the result that the high levels of yield risk, coupled with strong risk aversion, leads to under investment in agriculture. This is understandable since survival is often at stake. The risk aversion does not relate to the willingness to take risk, but rather the ability to do so on account of wealth differences.

As an example, Cajina (Cajina, 1981) utilising sample data from Nicaragua, estimated the yield variability (standard deviation) for three traditional weed control technologies - T_1 (one early weeding), T_2 (one late hand weeding) and T_3 (one early and one late hand weeding), plus one, improved system, T_4 (the chemical mulch system previously discussed)(Table 6).

Table 6

Actual yield obtained by Nicaraguan farmers in the first season of 1980 for three different types of weed control and a yield estimate for the improved technology

	Weed control technology			
	T1	T2	T3	T4
Yield (kgs/ha)	783	753	981	1,109
Standard deviation	212	444	470	222

The data only provides an estimate for the within-year variability, not the variability between years. However, the reaction of traditional farmers for between year variability is the same.

Cajina analysed the three technologies in a whole farm, linear programming model developed to maximise income. The farm was subject to capital, labour, and land contracts. Additional land was available for maize production and labour could be hired. As the level of risk aversion was increased, the optimum plans changed. The maize acreage was reduced and a shift occurred in the weed control technology from T_3 and T_2 to T_1. The amount of labour decreased, with hired labour actually ceasing when the risk aversion coefficient was increased to 2 (Table 7).

It should be noted that in the analysis, the transition to commercial agriculture increased the amount of hired labour, but the farm size for both the traditional and commercial producer is the same. Land is not a constraint, but capital and technology are. If they can be removed, which would probably require government action, traditonal farmers would also accept the new technology since the effect of risk aversion is no longer a factor. Without action, a continuation of the dual agriculture utilising different types of weed control is likely to continue.

Certain types of weed control technologies are inherently more risky than others. Pre-emergence weed control techniques are used in a prophylactic sense, as a prevention against weed losses. Their cost may be unnecessary if the weed population is less than expected. Most traditional farmers are unwilling to accept this potential financial loss, and wait until the weeds appear before action is taken. This can result in delayed weed control with subsequently lowered yield, but the farmers have determined that the risk of lowered yields from delayed weeding is less than the expected loss arising from the use of pre-emergence herbicides. In addition, incorporation is often required for pre-emergence herbicides. Traditional farmers often lack a power source adequate to incorporate herbicides effectively. Their reluctance to accept pre-emergence herbicides may not be solely due to risk aversion.

CONCLUDING COMMENTS

Weed control technology in the tropics and sub-tropics is likely to be conducted differently for the two types of agriculture - traditional and commercial. Government policy in attempting to provide cheap food and enhance foreign exchange has to a large extent been responsible for the continued existence, if not the creation of the dual agriculture which exists. Since the policy is unlikely to change, weed control practices will probably continue to be different for traditional and commercial agriculture, and weed control technology must be developed to meet both needs. The appropriate technologies for weed control in traditional agriculture must take account of not only the institutional and social forces (i.e., government policy, lack of credit, abundant family labour), but also the high degree of risk aversion evidenced by traditional farmers.

REFERENCES

Cajina, A. (1981). The Ex-ante Introduction of a Chemical Weed Mulch Weed Control System in the Atlantic Plain of Nicaragua. Unpublished M.S. thesis, Corvallis, Oregon State University.

de Janvry, A. (1981). The Agrarian Question and Reformism in Latin America. Baltimore, Maryland, John Hopkins University Press, 157-169.

Dhanakumar, V.G.; Perunal, G. (1982). Characteristics of Dryland Farms. In: Tamil Nadu Agricultural University Newsletter, M. Manohara (ed.) Tamil Nadu Agricultural University Press, 12, 2, 2.

Fonollera, R.E. (1977). The Impacts of Government Market Intervention on Weed Control Technology, Income and Employment : A Case Study of Basic Grain Farms in El Salvador, Central America. Unpublished Ph.D. dissertation, Corvallis, Oregon State University.

Frost and Sullivan, Inc. (1978). Pesticide Market in the U.S., South America and Mexico. New York, Frost and Sullivan, Inc.

Holm, L.G., Plucknett, D.L., Pancho, J.V., Herberger, J.P. (1977). The World's Worst Weeds : Their Distribution and Biology. Honolulu, The University of Hawaii Press.

IADS. (1981). Agricultural Development Indicators. New York, International ; Development Service.

\- (1979). A Look at World Pesticide Markets. In: Farm Chemicals, 142, 9, 61-65.

Moscardi, E.R. (1979). Methodology to Study Attitudes Toward Risk : The Puebla Project. In: Economics and the Design of Small Farmer Technology, A. Valdes, C.M. Scobie and J.L. Dillon (eds.) Ames, Iowa State University Press, 30-42.

McCarl, B.A. (1981). Economics of Integrated Pest Management. Special Report 636, Corvallis, Agricultural Experiment Station, International Plant Protection Center, and Department of Agricultural and Resource Economics.

Norman, D., Newman, M., Quedraogo, I. (1981). Farm and Village Production Systems in the Semi-arid Tropics of West Africa : An Interpretive Review of Research. Research Bulletin, No. 4, ICRISAT.

Sanders, J.H., Dias de Hollanda, A. (1979). Technology Design for Semi-arid Noreast Brazil. In: Economics and the Design of Small Farmer Technology, A. Valdes, G.M. Scobie and J.L. Dillon (eds.). Ames, Iowa State University Press, 102-119.

Talekar, N.S. (1981). Tropic Zones Accelerate Pesticide Breakdown. In: INFOLETTER, 51, November-December.

Young, D., Miller, S., Fisher, H., Shenk, M. (1978). Selecting Appropriate Weed Control Systems for Developing Countries. Weed Science, 26, 3, 209-212.

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MANAGING A SUSTAINABLE FARMING SYSTEM IN SRI LANKA

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Summary. In this investigation, which lasted three seasons, three aspects of weed control in Sri Lanka were studied. Firstly, No-till techniques and crop residue mulches were examined. Results indicated that herbicides were more effective than conventional tillage practices in controlling weeds. Crop yields were often much higher in no-till plots than in tilled plots. Compared with the unmulched plots, those mulched with rice straw at 4 and 8 t/ha reduced the weed dry matter by 22.4 and 40.6 per cent respectively. Crop yields showed linear responses to these mulching regimes.

Secondly, the use of live-mulch systems with creeping leguminous covers was studied. Suppression of weeds was high with legume covers and relatively high yields were obtained with *Phaseolus atropurpureus* live-mulch covers.

Thirdly, the use of leguminous shade trees was examined. Shade under *Leucana leucocephala* in 2 m wide avenues reduced weed growth considerably.

The significance of developing an integrated system based on these techniques suitable for upland cropping in the dry zone of Sri Lanka is discussed.

Keywords: tillage, mulch, cover crops, shade trees, Dry Zone, Sri Lanka herbicides, herbicide mixtures, integrated system

INTRODUCTION

Weeds present a very serious problem in upland agriculture in the dry zone of Sri Lanka. Several investigations have shown that weed proliferation has resulted in the adoption of shifting cultivation (Stockdale, 1926; Joachim and Kandiah, 1948). Abeyratne (1962) stated that weed control is a major factor contributing to better management of an upland farming system in the dry zone.

Abeyratne (1956, 1962) has discussed the use of tillage for weed control in the dry zone. In fact, tillage practices have been used more frequently to control weeds than any other method. However, there appears to be a serious conflict in tillage operations between the benefits from weed control and the undesirable effects on soil erosion due mainly to heavy rainfall during monsoon periods. If tillage practices are to be successful in controlling weeds without enhancing soil erosion, they must leave a protective residue on the soil surface.

Various mulches have been found to effectively reduce weed growth (Webster and Wilson, 1966; Abeyratne, 1956; Kirinde, 1957). The effectiveness of the mulches in preventing weed growth is thought to be a reduction in light intensity (Webster and Wilson, 1966).

Traditionally, forest or bush fallow have been used to control weeds in shifting cultivation systems (Joachim and Kandiah, 1948). The fallow period which is characteristic of this system rejuvenated the soil fertility, restored a desirable soil structure, and controlled weeds. This system, however, requires an extensive farmland although it does not require costly inputs.

Unfortunately, the rapid increase in population of Sri Lanka over the past few decades has disrupted shifting cultivation as a traditional system of farming in the dry zone. The limited arable land has been used quite intensively for cropping, which ultimately reduced the fallow period. This change in cropping patterns in turn has caused many problems. For example, exposure of large areas of bare soil for long periods has greatly enhanced the extent of erosion (Darwent, 1981). Long cropping periods followed by short fallow periods have led to a considerable depletion of nutrient status of the soil, with control of grass weeds giving a more serious problem than broad-leaved weeds (Kirinde, 1957).

The dry zone of Sri Lanka has a high potential for adopting a productive and sustainable farming system. The objective must be to plan a strategy to overcome the decline of soil productivity and to evolve a stable and productive agricultural system. The end result would be better control of weed growth under these conditions.

METHODS AND MATERIALS

Field studies were conducted at the Regional Agricultural Research Station in Maha Illuppallama, Sri Lanka. The soil type was predominantly Reddish Brown Earth which apparently has a low water holding capacity. A characteristic feature of this soil type is that it loses water and hardens quickly as the rain subsides.

In many parts of the dry zone, two cropping seasons, namely "Maha" (October to January) and "Yala" (March to July), have evolved as a result of the bimodal pattern of rainfall during North-East and South-West Monsoon periods.

In all experiments, the herbicide applications were controlled droplet application (CDA) at 40 l/ha using a Micron Herbi Applicator. The seeding was done by using a Rolling Injection Planter, developed by the International Institute of Tropical Agriculture (IITA) in Nigeria.

Experimental Procedures

Experiment I : Conventional tillage versus zero tillage Conventional manual tillage followed by "mammoty" (hoe) weeding as practised by local farmers was compared with a zero tillage method. The experiment was carried out for several successive seasons with appropriate crop rotations.

Glyphosate at the rate of 4 l/ha (formulated product) was sprayed onto the existing weeds and the crop was injection planted into the resulting mulch. Mixtures of metobromuron and metolachlor ('Galex') and alachlor and atrazine ('Primextra') at doses of 3 l/ha (formulated product) and 4.5 l/ha (formulated product) respectively were used as pre-emergence herbicides for cowpea (*Vigna unguiculata* L.) and maize (*Zea mays* L.). No pre-emergence herbicides were used for sesame (*Sesamum indicum* L.) and finger millet (*Eleusine coracana* L.Gaertn.).

Two "mammoty" weedings 15 and 30 days after seeding were carried out in the tilled plots.

Experiment II : Use of crop residue as a mulch An experiment was conducted with tillage versus no tillage, chemical weeding versus no weeding, and three levels of rice straw (0, 4 and 8 t/ha). Cowpea was injection seeded, fertilized and a mixture of metobromuron and metolachlor at a dose of 3 l/ha (formulated product) was applied to the appropriate plots, soon after which the plots were mulched.

Experiment III : Use of live mulches *Phaseolus artropurpureus* (Siratro), *Centrosema pubescens* (Centro) and *Pueraria phaseoloides* (Kudzu) were used as live mulches in this investigation with a cover of weeds serving as the control.

Covers of all these legumes were sprayed with a growth regulator CGA 47283 (Ciba-Geigy) at a dose of 8 kg/ha followed 5 days later by 2 l/ha of paraquat. Weeds in the control no-tilled plots were sprayed with glyphosate. Paraquat spraying was found necessary to dessicate the dense leafy legume cover through which crop emergence would have been difficult. Each plot was injection seeded with maize. No fertilizer was added.

Experiment IV : Avenue cropping (or alley cropping or sylvi-agriculture) Rows of tree legume (*Leucaena leucocephala* (Ipil-ipil) were grown in avenues 2 m wide (0.5 m within row spacing) and compared with bare plots. One half of each plot was tilled and tree loppings in the legume plots were incorporated. In the other half, loppings were spread on the ground and crops established no-till. Each sub-plot with legume trees accommodated two lopping treatments, *viz.* 0.5 m and 1.0 m above ground. Thereafter, maize and cowpea were established. The foliage of *L. leucocephala* was lopped prior to crop establishment and later twice before harvesting the crops. No fertilizer was added.

RESULTS AND DISCUSSION

Till vs. No-Till : The major weed in the field at the beginning of "Maha" 1980/81 season was *Cynodon dactylon*. Continuous cultivation and the use of herbicides gave a shift in weed population, *C. dactylon* dominated in ploughed plots, but broad-leaved species, such as *Tridax procumbens*, *Crotalaria anagyroides*, *Acanthospermum hispidum*, *Euphorbia heterophylla*, *Cleome viscosa* and grasses such as *Echinochloa colona*, *Digitaria adscendens*, *Dactyloctenium aegyptium* and *Chloris barbata* were dominant in no-till plots.

Table 1

The effect of tillage on weed growth

Treatment	Weed Dry Weight (g/m^2)				
	"Yala" 1981	"Maha" 1981/82		"Yala" 1982	
		a	b	a	b
Tilled	10.4	25	77	66	178
No-tilled	33.8	48	74	105	84
LSD (P = 0.05)	8.3	12	NS	20	NS
Cowpea crop	23.0	39	89	97	107
Sesame crop	21.2	-	-	74	155
Maize crop	-	34	62	-	-
LSD (P = 0.05)	-	NS	25	11	NS

a = measured 15 days after sowing
b = " 30 " " "

Excellent control of weeds was achieved in no-till plots ($P = 0.01$)(Table 1). Despite "mammoty" weeding of the tilled plots at 15-day intervals after planting, C. dactylon growth was rather heavy. In no-till plots during "Yala" 1982, weed regeneration was considerable probably due to the reduced efficacy of the metobromuron and metolachlor mixture because of insufficient rainfall following its application.

The reason why the weed growth was inconsistent in most cropping situations is not clear. However, weeding after 15 days in tilled plots will have affected the weed growth as well as crop development.

Table 2

Effect on tillage on crop yields

Treatment	Crop Yield (Kg/ha) "Yala" 1981		"Maha" 1981/82		"Yala" 1982	
	Cowpea	Sesame	Cowpea	Maize	Cowpea	Millet
Tilled	706	474	528	549	844	670
No-till	467	150	348	366	854	394
LSD ($P = 0.05$)	93	96	157	191	NS	112

Table 2 shows that higher yields could be obtained from no-till plots. The lower yields of crops for the tilled plots may reflect the competitive ability of C. dactylon rather than tillage per se. Despite yields being very low in "Yala" 1981 and "Maha" 1981/82 due to drought conditions, the no-till plots gave a much higher crop yield ($P = 0.05$) than tilled plots. This may be due to a better retention of soil moisture in the mulched no-till plots.

Crop residue mulches : A significant reduction ($P = 0.05$) in weed dry matter yields was observed in the no-till plots (Table 3).

Table 3

Effect of tillage on weed growth

Treatment	Weed Dry Wt. (g/m^2)
Tilled	13.8
No-till	8.7
LSD ($P = 0.05$)	1.4

Furthermore, there was a significant linear reduction ($P = 0.05$) in the weight of weed dry matter when straw mulches were added (Table 4).

Table 4

Effect of mulch on weeds (g/m^2)

Treatment	Weed Dry Wt.
No mulch	14.3
Mulching 4 t/ha	11.1
Mulching 8 t/ha	8.5
LSD (P = 0.05)	5.4

A highly significant interaction (P = 0.01) was observed between tillage and weeding and the yield of cowpea (Table 5).

Table 5

Effect of tillage and chemical weeding on cowpea yield (kg/ha)

Treatment	Tilled		No-till
Chemical weeding	534		608
No weeding	277		552
Between tillage LSD (P = 0.05)		67	
Between weeding LSD (P = 0.05)		166	

It is clear from the above results that the mixture of metabromuron and metolachlor appreciably increased the crop yield of cowpea in tilled plots.

Table 6

Effect of mulch on cowpea yield (kg/ha)

Treatment	Yield
No mulch	362
Mulching 4 t/ha	491
Mulching 8 t/ha	625
LSD (P = 0.05)	65

Table 6 shows that cowpea yields increased linearly (P = 0.05) with increasing rate of mulching. Each tonne per hectare of mulch resulted in a 33 kg/ha increase in cowpea yield. This suggests that a decreased weed growth was responsible at least in part for the increased cowpea yields.

Live mulches : *P. atropurpureus* and *C. pubescens* re-established themselves satisfactorily following paraquat treatment. However, the application of paraquat nearly killed *P. phaseoloides* and its re-growth was poor.

Leguminous covers did not appear to show any significance in controlling weed growth until 30 days after sowing. At the second observation (i.e., 55 days after sowing), *C. pubescens* and *P. atropurpureus* appeared to suppress weed growth while in the weakened *P. phaseoloides* and no-till plots, the weed cover increased (Table 7).

Table 7

Effect of live-mulch cover on weed growth (g/m^2)

Mulch	Sample time 30 days	 55 days
C. pubescens	29.2	15.6
P. phaseoloides	41.4	74.0
P. atropurpureus	48.0	32.2
Weed cover	47.2	89.4
LSD (P = 0.05)	NS	56.0

Table 8

Effect of live-mulch cover on maize yield (kg/ha)

Mulch	Yield
C. pubescens	898
P. phaseoloides	1,226
P. atropurpureus	1,459
Weed cover	588
LSD (P = 0.05)	334

Table 8 shows that maize yields were greater in live-mulch plots than in bare plots (P = 0.05). Although there was no appreciable difference in maize yields under *P. atropurpureus* and *P. phaseoloides* covers, the highest maize yield was obtained in the live-mulch plots in which *P. atropurpureus* was maintained. Maize yields in live-mulch covers were not related to weed growth.

Avenue cropping : It is interesting to note that weed growth was much lower (P = 0.05) in *L. leucocephala* avenues than in the control (Table 9). This could be the result of dense shade occurring under profusely growing *L. leucocephala* during the 'off' or non-arable season. However, there was no effect of tillage or lopping heights on the growth of weeds (Table 10).

Table 9

Effect of avenue cropping on weed growth

Treatment	Weed dry wt. (g/m^2) Maize	 Cowpea
Leucaena	19	17
Control	96	123
LSD (P = 0.05)	20	35

Table 10

Total dry matter yield (kg/ha) of leaf and stem from three loppings during "Maha" 1981

	Lopping height (m)					
	0.5		1		Mean	
	Leaf	Stem	Leaf	Stem	Leaf	Stem
Tilled	1,719	3,051	2,755	2,963	2,737	3,007
No-till	2,889	3,085	2,986	3,166	2,938	3,125
Mean	2,804	3,068	2,871	3,065	2,838	3,066

Total biomass productivity which was comparable for tilled and no-till plots, was an average of 3 ton stems (wood) and 2.8 ton leaf (dry weight basis per hectare). Thus, apart from mulch and organic carbon, the leaf material alone would have added approximately 90 kg N, 9 kg P and 73 kg K per ha in one cropping season (Weerakoon, 1982).

Table 11

Average yields of different crops (kg/ha)

Treatment	Maize		Cowpea
Leucaena	728		424
Control	579		499
LSD (P = 0.05)		113	
Within control			
Tilled	522		428
No-till	633		569
LSD (P = 0.05)		125	

Crop yields were again low on account of the drought that prevailed during the cropping season.

However, maize performed better in the avenues of L. leucocephala than in the bare plots, whilst cowpea yields were the same under both treatments, suggesting that the alley width may have some adverse effects on the growth of cowpea (Table 11).

Herbicides have emerged as a practical alternative to tillage for controlling weeds without much disturbance or exposure of the soil. Furthermore, results showed that effective weed control could be achieved if crop residue mulches (e.g., paddy straw) are incorporated into the system. In both situations, desiccated weed trash or straw function as a surface mulch to protect the soil against erosive forces of rain (Greenland, 1975) and depletion of organic matter, due to direct exposure to sunshine, as stated by Lal (1981).

The fast growing perennial legumes have the advantage of smothering weeds more efficiently and provide adequate protection to the soil. In addition, the planting of leguminous covers helps to recycle a substantial quantity of nutrients as a result of organic litter being added to the soil (Tan et al, 1976).

An integration of permanent tree crops with seasonal food crops in avenue cropping technique, has the advantage of natural recycling of fertility and minimising weeds through shading, while providing vital by-products such as fuel-wood and fodder. Thus, avenue cropping has the greatest potential for developing a stable and sustainable productive system for intensive cropping which can replace the wasteful shifting cultivation practice in the dry zone of Sri Lanka.

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REFERENCES

Abeyratne, E.L.F. (1956). Dry land farming in Ceylon. Tropical Agriculturist, 111, 191-229.

Abeyratne, E.L.F. (1962). Prospects for agricultural development in the dry zone. Proc. 18th Annal Session Ceylon Association Advance Science, pp. 58-71.

Darwent, A.L. (1981). Contour strip cropping as a method of farming rainfed upland soils in the dry zone of Sri Lanka. Report of the Sri Lanka - Canada Dry Zone Project.

Greenland, A.L. (1975). Bringing the green revolution to the shifting cultivation. Science, 190, 841-844.

Joachim, A.W.R., Kandiah, S. (1948). Soil fertility studies. The effect of shifting (chena) cultivation and subsequent regeneration of vegetation on soil composition and structure. Tropical Agriculturist, 104, 3-11.

Kirinde, S.T.W. (1957). Weed control in dry land farming. Tropical Agriculturist, 113, 131-146.

Lal, R. (1981). Deforestation and hydrological problems. In R. Lal and E.W. Russel (Editors) "Tropical Agricultural Hydrology" J. Wiley & Sons, Chichester, U.K.

Stockdale, F.A. (1926). The Chena problems and some suggestions for its solution. Tropical Agriculturist, 66, 199-208.

Tan, K.H., Pushparajah, E., Shepherd, R.S. and Tech, C.H. (1976). Calopogonium caeruleum, a shade tolerant leguminous cover for rubber. Proceedings Rubber Research Institute, Malaysia Planters' Conference, Kuala Lumpur, 1976.

Webster, C.C., Wilson, P.N. (1966). Agriculture in the tropics. Longman Group Ltd., London.

Weerakoon, W.L. (1982). Conservation Farming Programme in Sri Lanka. Paper presented at the Symposium on Tropical Agriculture jointly organised by Sri Lanka Pugwash Group and the Agrarian Research and Training Institute, 5-10 July, 1982, Colombo.

CHANGE OF CROP MANAGEMENT BY USING BENTAZONE AND SETHOXYDIM FOR POST-EMERGENCE WEED CONTROL IN SOYABEANS

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Summary. Sethoxydim, a systemic post-emergence over-the-top grass herbicide with selectivity in many non-grass crops, has been intensively tested by BASF in Brazil. Control of most important grasses like *Brachiaria plantaginea* and *Digitaria sanguinalis*, as well as post-emergence broad spectrum weed control in mixture with bentazone for in-crop weed control in soyabeans is reported. Also combinations with 2,4-D for control of existing weeds before soyabean planting has been investigated. Due to its wide application window and its ability to control almost all grasses, sethoxydim offers a new dimension in grass control. Combinations with post-emergence herbicides like bentazone for control of broadleaved-weeds give the farmer a new management tool to help him conserve his soil and optimize use of energy, water, nutrients and manpower resources.

Keywords: bentazone, sethoxydim, soyabeans, grass-weeds, broadleaved-weeds, mixtures, Brazil.

During the last ten years soybean has been the fastest growing crop in Brazil. In 1970 soybeans occupied just 1.2 million hectares, whereas in 1982 this area increased up to 8.3 millions. In addition to this tremendous increase, a technical evolution started taking place in crop production methods - "conservation tillage". This term includes all forms of reduced tillage as well as no-till. For example, no-till or "plantio direto" offers some important benefits - it requires less time, fuel, labour and fewer trips through the field and has been shown to be the most cost effective method of reducing soil erosion (Table 1).

Table 1

Soil loss, labour and fuel consumption in different tillage-systems

Tillage-system	soil-loss (t/ha)	labour (h/ha)	fuel (l/ha)
conventional tillage	57.0	5.84	25.4
plantio direto (no till)	5.5	1.24	2.6

Source: Plantio direto no estada Parana; no 23; Aug. 81

Soybean yields have proved to be at least as high with no-tillage as with conventional tillage, if sufficient weed control can be achieved. Traditional weed control systems in conventional planted soybeans in Brazil mainly included the use of preplant incorporated herbicides and/or one or more hoeings. Since it is extremely difficult or impossible to cultivate no-tilled fields and to incorporate herbicides, other weed control systems for in-crop weed-control have to be established.

The introduction of soil-acting pre-emergence herbicides, which must not be incorporated in the soil, accelerated the trend towards no-till to some extent. However, performance of these herbicides is somewhat erratic, especially in the presence of dense mats of straw-residues on the soil surface at time of application. They also need rain to be effective. Therefore the decision to move from the conventional to the no-till system requires a compromise between the risk of having some weeds with erosion controlled and excellent weed control with erosion uncontrolled.

It seems, if tillage is reduced, that additional emphasis should be placed on postemergence herbicides. Those available for broadleaf weed control in soybean include bentazone, acifluorfen and chloramben. Selection will depend on such factors as weed species present and degree of selectivity desired. For grass control diclofop-methyl has the appropriate selectivity. However, the application window is narrow, limiting flexibility in use of that compound. Sethoxydim, a more potent selective over-the-top postemergence grass herbicide, which is already registered in tobacco and non-edible crops, is being developed by BASF in Brazil. This paper describes herbicidal properties of sethoxydim (code name BAS 9052 0 H) and combinations with bentazone and 2,4-D under Brazilian conditions.

METHODS AND MATERIALS

Presented trial results were obtained from field trials during 1979-1982. More than 200 trials have been conducted in soybeans with sethoxydim in Brazil. For plot trials a randomized block design with 3-4 replications (plot size 10-20 m^2) have been used. Herbicide application was done with a knapsack sprayer (pressure : 2.5 - 3.5 Pa; water volume : 200 - 400 l/ha). Demonstration trials have been sprayed by farmer's equipment with a pressure between 2.5 and 4 Pa and spray volumes between 200 and 450 l/ha. In all trials, a 20% - sethoxydim formulation (BAS 9052 0 H, 184 g ai/ha EC) was used. All treatments with sethoxydim include 1.5 - 2.0 l/ha oil-concentrate. Herbicidal activity was expressed as percent control. Evaluations presented in this paper were made around 6 weeks after application. Crop injury was evaluated according to the 0-10 scale; 0 = no injury; 10 = total damage.

RESULTS

Crop tolerance

So far no significant injury has been observed on any non-grass crop, when treated with doses at least twice that required for effective postemergence grass control. Selectivity of sethoxydim and combinations with betazone in soybeans are presented in Table 2.

Table 2

Selectivity of sethoxydim and sethoxydim + bentazon in soybeans

Product	rate (kg ai./ha)	n	7 DAT	21 DAT
			crop injury	
Sethoxydim	0.1	42	0	0
	0.23	48	0	0
	0.5	14	0	0
Sethoxydim + Bentazone	0.1 + 0.75	28	1.1	0
	0.23+ 0.75	26	0.9	0
	0.5 + 0.75	4	1.3	0

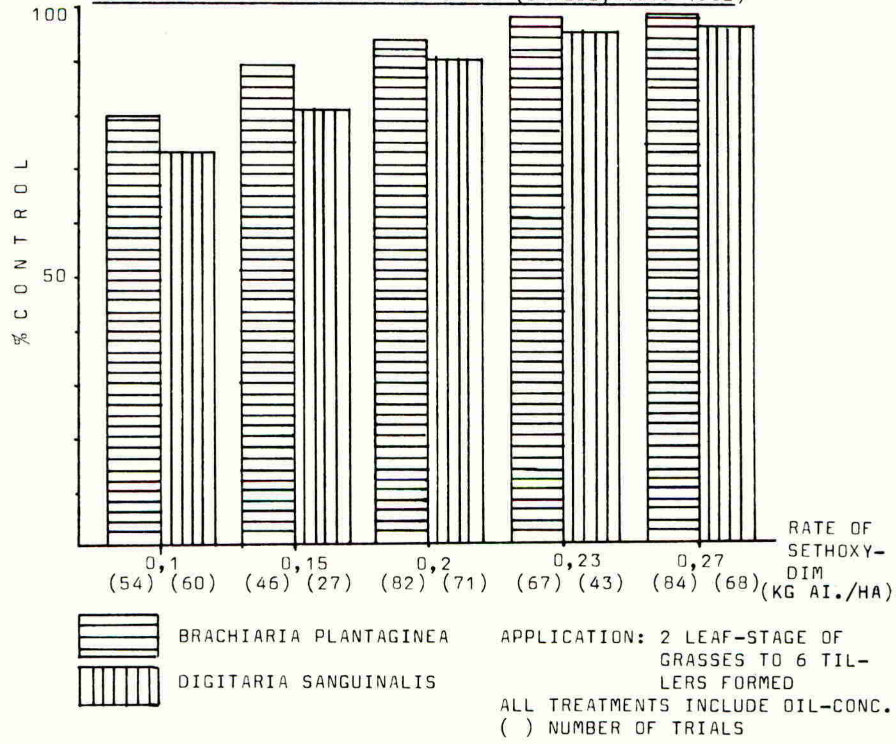
n = number of trials

Herbicidal efficacy in crop weed control

Until now no-tillage is mainly practised in Parana and Rio-Grande do Sul. In these areas Brachiaria plantaginea (alexandergrass) and Digitaria sanguinalis (large crabgrass) are the dominant grasses. Sethoxydim has shown to be highly active in postemergence application against these grasses (Fig. 1).

FIG. 1

EFFICACY OF SETHOXYDIM ON BRACHIARIA PLANTAGINEA AND DIGITARIA SANGUINALIS IN SOYBEANS (BRAZIL; 1979-1982)

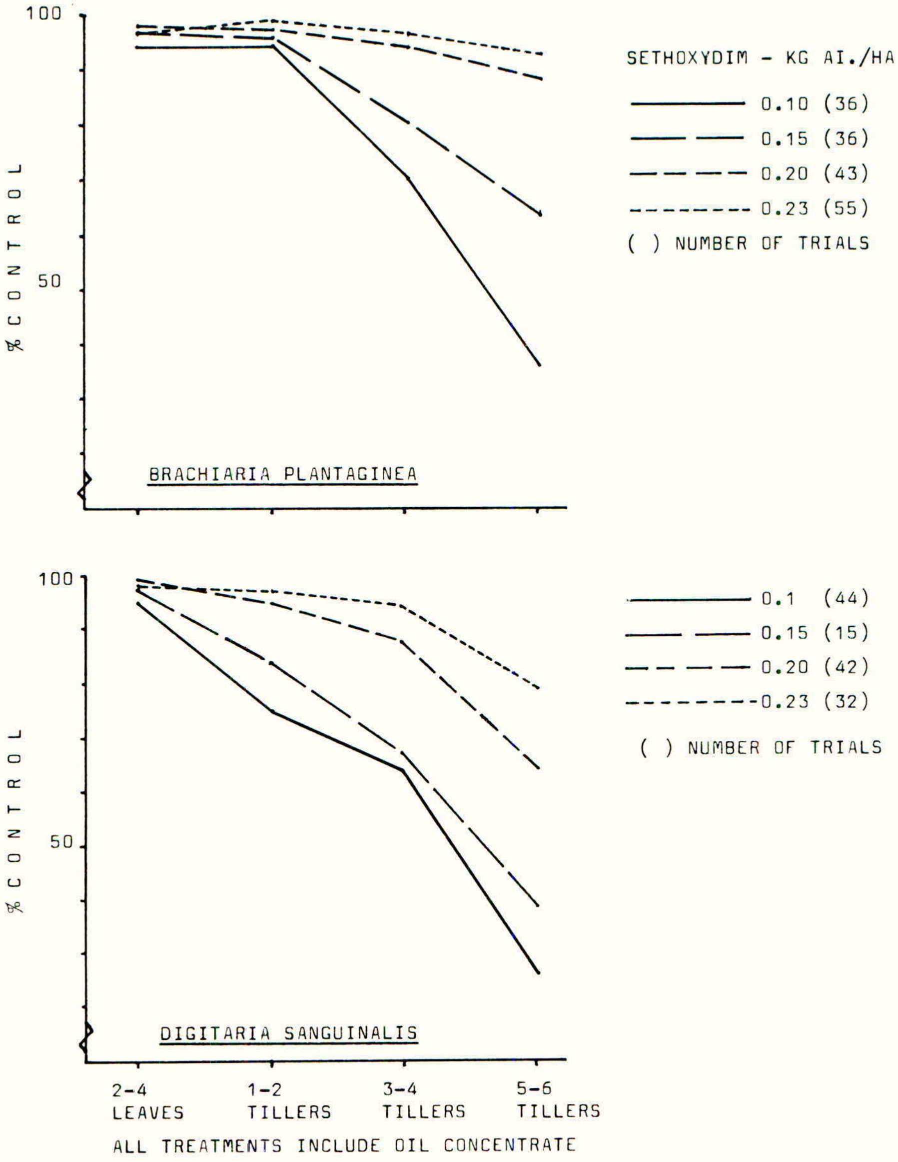


The dose required for excellent control depends on grass growth stage at time of application (Fig. 2). The smaller the grasses the lower the dose of sethoxydim which is needed for substantial control.

Applications before the 2-4 leaf stage of grasses should be avoided, because new germination of grasses may occur.

FIG. 2

INFLUENCE OF GRASS-GROWTH-STAGE ON EFFICACY OF SETHOXYDIM



ALL TREATMENTS INCLUDE OIL CONCENTRATE

In combination with bentazone, almost all important broadleaved weeds like Sida spp., Bidens pilosa, Acanthospermum hispidum, Ipomoea spp. as well as grasses can be controlled well simultaneously (Fig. 3).

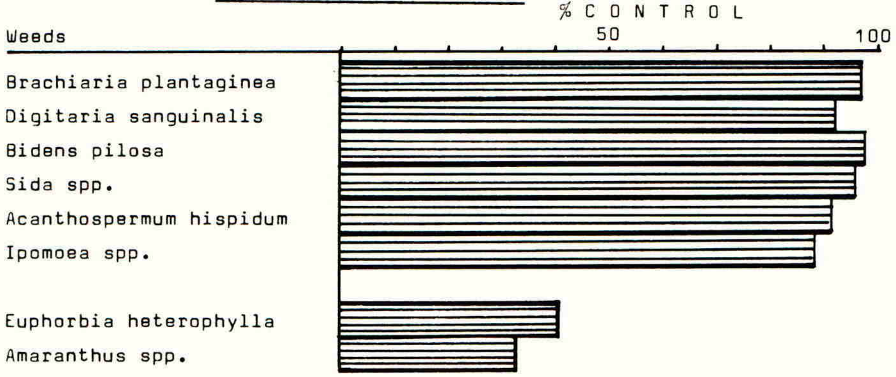


FIG. 3

Efficacy of sethoxydim + bentazone on most important weeds in Brazil

Dose of sethoxydim : 0.2 kg ai./ha
Dose of bentazon :0.75 kg ai./ha
Number of trials : 18

Pre-crop weed control

For control of weeds which grow in the period between wheat harvest and soybeans planting or, if no wheat-soybean rotation is practised, between soybean-harvest and soybean planting, herbicides like paraquat, diquat, glyphosate and combinations with 2,4-D or pre-emergence herbicides are used. Also, as shown in Table 3, sethoxydim in mixture with 2,4-D has potential for clean-up purposes before soybean planting. Application should be done at least 10-14 days before desired planting date.

Table 3

Efficacy of sethoxydim + 2.4-D against weeds grown before soybean-planting

Weed	Sethoxydim + 2.4-D	Glyphosate + 2.4-D
(kg ai./ha)	0.27 + 1.0	1.0 + 1.0
Brachiaria plantaginea	100	100
Digitaria sanguinalis	95	100
Triticum aestivum	100	100
Sida spp.	100	100
Bidens pilosa	100	100
Richardia brasiliensis	100	100
Acanthospermum australe	100	100

Number of trials : 2

DISCUSSION

The first economic, effective grass control in soybeans was made possible with the introduction of pre-plant incorporated herbicides. This was around 20 years ago. Now, another revolution in grass control is about to take place with the introduction of postemergence grass herbicides like sethoxydim. This systemic herbicide can be used in soybeans as well as a multitude of other broadleaved crops and controls nearly all grasses. Selectivity in broadleaved crops is due to physiological tolerance to the herbicide; so there is no necessity to protect the plant by using selective application techniques like directed sprays, ropewick applications or recirculating sprayers. Without a herbicide with such properties, spread of conservation tillage systems like no-till or plantio direto and solid seeded soybean system is limited. The introduction of a herbicide with the properties of sethoxydim sill significantly accelerate the trend towards new crop production systems. Sethoxydim has been shown highly effective on annual and perennial grasses, while bentazone, the other well-known over-the-top herbicide from BASF, controls the most important dicotyledonous weeds in soybeans. Both products together give the farmer a new management tool to help him conserve his soil and optimise use of energy, water, nutrients and manpower resources.

Until now, weeds growing in the interval between wheat harvest and soybean planting or between soybean harvest and soybean planting, have been controlled before planting with paraquat, diquat, glyphosate and combinations with 2,4-D and pre-emergence herbicides. Due to its wide application window, sethoxydim in combination with 2,4-D-ester can also be used to burn-down treatments to eliminate existing weeds, grown before soybean planting on the no-till land.

These examples show that sethoxydim alone or in combination with broadleaved herbicides can be flexibly used in different crop-weed situations to control weeds with an overall postemergence weed control system.

Use of pre-emergence herbicides is preventive in nature since they normally must be applied before weeds emerge. The use of postemergence weed control tactics, however, allows the grower to treat only those areas or fields where weed populations are observed. Due to its wide application window and its ability to control almost all grasses in many broadleaved crops, sethoxydim offers a new dimension in weed control.

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GRASS WEED CONTROL IN SOYBEANS WITH HOE 33171

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Summary. Hoe 33171 (Fenoxaprop-ethyl) is a new postemergence grass herbicide for the use in soybeans, which has been developed by Hoechst AG, Frankfurt. It acts primarily through the foliage.

Applications on annual grasses provide optimal activity when grasses are in the 4 leaf to 2 tiller stage of growth. Control of both annual and perennial grasses is achieved with a dose of 170 g a.i./ha.

A slight increase of this dose is necessary to overcome antagonistic effects which occur in mixtures of Hoe 33171 with broadleaved postemergence herbicides.

Sorghum halepense (Johnsongrass) should be treated at a height of 20-40 cm. Under unfavourable conditions regrowth from Johnsongrass through rhizomes may occur. In this case a second application one month after the first treatment provides season long control. A good crop stand, narrow row soybeans or a timely cultivation may eliminate the need for a second application. Hoe 33171 can be integrated into soybean production for a complete postemergence weed control system. Fenoxaprop-ethyl, soybean, grassweeds, *Sorghum halepense*, postemergence, mixtures, Argentina, Brazil, USA.

INTRODUCTION

Hoe 33171, proposed common name fenoxaprop-ethyl, is a compound of a group of grassy-weed herbicides being developed by Hoechst AG, Frankfurt.

Data on the mode of action, chemistry and toxicology are given in the papers presented earlier at this conference (Bieringer *et al.*, 1982, Köcher *et al*, 1982)

Hoe 33171 is a postemergence herbicide which controls annual and perennial warm-season grasses in broadleaved crops. It is formulated as a 120 g/l EC. Three years results (1979 - 1981) from the main soybean growing areas of North and South America are presented.

METHODS AND MATERIAL

Field trials (1979 - 1981) have been conducted in soybeans under different climatic conditions, various cropping systems and different weed control programs in Argentina, Brazil and the United States of America.

The trials were made in randomized block designs with 3 to 4 replications. Plot sizes varied from 10-20 m². Applications were made by small van der Weij plot sprayers with flatfan nozzles. The pressure at the nozzles was 3 Pa, the amount of water used 200-400 l/ha.

RESULTS

a) Annual grass control

Hoe 33171 is very effective on annual grasses. Results of three years studies with the main species are given in table 1.

Table 1

Annual grass control (in %) by Hoe 33171 on soybeans (USA and Brazil 1979 - 1981)

	Grass stage at application			
	grasses 4-6 leaves		grasses 1-2 tillers	
dose g a.i./h a	170	220	170	220
Setaria viridis	98 (35)	96 (23)	98 (24)	99 (24)
Setaria faberii	94 (44)	96 (27)	98 (26)	99 (27)
Setaria lutescens	97 (37)	98 (20)	96 (23)	96 (23)
Echinochloa crus-galli	95 (36)	95 (24)	97 (25)	98 (24)
Panicum dichotomiflorum	91 (14)	96 (17)	99 (17)	99 (17)
Digitaria sanguinalis	92 (22)	95 (20)	92 (2)	94 (2)
Eleusine indica	97 (15)	95 (11)	99 (2)	99 (4)
Brachiaria platyphylla	95 (9)	97 (9)	89 (3)	91 (3)
Zea Mays	98 (6)	100 (6)	88 (3)	89 (3) (6-8 leaf)

Assessments 6-8 weeks after application.

( ) = number of trials; 75 - 95 cm rowspacing.

At a dose of 170 g a.i./ha and the early application timing (4-6 leaf) the grasses were controlled between 91 and 98 %. Control at the later timing (1-2 tillers) was generally better except with Brachiaria platyphylla and corn. In comparison with 170 g a.i./ha the 220 g a.i./ha dose provided only a slight increase in control.

b) Perennial grass control

Hoe 33171 control Sorghum halepense (Johnsongrass) very effectively (table 2).

Table 2

Control (in %) of rhizome Johnsongrass by Hoe 33171 (1980 - 1981)

		USA DAT			Argentina DAT		
height of grass (cm)	dose g a.i./ha	8-15	20-30	40-60	8-15	20-30	40-60
25 - 40	170	87 (17)	78 (15)	68 (11)	91 (6)	96 (6)	97 (6)
	220	92 (18)	80 (18)	77 (11)	92 (6)	97 (6)	97 (6)
40 - 80	170	-	-	-	86 (3)	83 (3)	75 (3)
	220	82 (8)	78 (9)	75 (7)	88 (3)	88 (3)	75 (3)

( ) = number of trials

75 - 95 cm rowspacing

At 25 - 40 cm grass height Hoe 33171 with 170 g a.i./ha gave 87 % and at 220 g a.i./ha 92 % control of Johnsongrass in US tests. Results from Argentinian trials showed 91 % and 92 % control. In US tests some regrowth from rhizomes occured and reduced the control after 40 - 60 DAT to 68 % at 170 g a.i./ha and to 77 % at 220 g a.i./ha. The results from Argentina showed no regrowth of Johnsongrass. Hoe 33171 applied on 40 to 80 cm high Johnsongrass was less effective than at earlier applications at 20 to 40 cm height of the grass weed. In cases where regrowth occurs a second application of Hoe 33171 gives season long control of Johnsongrass (table 3).

Table 3

Sequential application of Hoe 33171 for Johnsongrass control (in %) in soybeans (USA 1980 - 1981)

	1st application DAT		2nd application DAT	
dose g a.i./ha	10-15	30-40	60-80	harvest
110 + 110	83 (5)	80 (5)	86 (5)	97 (3)
170 + 170	91 (7)	85 (7)	97 (7)	97 (3)
220 + 220	89 (11)	86 (11)	95 (11)	92 (8)

( ) = number of trials;
first application was made at 25-40 cm Johnsongrass, second application followed after 4-6 weeks; 75-95 cm rowspacing

Two applications of 110 g a.i./ha provided good season long Johnsongras control. Higher doses such as 170 + 170 or 220 + 220 g a.i./ha did not increase the control.

c) Control of annual and perennial grasses by Hoe 33171 in narrow and wide row soybeans

Six studies conducted in the midwest of USA 1981 showed no major effect of row spacing on the annual grass control (table 4).

Table 4

Control of annual grasses (in %) by Hoe 33171 in narrow versus wide row soybeans (USA 1981)

assessments (DAT)	14		60		80		100	
rowspacing (cm)	18	96	18	96	18	96	18	96
dose g a.i./ha								
170	97 (4)	97 (4)	99 (5)	98 (5)	97 (5)	95 (5)	97 (5)	97 (5)
220	98 (4)	99 (4)	99 (6)	98 (6)	99 (6)	97 (6)	99 (6)	98 (6)

Growth stage at application 3 leaves to 2 tillers;
annual grasses: Setaria spp., Panicum dichotomiflorum, Echinochloa crus-galli
( ) = number of tests; tests conducted in Midwest (USA) 1981 side by side.

Johnsongras control, however, was influenced by rowspacing at least at a single application of Hoe 33171 (table 5). Whereas at sequential applications no differences between Johnsongrass control in narrow and in wide row soybeans could be observed.

Table 5

Control of Johnsongrass (in %) by Hoe 33171 in narrow versus wide row soybeans; average of 3 trials, USA 1981

assessments (DAT)	14		30		55		80	
row spacing (cm)	18	96	18	96	18	96	18	96
dose g a.i./ha								
170 + 170*	93	92	92	82	99	99	99	99
220	94	92	93	85	92	80	92	77

* second application 30 days after first application

height at application 25 - 40 cm

d) Control of annual grasses and Johnsongrass by Hoe 33171 tankmixed with bentazone and acifluorfen

The results indicate that slight antagonistic effects in grass control can occur if Hoe 33171 is tank-mixed with bentazone or acifluorfen (table 6).

Table 6

Control of annual grasses and Johnsongrass (in %) by Hoe 33171 in tankmixtures with bentazone and acifluorfen (USA, Brazil)

product	dose g a.i./ha	annual grasses	Johnsongrass
Hoe 33171	170	95 (14)	86 (9)
Hoe 33171 bentazone	170 1100	89 (13)	75 (7)
Hoe 33171 acifluorfen	170 550	85 (8)	67 (7)
Hoe 33171	220	96 (10)	92 (7)
Hoe 33171 bentazone	220 1100	90 (29)	78 (7)
Hoe 33171 acifluorfen	220 550	92 (8)	69 (8)

Assessments 4-6 weeks after application; annual grasses: Setaria spp., Echinochloa crus-galli, ( ) = number of trials.

95 % control was achieved with Hoe 33171 at 170 g a.i./ha compared to the mixtures with bentazone which gave 89 % control, and with acifluorfen giving 85 %. With the 220 g a.i./ha dose the antagonism is slightly less than with 170 g a.i./ha. Thus, the tankmix with bentazon shows less antagonism than the mixture with acifluorfen on control of annual grasses. The same applies when these mixtures are used to control Johnsongrass. Figures in the table above show that use of Hoe 33171 alone at a rate of 220 g a.i./ha gave 92 % control. However, the mixtures with bentazone resulted in 78 % control and the tankmix with acifluorfen gave 69 % control.

e) Crop tolerance

Hoe 33171 showed no phytotoxicity on soybeans with more than double the dose of 220 g a.i./ha.

DISCUSSION

Hoe 33171 gives excellent post-emergence control of annual and perennial warm-climate-grasses with rates of 170 to 220 g a.i./ha. Optimum control of annual grasses is achieved when the grasses are at the 1 to 2 tiller stage. Earlier applications at 4 to 6 leaf stage give slightly lower control due to weed emergence after treatment (table 1). This illustrates the importance of not spraying too early since Hoe 33171 only controls grasses present at application. It also demonstrates the excellent flexibility of the product in controlling grasses over a wide range of growth stages.

Control of Sorghum halepense, the most important perennial grass weed in soybean growing areas, is achieved with the same dose rates as required for annual grass control (table 2). Best results are obtained when S. halepense is 25 to 40 cm high. Under unfavourable conditions such as poor crop stands or slow weed growth after application, some regrowth from rhizomes may occur. In these situations a second application of Hoe 33171 at 170 g a.i./ha gives excellent season long control (table 3). However, in most cases this will not be necessary.

Results of the row spacing trials given in table 5 show that in narrow rows the crop canopy effectively suppresses regrowth of S. halepense whereas in wide rows the farmer has the option of a second application or inter-row cultivation. The results in table 4 show no effect of row spacing on annual grass control. However, in some climatic conditions when the germination period is prolonged, control may be improved through the more intensive crop competion in narrow row soybeans.

To complete the post-emergence weed control system for soybean production, tankmixtures of Hoe 33171 with bentazone and acifluorfen are being developed. These mixtures are possible if the broadleaved weeds have the appropriate stages and the annual grasses have mostly germinated. However, slight antagonistic effects may occur if Hoe 33171 is mixed with bentazone or acifluorfen. This can be compensated by a higher dose (220 g a.i./ha) of Hoe 33171. Further results not mentioned in the experimental part indicate that no antagonism occurs if Hoe 33171 is applied 4 to 6 days after bentazone or acifluorfen. With Hoe 33171 a postemergence grass herbicide has been found to complete the postemergence weed control systems for soybeans.

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REFERENCES

Bieringer, H., Hörlein, G., Langelüddeke, P. and Handte, R. (1982) Hoe 33171 - a new selective herbicide for the control of annual and perennial warm climate grass weeds in broadleaf crops. Proc. 1982 British Crop Protection Conference (in prep).

Köcher, H., Kellner, H.M., Lötzsch, K. and Wink, O. (1982) Mode of action and metabolic fate of the herbicide fenoxaprop-ethyl, Hoe 33171. Proc. 1982 British Crop Protection Conference (in prep).

Proceedings 1982 British Crop Protection Conference - Weeds

THE USE OF MSMA AND DSMA FOR POST-EMERGENCE WEED CONTROL IN TROPICAL AND SUB-TROPICAL AGRICULTURAL CROPS

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Summary. MSMA (monosodium methylarsonate) and DSMA (disodium methylarsonate hexahydrate) have been shown to provide effective post-emergence control of such troublesome weed species as *Axonopus compressus*, *Cyperus esculentus*, *Digitaria longiflora*, *D. sanguinalis*, *Ischaemum muticum*, *I. timorense*, *Lygodium scandens*, *L. flexuosum*, *Paspalum conjugatum*, *Rottboellia exaltata*, and *Sorghum halepense*. These weeds are found in rubber, oil palm, coconut, cocoa, sugarcane, cotton and low altitude coffee plantations and can be controlled with doses from 2.0 to 13.2 kg a.i./ha of MSMA and DSMA. Further enhancement of grass and broadleaved weed control in selected crops has been demonstrated by combining MSMA or DSMA with ametryne, dalapon, diuron, 2,4,-D, or paraquat, either tank-mixed or as formulated products.

Key Words. MSMA, DSMA, herbicide mixtures, annual grasses, broad-leaved weeds, perennial grasses, plantation crops, cotton, Africa, Asia.

INTRODUCTION

Most of the land area classified as being tropical or sub-tropical can be regarded as being "third world" or the lesser developed countries. As much as 90% of the population in those areas depend on agriculture for livelihoods and nearly 90% of the agriculture in those areas consist of no more than subsistence farming. Ebner (1980) points out that in these regions the use of herbicides cannot be considered as an established crop production technique. This is not likely to change significantly during this decade, though economic pressure will begin to have an impact.

The 500% increase in petroleum prices during the 1970's has increased the demand for fibre and oil crops. Further the discovery of oil and gas in tropical and sub-tropical regions of Southeast Asia, Western Africa and Mexico will be likely to result in a shift from agricultural to industrial development. As educational levels of the populations improve, the agricultural labour force will decline in favour of higher paying skilled jobs, placing an even more critical demand on agricultural outputs.

However, until such resources are developed, those countries rely on speciality agricultural exports as a source of foreign exchange needed to import food. Those exports include groundnuts (peanuts), sugar from sugarcane, cotton or textiles, palm oil, rubber, coffee, tea, coconut, and cocoa. It is those crops that local and foreign governments are prepared to develop by financing research and aid programmes and where production has become more sophisticated. Nearly all the imported pesticides used in developing areas are used for those projects. In those areas the uses of herbicides are becoming increasingly important.

Lee (1977) describes 17 weed species which are most serious in Malaysia. Thirteen of those are found in rubber, oil palm coconut, coffee and cocoa. Of those thirteen, six are broad leaved, three are ferns, and four are grasses. The species include Axonopus compressus, Paspalum conjugatum, Ischaemum muticum, I. timorense, Digitaria longiflora, D. sanguinalis, Lygodium scandens, L. flexuosum, Imperata cylindrica, Cynodon dactylon, Ottochloa nodosa, Cyperus spp, Scleria spp, Cyclosorus gongyloides and Stenochleana palustris.

Doll (1980) described Cyperus esculentus and Rottboellia exaltata as being the most serious weed problems in Latin America. Turner (1981) describes R. exaltata as a new and potentially serious problem in sugarcane growing areas of South Africa, and Millhollon (1965) reported the same in the United States. Akobundu (1980) lists C. esculentus, C. rotundus, C. dactylon, Eleusine indica, Digitaria spp, R. exaltata and Commelina spp. as being most widely distributed and often the most serious weed species throughout tropical Africa. In humid or irrigated regions of the sub-tropics Kleifield (1970) and Millhllon (1970) describe S. halepense as a serious grass problem in cotton and sugarcane.

Muir (1979) reported the hazards of poor weed management in rubber plantations. Not only do weeds compete with nutrients and moisture, but dense populations make tapping or harvest of latex difficult and pose a fire hazard during the less humid seasons, particularly in immature plantings. This is true for most perennial tree crops. Hand weeding (slashing) is a widely used method of weed control throughout most of the tropics and should not be abandoned entirely on plantations in order to maintain full time employment of local labour. However, slashing becomes difficult when the same labour force is required during harvest or tapping. Another question is whether total weed control is desirable in certain crops due to increased soil erosion. For those reasons, management programmes incorporating both mechanical and chemical weed control have been tested and adopted in parts of West Africa.

Because of the diversity and complexity of weed species and climatic conditions in the tropics-subtropical regions, few if any herbicides when used alone have provided cost effective weed control. In Malaysia many herbicide recommendations for rubber and oil palm include herbicide mixtures (Anon, 1981). In certain crops and particularly on new plantations, multiple applications of herbicide are required during the year and contact post-emergence activity is essential.

MSMA (monosodium methylarsonate and DSMA (disodium methylarsonate hexahydrate) were first recognised as having a post-emergence activity against S. halepense and Cyperus spp. from trials conducted in Israel, Malaysia and the United States during the 1960's. Cotton and sugarcane were found to have good to excellent tolerance to directed sprays.

Arle and Hamilton (1971) reported that single or multiple post directed applications of MSMA had little effect on cotton yields, nor did single topical applications of 2.2 kg a.i. if applied before first bloom.

Hamilton (1979), Keeley and Thullen (1970, 1971) describe the effects of arsenical herbicides on C. esculentus and C. rotundus. C. esculentus absorbed arsenical herbicides more readily than C. rotundus, but multiple applications of MSMA would control C. rotundus.

Similarly Millhollon (1970) found that two applications of MSMA at 4.0 + 4.0 kg or 4.0 + 2.5 kg a.i./ha resulted in effective contact control of rhizome S. halepense in sugarcane.

Kleifield (1970) demonstrated the combined effects of preplant incorporated trifluralin treatments on cotton fields followed by post-emergence treatments of MSMA on S. halepense. The combined treatment reduced the number of MSMA applications to control S. halepense thus reducing the risk of cotton injury that could result from multiple or late MSMA applications.

Because MSMA and DSMA are selective contact grass herbicides, mixtures and combinations with broad-leaved herbicides are often desired to give economical yet broad spectrum weed control. The purpose of this paper is to summarise research results over the past 15 years in developing cost effective herbicide combinations in various tropical and sub-tropical crops.

METHODS AND MATERIALS

The results herein are summarised from replicated field trials conducted at numerous locations throughout tropical and sub-tropical regions. Evaluations were made with MSMA and DSMA alone to determine overall weed control spectrum, doses and crop tolerance in specific locations and under various ecological, environmental and edaphic conditions. Further herbicide combinations were tested including MSMA and DSMA to determine compatability, crop tolerance and efficacy.

RESULTS AND DISCUSSION

Though MSMA and DSMA are found to be effective against a large spectrum of grasses, the results summarise those species which are most difficult to control with most herbicides.

Cotton. MSMA and DSMA applied as a directed spray in cotton at rates 2.0 to 2.5 kg a.i./ha provided effective control of C. esculentus and S. halepense. Where grass populations were dense, or C. rotundus was present a second application was required ten days to two weeks later. Cotton showed excellent tolerance to MSMA or DSMA when directed or even broadcast topical sprays were applied. Single applications at 2.0 kg a.i. may be applied topically or by aerial application in this manner though directed spraying is most preferred. Weeds and grasses were best controlled when less than 15 - 20 cm in height and actively growing. No more than two applications should be made, the first being after cotton has reached a height of 8 cm. Cotton should not be treated after first bloom.

Post emergence treatments of MSMA at 2.0 kg/ha combined with cyanazine at 0.9 kg or prometryne at 1 kg/ha resulted in effective grass and broad-leaved weed control following pre-emergence cyanazine or prometryne treatments.

MSMA plus methazole at 1.8 plus 1.8 kg a.i./ha respectively as post directed sprays also gave excellent weed control in cotton not having pre-emergence or pre-plant herbicide treatments.

MSMA or DSMA applied as post-emergence directed sprays at 1.6 to 2 kg a.i./ha following a pre-emergence fluometuron treatment at from 0.9 to 2 kg a.i./ha or combined with fluometuron at 0.9 kg a.i./ha and applied as directed sprays also resulted in commercial broad spectrum weed control.

Because the activity of MSMA and DSMA are temperature dependant, and certain cotton producing areas may extend out of sub-tropical regions, MSMA should only be applied after night temperatures exceed 21°C for maximum activity.

Sugarcane. The control of S. halepense by, and tolerance of sugarcane to MSMA were demonstrated in the early 1960's. The importance of R. exaltata as a new and potentially major weed problem has only been recently investigated, and its control has been demonstrated with directed post-emergence sprays of MSMA at from 2.0 to 4.0 kg/ha, particularly in Eastern and Southern Africa. No commercially available herbicide has provided acceptable control of R. exaltata except MSMA.

Combinations of MSMA with diuron at 2.1 + 2.4 kg a.i./ha provided commercial control of R. exaltata, C. esculentus and Paspalum spp. plus effective overall broadleaved weed control.

Further, the experimental results from South Africa showed MSMA alone or in combination, particularly with diuron, to be less phytoxic than standard herbicide treatments of diuron plus paraquat.

MSMA combined with ametryne at 2.1 plus 2.5 kg a.i./ha provided effective control of R. exaltata, C. esculentus, Paspalum spp, Eleusine indica, Digitaria spp, in addition to effective broadleaved weed control.

As a result MSMA was recommended as part of a herbicide programme where Rottboellia, Cyperus and Paspalum spp. exist. Cost effective herbicide programmes include MSMA at 2.1 kg a.i./ha in newly planted or ratoon sugarcane following or combined with applications with atrazine, ametryne, diuron, or 2,4-D to give broad-spectrum weed control.

Oil Palm, Rubber, Cocoa. MSMA and DSMA were evaluated under various conditions to determine crop tolerance and spectrum of efficacy. As a result combinations of MSMA with other known herbicides were evaluated and four major combinations have been selected as commercial materials that can be tank mixed or formulated. They included DSMA, the sodium salt of 2,4-D and diuron; DSMA plus diuron; paraquat plus MSMA; and MSMA, ametryne and 2,4-D.

A three-way combination of DSMA combined with 2,4-D and diuron and applied at 5.0, 1.0, and 0.4 kg a.i./treated hectare respectively provided effective control of P. conjugatum and fair control of S. palustris. Control of those species were enhanced and O. nodosa, Nephrolepis bissenata, A. compressus, and Mikania micrantha were controlled by a four-way mixture of DSMA, 2,4-D, diuron and paraquat at the respective rates of 3.0, 0.6, 0.25 and 0.2 kg a.i./treated hectare.

In West Africa a formulated combination of MSMA, ametryne and 2,4-D applied at respective doses of 2.0 kg, 0.67 kg and 0.93 kg a.i./treated hectare provided effective broad spectrum grass and broadleaved weed control in oil palm, being weak only against Eupatorium spp.

Coffee. MSMA trials conducted on coffee in East Africa at rates of 2.2 to 4.3 kg a.i./ha resulted in erratic performance. Though coffee had excellent tolerance to MSMA, efficacy was affected by altitude. At or below 1,800 m excellent control of Cyperus spp and other grasses was recorded. Above that elevation the efficacy was reduced. This was largely attributed to increased cloud cover and lower temperatures at the higher altitudes. However, in low altitude coffee, MSMA could be an effective herbicide used in combination, or in conjunction with other herbicides.

CONCLUSION

The diversity of weed species and growing conditions in tropical and sub-tropical climates dictate that where herbicides are used, herbicide combinations are most often necessary. Those herbicides and combinations must be readily available, cost-effective and control a number of difficult weed species.

Any herbicide mentioned in this report plus many others can be used alone to provide selective weed control. However, tank-mixes for broad spectrum control will reduce the number of applications and by formulating the combinations as package mixes mixing errors can be avoided.

For optimum performance of MSMA and DSMA alone or in combinations, temperatures must be above 21°C. As with all contact herbicides it is necessary that 6-8 hours elapse between application and rainfall or irrigation. Weeds should be actively growing at the time of application and weed foliage should be less than 20 cm in height. *Rottboellia* spp, however, has been effectively controlled at heights of 40 cm.

MSMA or DSMA alone or in combination can be used following many pre-plant or pre-emergence herbicide treatments for spot treatment or clean-up operations for such grasses as *Panicum* spp, *Paspalum* spp, *Cyperus* spp, *R. exaltata* and *S. halepense*.

In sugarcane and cotton directed sprays should be used, however, one topical or broadcast spray of MSMA or DSMA alone at 2.0 kg a.i./ha can be used on cotton as a salvage operation without significantly affecting yield if applied before first bloom.

APPENDIX I : Compared efficacy of MSMA or DSMA alone or in combinations with ametryne, diuron, dalapon, 2,4-D and Paraquat.

Weed Species	MSMA/DSMA	Ametryne	Diuron	(DSMA) Dalapon	2,4-D	Paraquat	2,4-D Ametryne
		HERBICIDE COMBINATIONS WITH MSMA OR DSMA					
Axonopus compressus	++	++	+++				
Cynodon dactylon	O	++	++	+++	O	(O–+)	++
Cyperus esculentus	++	++	++	++	++	+++	++
Cyperus rotundus	(O–+)	+	++	++	(O–+)	+	+
Digitaria longiflora	+++	+++	+++	+++	+++	+++	+++
Digitaria sanguinalis	+++	+++	+++	+++	+++	+++	+++
Imperata cylindrica	O						
Ischaemum muticum	++	++	+++	+++	++	++	++
Ischaemum timorense	++	++	+++	+++	++	++	++
Lygodium scandens	+++	+++	+++	++	++	++	++
Lygodium flexuosum	+++	+++	+++	+++	+++	+++	+++
Ottocloa nodosa	O		++			+++	
Panicum spp	+	++	++	+++	++	+++	++
Paspalum conjugatum	++	+++	+++	+++	+++	+++	+++
Paspalum spp	+	+++	+++	+++	+++	+++	+++
Rottboellia exaltata	+++	+++	+++	+++	+++	+++	+++
Scleria pterota	O						
Sorghum halepense	++	++	++	++	++	+++	++
Sorghum verticilliflorum	+	++	+++	+++	+	++	++
Broad leaf - general	(O–+)	++	++	(O–+)	+++	++	+++

O = Not controlled
(O–+) = Some control but requiring multiple applications
\+ = >50% control
++ = >75% control
+++ = >90% control

APPENDIX II : Crop tolerance to MSMA, DSMA, and herbicide combinations tested as directed sprays.

Crop	MSMA/DSMA Alone	Ametryne	Diuron	Dalapon[6]	2,4-D	Paraquat	2,4-D Ametryne
Cotton	+ - ++	O	+ - ++ -	O	O	O	O
Sugarcane	+ - ++[1,2]	+ - ++[1,2]	+ - ++[1,2]	+ - ++[1,2]	+ - ++[1,2]	+ - ++[1,2,3]	+ - ++[1,2]
Rubber	++	++	++	+ - ++[4]	+ - ++[1,5]	++[1]	+ - ++[1,5]
Oil Palm	++	++	++	++	+ - ++[1,5]	++[1]	+ - ++[1,5]
Cocoa	++		+			++[1]	
Coffee	++	++[1]	++[1]	++[4]	O	++[1]	O
Citrus	++	++[1]	++[1]	++[4]	O	++[1]	O

O = Not tolerant - not recommended

\+ = Slight phytotoxicity possible

++ = Excellent tolerance

[1] Directed sprays only. Avoid herbicide contact with crop foliage

[2] Some varietal differences in tolerance have been observed

[3] Spot treatments only

[4] Established trees. Not on newly planted trees or nurseries

[5] Sodium salt or low volatile formulations only

[6] With DSMA only

LITERATURE CITED

1. Akobundu, I. Okezie, (1980). Weed Science Research at the International Institute of Tropical Agriculture and Research needs in Africa. *Weed Science 28*: 439-445.

2. Anon. (1981). Registered Pesticides List. Ministry of Agriculture Malaysia. Pesticide Board. 1982.

3. Arle, H.F., Hamilton, K.C., (1971). Topical applications of DSMA and MSMA in irrigated cotton. *Weed Science 19*: 545-549.

4. Doll, J.D. (1980). Weed Science at CIAT (Centro Internacional de Agricultura Tropical) and weed problems in Latin America. *Weed Science 28*: 454-460

5. Ebner, L. (1980). Advances in Chemical Weed Control in the tropics and s. tropics as an integrated part of protection. *Proceedings 1980 British Crop Protection Council - Weeds 3*: 813-822.

6. Hamilton, K.C. (1979). Repeated foliar applications of MSMA on purple nutsedge. *Weed Science 19*: 675-678.

7. Janson, L.L. (1971). Morphology and photoperiodic responses of yellow nutsedge. *Weed Science 19*: 210-219.

8. Keeley, P.E., Thullern, R.J., (1970). Vitality of tubers of yellow nutsedge treated with arsenical herbicides. *Weed Science* 18: 437-439.

9. Keeley, P.E., Thullern, R.J., (1971). Control of nutsedge with organic arsenical herbicides. *Weed Science 19*: 601-607.

10. Kleifield, Y. (1970). Combined effect of trifluralin and MSMA on Johnsongrass control in cotton. *Weed Science 18*: 16-19.

11. Lee, S.A. (1977). An analysis of weed research in West Malaysia (1912-1976). Malaysian Plant Protection Society Report.

12. Millhollon, Rex. W. (1965). Growth characteristics and control of *Rottboellia exaltata*, l.f. A new weed in sugar cane. *Sugar Bulletin 441*: 82-88.

13. Millhollon, Rex. W. (1970). MSMA for Johnsongrass control in sugarcane. *Weed Science 18*: 333-336.

14. Muir, J. (1979). Importance of weed control in rubber. Unpublished. Firestone Plantations, Harbel, Liberia.

15. Turner, P.E.T. (1981). The effects of post-emergence herbicide treatments on sugarcane in South Africa. *Proceedings of The South African Sugar Technology Association* pp 99-105.

SESSION 7C POSTER

THE BIOLOGICAL BACKGROUND TO WEED CONTROL

Proceedings of the 1982 British Crop Protection Conference - Weeds

HERBICIDE RESISTANCE IN WEEDS - AN INEVITABLE CONSEQUENCE OF HERBICIDE USE?

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Summary Evolution of herbicide-resistance in previously susceptible weed populations is a relatively new and growing problem. This paper describes the occurrence of herbicide-resistance, particularly in the United Kingdom, and outlines the characteristics of herbicide-resistant weeds. The process of evolution of herbicide-resistance is analysed in order to provide an explanation of whether development of resistance is necessarily a predictable outcome of herbicide use, in relation to particular chemicals and weed management practices. Strategies for avoidance or alternatively containment of herbicide-resistant weed populations are discussed.

INTRODUCTION

The relatively recent occurrence of resistance to herbicides in weed species which were previously susceptible, is now becoming an increasingly common event in North America and Western Europe. Occasional herbicide-resistant weed populations are also appearing in other parts of the world such as Egypt and Japan.

Herbicide-resistance is just one more example of the extraordinary capacity of living organisms to adapt to new environments. Consequently man has been involved in a recurrent battle with nature in order to cope with loss of effectiveness in a wide variety of pest control measures. Entomologists have now become quite experienced in coping with resistance to insecticides since more than 400 species of insects and related arthropods have now evolved resistance. Breakdown in genetic crop resistance to plant pathogens has been a problem for many years and more recently, resistance to crop fungicides and antibiotics have become much more common. These more important examples of resistance problems make it clear that when herbicide-resistance is placed in the overall context of crop protection, it is a relatively minor problem. Nevertheless individual growers do not view it in this way, to them it is a real and urgent problem which requires the development of cost-effective strategies to both avoid herbicide-resistance and to contain the problem when it occurs.

OCCURRENCE OF HERBICIDE-RESISTANCE IN NORTH AMERICA AND WESTERN EUROPE

There are now so many authenticated cases of herbicide resistance in weed species that it is not possible comprehensively to review the current situation in this paper. A newly published book Herbicide Resistance in Plants (LeBaron & Gressel, 1982) provides a detailed review of all known cases of resistance up to mid 1981. At present 30 annual weed species in 18 genera are known to be resistant.

Although isolated occurrences of resistance to several different herbicides have been reported during the last decade (e.g. resistance to paraquat, metribuzin and trifluralin), resistance to triazine herbicides (mainly atrazine and simazine) has been the major problem. In the United States of America, triazine-resistance first appeared in the mid 1960's and now occurs in at least 23 different states.

Western Washington is particularly seriously affected. For example in this region, triazine-resistant Senecio vulgaris (groundsel) now occurs in the majority of maize fields (circa 250,000 ha are affected) and resistant Amarathus powellii (Powell amaranth) also occurs in more than 100,000 ha. In eastern U.S.A., A. hybridus (Smooth pigweed) occurs in maize fields in Virginia, New York, Delaware, Pennsylvania, Massachusetts and Maryland (in Maryland more than 50,000 ha contain triazine-resistant A. hybridus). In Canada triazine-resistant Chenopodium album has become common in Ontario and at least 100,000 ha of maize fields are infested with resistant populations.

During the mid/late 1970's in Europe, several Amaranthus spp. have developed triazine-resistance, particularly in vineyards in Switzerland and in maize fields in France, Austria and Hungary. In France, C. album has evolved triazine-resistance in maize fields in many widely scattered locations (circa 300,000 ha are affected). These are just a few of the more significant examples of triazine-resistance in weeds outside the United Kingdom.

OCCURRENCE OF HERBICIDE RESISTANT POPULATIONS OF ANNUAL WEEDS IN THE UNITED KINGDOM

Until early 1981 there had been just one case of herbicide-resistance in the United Kingdom - resistance to paraquat in a population of Poa annua (LeBaron & Gressel, 1982). However during 1981 and 1982 there has been a substantial increase in reports of triazine-resistance (mainly simazine-resistance) in S. vulgaris (and in one population of P. annua) in plant nurseries, orchards, soft fruit and hops. Some of these putative cases of resistance have been confirmed at Liverpool University using a comparative test of seedling growth in compost, which has simazine added or not (see Holliday and Putwain, 1977).

Populations suspected to be simazine-resistant were compared with known resistant and susceptible populations using concentrations of simazine up to 5 kg ha^{-1} ai. To date eight populations of S. vulgaris and one population of P. annua are known to be highly resistant to simazine. The locations of these populations are shown in Table 1.

SOME GENERAL CHARACTERISTICS OF TRIAZINE-RESISTANT WEEDS IN THE U.K.

1) Pattern of appearance of triazine-resistance

Simazine-resistant populations of S. vulgaris have occurred in widely scattered locations in the United Kingdom within a few months of each other. Apparently there have been several independently selected mutants for simazine-resistance and there are probably several different resistant strains present in the United Kingdom. Downwind spread of resistant S. vulgaris from its original site to an adjacent (within 1.0 kilometer) plant nursery has been recorded at one location. Local dispersal of resistance genes in wind dispersed seed or widespread dispersal in containerised nursery stock will always be likely to occur. Appropriate precautions will have to be taken by growers if they are not to become exporters of resistance genes.

2) Frequency of resistance genes in unselected populations

To date triazine-resistance has only appeared in a small proportion of the plant species which have been exposed to triazine herbicides. If we consider common weed species such as S. vulgaris or P. annua, only a minute proportion of the total number of populations which have been regularly exposed to triazine herbicides, have actually evolved resistance thus far. This suggests that major genetic variation for resistance is very rare in most species and populations; so rare that we know

Table 1

Occurrence of triazine-resistant weeds in the United Kingdom

Location	Species	Simazine rate*	Crop	Year resistance confirmed	Land area infested
Hilderstone, Stone, Staffordshire.	*S. vulgaris*	5.0	Tree nursery stock	1981	25 ha
Moddeshall, Stone, Staffordshire.	*S. vulgaris*	5.0	Plant nursery stock	1981	17 ha
Shugborough, Staffordshire.	*S. vulgaris*	5.0	Strawberries	1981	8 ha
Maidstone, Kent.	*S. vulgaris*	5.0	Apples, hops	1981	80 ha (approx.)
Wolverhampton, West Midlands.	*S. vulgaris*	5.0	Apples, blackcurrants	1981	80 ha (approx.)
Staplehurst, Kent.	*S. vulgaris*	5.0	Vines	1982	-
Market Drayton, Shropshire.	*S. vulgaris*	5.0	Plant nursery stock	1982	2 ha
Hilderstone, Stone, Staffordshire.	*P. annua*	1.5	Tree nursery stock	1982	-

* Rate of addition of simazine in seedling test, kg ha^{-1}

very little about the amount of major genetic variation for triazine-resistance which exists in natural populations before exposure to herbicides. Holliday and Putwain (1980) screened for resistance to simazine, 46 populations of *S. vulgaris*, collected from several different fruit farming locations in England, but they found no evidence of resistance. This was a small sample but Sykes (1980) screened for resistance to simazine, many species of *Brassica*, more than 100 cultivars and more than 50,000 individual seedlings and none showed major gene resistance to simazine. Even more cultivars of soybean (2700) (Anderson, 1969) were screened for resistance to atrazine, but none were found. In the United Kingdom alone, the number of seedlings of *S. vulgaris* or *P. annua* which are being unintentionally screened each year by commercial growers for resistance to triazines, must be tens if not hundreds of millions, and then just for two species. Genes for triazine-resistance must be absent in many natural populations of weed species. This argument could be extended to other herbicides which have been used extensively and regularly in crop monocultures, where in general herbicide-resistance has not become a problem. However in these other cases, lack of selection pressure may be equally important in causing a low rate of evolution of resistance. This is because other herbicides have not been used so continuously as simazine and are generally less persistent.

3) Maternal inheritance

Maternal inheritance of triazine resistance has been demonstrated in several weed species (e.g. *P. annua*, *Amarathus* spp, *Brassica campestris*) and is apparently the most common form of inheritance of resistance (see Scott and Putwain, 1981). However this is not always so, since susceptibility to atrazine in maize is inherited by a single allele with Mendelian segregation (Grogan et al, 1963). Since the mechanism of action of triazine herbicides resides in chloroplast thylakoid membranes, it seems probable that chloroplast DNA may be involved in maternal inheritance of resistance. Nevertheless, involvement of nuclear DNA cannot be entirely ruled out, since inheritance of many chloroplast proteins is controlled by nuclear DNA (Kung, 1977).

A most important consequence of maternal inheritance of triazine resistance is that the frequency of resistant phenotypes in a population will build up very rapidly from a low initial frequency. There will be no outcrossing with susceptible phenotypes growing in adjacent areas not treated with the herbicide. Thus the increase in the frequency of resistant phenotypes will be even more rapid than if there was simple Mendelian inheritance with a dominant allele for resistance. Just a few seeds/fruits dispersed naturally or dispersed by farm machinery or in nursery stock transferred to another plant nursery would be sufficient to initiate a rapid build up of resistance.

IS EVOLUTION OF RESISTANCE AN INEVITABLE CONSEQUENCE OF HERBICIDE USE?

The significance of mode of action of herbicides

The major mode of action of triazine involves herbicide binding on to chloroplast thylakoid membranes at a specific site. Herbicides with highly site specific modes of action (e.g. phenyl urea herbicides) are more likely to be inactivated by a single gene mutation (which induces a small change at the site-of-action) than herbicides which cause more general disruption of plant growth and development such as 2,4-D and other growth regulator types of herbicide which have multiple sites of activity (e.g. benzoic acid herbicides such as dicamba and 2,3,6-TBA).

The evidence for this argument is not entirely supportive since artificial selection for resistance to 2,4-D has resulted in resistant cell cultures of carrot (Gressel, 1979) and Nicotiana sylvestris (Zenk, 1974). However in neither case was it shown that the resistant phenotype was expressed in intact plants directly derived from the cell cultures.

Good supportive evidence stems from parallel evolution of resistance to crop fungicides. The resistance problem is relatively recent because until the late 1960's the main disease control agents were sulphur and copper compounds, dithiocarbamates and phthalimides which all have multi-site modes of action. Pyrimidines and benzimiclazoles have more specific sites of action and as a result many strains of fungi resistant to these groups of chemicals have appeared. The same principles may also apply to herbicides although fortunately evolution in higher plants proceeds rather more slowly than in fungi.

Rates of evolution of resistance

(a) Naturally occurring variability in resistance

The amount of genetic variability for resistance in natural populations of weed species on which herbicide selection can act, will limit the rate of evolution of resistance. Evidence of the presence of major genes for resistance to herbicides shows that these are quite rare in natural populations of weed species. Resistance genes are probably widely distributed and scattered, in a similar way to the occurrence of genes for warfarin-resistance in rats (Rattus norvegicus). The pattern of occurrence of triazine-resistance in North America and Western Europe, with widely scattered foci of resistance and at least initially, a few years between occurrences of resistance in any particular species, tends to confirm this conclusion.

Polygenically controlled variation in sensitivity to herbicides in weeds has been reported several times and may involve differences between populations or clones (see Holliday and Putwain, 1980). A more or less continuous pattern of variation has been found. Deliberate recurrent selection of P. annua by metoxuron (Grignac, 1975) and of Sinapis alba by simazine (Sykes, 1980) are the only examples of exploitation of variability in resistance (in intact plants) which resulted in the progressive build up of herbicide resistance. In the case of P. annua, 24 cycles of selection resulted in a comparatively resistant population. In natural populations it is not at all clear whether a gradual build up in tolerance in a population (Holliday and Putwain, 1980) would eventually develop into full resistance as a result of progressive genetic recombination and selection.

(b) Mutation frequency for resistance

The geographical occurrence and distribution of resistance genes will be dependent on spontaneous mutation frequency. This will probably vary from one species to another and between geographically separated populations of the same species as it does in plant pathogens. Probably resistance genes do not occur at all in some weed species or do not occur for specific chemicals. There is a close analogy with some protectant fungicides where genes for resistance have not been found.

At the present time, there is no data concerning spontaneous mutation rates for herbicide-resistance in natural populations of weeds. Thus it is only possible to guess at likely mutation frequencies to within one or two orders of magnitude, using mutation frequencies for other plant characters and fungicide resistance as guidelines. Chaleff and Parsons (1979) estimated a frequency of about 1 in 10^5 for resistance to picloram in tobacco cell cultures, but this could be an overestimate since several loci could have independently mutated. A mutation frequency of about 1 in 10^7 or 10^8 would seem a more realistic estimate for most weed species/chemicals. Frequencies such as these should produce several individuals with a resistant genotype (for major crop/herbicide combinations) somewhere in the U.K. each year.

(c) Selection pressure

Selection is of vital importance in determining the rate of evolution of herbicide resistance. Two factors are important. These are selection intensity and duration. Selection intensity is the effectiveness of a herbicide, measured as percent mortality of the weed population (or reduction in weed seed output per unit area). Duration of selection is the period of time during which selection acts. The product of selection intensity and duration over a whole growing season is the ultimate measure of selection pressure.

Many pre- and post-emergence herbicides used in arable and horticultural crops kill weeds very effectively and percent kill around 90-95 can regularly be achieved. Clearly many herbicides are only commercially successful if they achieve relatively high mortality of weed populations. Nevertheless suppression of growth and reproduction of weeds by crop competition may frequently be an important adjunct to any chemical control measure (e.g. Cussans, 1970), which actually reinforces selection by the herbicide.

Residual herbicides used in orchards, tree nurseries, industrial sites etc., may be equally effective in causing plant mortality. This is illustrated by the work of Holliday (1978) who examined the population dynamics of S. vulgaris in two blackcurrant plantations. In one simazine was applied each year in early March, in the other weed control was only by cultural means in autumn and early spring. The seasonal pattern of germination of S. vulgaris (groundsel) and the survival of individuals which ultimately reproduced, was measured over a period of two years. Between March and June, use of simazine in blackcurrants caused greater than 99% mortality of groundsel seedlings whereas during the same period in the plantation without simazine, there was relatively good survival of seedlings.

Selection intensity was very high and the duration of selection was more than three months. However even with a residual herbicide such as simazine, many seedlings which emerged in late summer and autumn escaped selection by the herbicide. Only approximately 36% of seedlings which emerged during the growing season were exposed to phytotoxic concentrations of simazine.

Many post-emergence herbicides with mainly foliar uptake and relatively short soil activity will provide a considerably shorter duration of selection. Thus the real selection pressure caused by many herbicides may be rather less than one might presume from the apparently high mortality often observed.

The process of selection may be complicated further by the use of more than one herbicide on a single crop. For example, an autumn pre-emergence herbicide in winter cereals may be followed by a spring post-emergence herbicide. In orchards and bush fruits where simazine is routinely applied in late winter/early spring, paraquat, glyphosate or dichlobenil may be used during the summer months to clear patches of perennial weed species or late germinated annual weeds. Any newly arisen resistant individuals would probably be eliminated by these subsequent herbicide treatments. The rate of evolution of resistance in annual weed populations would therefore be reduced.

Repeated intensive use of herbicides such as paraquat and glyphosate in horticulture may provide a relatively long duration of selection. If successive cohorts of seedlings which arise during a growing season are regularly exposed to one or other of these herbicides, this could well provide a high overall selection pressure.

Herbicide selection pressure clearly depends on the type of herbicide, type of crop and spray programme. There appear to be two situations which provide the maximum probability of evolution of herbicide resistance;

a) Recurrent application of residual herbicides in a perennial crop (e.g. orchards, bush fruit, tree nurseries) with major reliance on one chemical. Simazine, being a low cost product, is the prime example.

b) Recurrent intensive application of herbicides designed to kill the majority of weeds present. In this category, the best candidates are paraquat and glyphosate when used in plant nurseries or industrial areas. Predictions are given in table 2 as to the crop/herbicide/weed species combinations where evolution of resistance is most likely to occur. The predictions are based on probable selection pressures in the presence of the herbicides coupled with a knowledge of the occurrence of genetic variation in resistance to the chemicals in crop or weed species.

STRATEGIES FOR AVOIDING EVOLUTION OF HERBICIDE RESISTANT WEED POPULATIONS

There are various theoretical strategies for avoiding evolution of herbicide resistance. Not all the strategies are feasible, practical or economically viable for particular schemes of crop management or particular weed problems. Individual growers and MAFF advisory officers must decide which strategies, if any, are appropriate for their own particular circumstances. Suggested strategies are as follows;

a) Increase crop rotation. Additional break-crops which utilise completely different herbicides would reduce the rate of evolution for resistance (see Gressel, 1982). This may not be economically feasible for growers with a commitment to recurrent cereals and is impossible for fruit growers, plant nurserymen etc.

b) Use herbicide mixtures more frequently or use two or more herbicides on the

Table 2

Combinations of herbicide and weed species where evolution of resistance may occur

Chemical	Species	Situation	Comments
Paraquat	Poa annua other annual weed species?	intensive horticultural use	genetic variation in paraquat resistance occurs in P. annua
Glyphosate	Poa annua other annual weed species?	intensive horticultural use	-
Glyphosate	Agropyron repens	preharvest use in cereals	possible increase in the frequency of tolerant clones
Urea herbicides particularly chlortoluron/ isoproturon	Alopecurus myosuroides	cereal monoculture	a major gene for chlortoluran resistance occurs in wheat. A. myosuroides is a genetically variable species
Simazine	Stellaria media Chenopodium album Capsella bursa-pastoris	orchards, bush fruits plant nurseries	genes for resistance occur in Stellaria and Chenopodium in continental Europe

same crop at different times. However the two herbicides should be of completely different mode of action. Evolution of resistance to dissimilar chemicals should be slower. For purely practical reasons this approach already happens in for example, winter cereals where autumn application is sometimes followed by spring application of a different chemical.

c) Do not use one chemical recurrently in the same fields. This applies particularly to orchards, bush fruits, plant nurseries etc. Rotation of herbicides by switching to alternative chemicals every two or three years would delay the onset of resistance. There would probably be an economic penalty since alternative herbicides would often cost more.

d) Do not use herbicides which have a specific site of activity in the plant. The assumption is that resistant populations would be more likely to evolve in response to such chemicals. However growers have to use the most effective and low-cost chemicals whatever their mode of action, so that this approach is not generally feasible.

e) If possible, avoid intensive and recurrent use of herbicides where genetic variability to the particular chemical is known to occur in a crop or weed species. For example genetic variability for paraquat resistance occurs in Lolium perenne and P. annua, why not in other grass species? Likewise major gene resistance to chlortoluron occurs in wheat. Such genes may also occur in a genetically variable grass such as Alopecurus myosuroides.

f) If it is not possible to avoid a programme vulnerable to development of resistance, growers should be constantly vigilant. When a patch of a particular weed species is not controlled by a chemical which has been effective at the same site in previous years and is effective at adjacent sites in the same year, the patch should be killed with another chemical before seed dispersal occurs. Alternatively if the same chemical fails to control the same weed species in two successive growing seasons when the chemical was previously effective, resistance may be reasonably suspected. Growers should contact their local ADAS advisor sooner rather than later. A few growers with simazine resistant groundsel sat on the problem for 18 months before informing their local horticultural advisory officer. The sooner a resistant population is contained, the less likely is it to spread to other growers.

It is interesting to note that rotation of crops would be the only practicable possibility when only one herbicide is available to cope with a particular weed problem. Fortunately this is an increasingly rare situation. Is this all an argument for retaining certain "outclassed" chemicals even though they may seem less cost-effective?

GROWERS TACTICS FOR COPING WITH RESISTANCE - IS ERADICATION POSSIBLE?

Once a herbicide-resistant weed population has become established, the grower is obviously faced with the problem of how to cope with it. Is total eradication of resistant populations a feasible and sensible approach to attempt? In most situations probably not for the following reasons;

a) Triazine resistant weeds are occurring with increasing frequency in the United Kingdom and are becoming quite common in Western Europe and North America. A general policy of attempted eradication is unlikely to succeed when new resistant populations continue to appear frequently.

b) Once a grower has realised that his crop has become infested by a herbicide-resistant weed, it will probably be too late to respond with eradicative measures since at least one, and probably more, generations of seed will have been widely dispersed into soil seed reserves. For example, species of *Amaranthus* and *Chenopodium* (known to be triazine-resistant) have considerable innate seed dormancy so that viable herbicide resistant seed will remain for many years at a relatively low frequency even when a grower switches to other herbicides. The build up of a resistant population from a low initial frequency of resistant phenotypes can be very rapid. For example, K.R. Scott (pers. comm.) found that the frequency of resistant phenotypes in a population of *S. vulgaris* increased from 2% to more than 98% in two growing seasons where simazine was applied once annually in spring. The same arguments apply to simazine resistant *S. vulgaris* and *P. annua* in the United Kingdom, even though innate dormancy is low in these two species, a small proportion of dispersed seed is held in soil seed reserves in a state of enforced dormancy and will remain viable for several years.

With most crops infested with herbicide resistant weeds, the only realistic option is long term containment of the herbicide resistant population by spraying a mixture of herbicides or switching to alternative herbicides. In the absence of the herbicide to which resistance originally evolved, resistant phenotypes are generally less fit (in terms of survivorship and reproduction) than susceptible types. For example the fitness of a Cheshire population simazine resistant *S. vulgaris* is 0.8 relative to a susceptible Cheshire population (K.R. Scott, pers. comm.). Thus with alternative herbicides, simazine resistant phenotypes of *S. vulgaris* will fall to a low frequency in the population after a few years.

Since triazine resistant populations of *S. vulgaris* (and to a much lesser extent, *P. annua*) are the main current problem in the United Kingdom, options for coping with these species are discussed hereafter.

1) Treatment with paraquat. Attempts have been made to kill simazine resistant S. vulgaris with repeated applications of paraquat. This financially expensive short term expediency has sometimes been coupled with even more expensive hand weeding. Use of paraquat is not a suitable long term option. During the spring and summer paraquat can only be used as a directed spray in orchards, some linedout nursery stock, and some bush fruit. Obviously it will be of no use in a crop such as strawberries. Unless a grower is extremely efficient in spraying all resistant plants before seed dispersal occurs, a paraquat treatment will simply clear existing vegetation and create an environment highly suitable for germination and establishment of new seedling populations, as soon as there has been adequate rainfall.

2) Grub out stock and sow down to grass. If a grass ley were sown and maintained on the resistant weed area for 4-5 years, complete eradication of triazine-resistant S. vulgaris might be achieved. This option would usually be impracticable and economically disastrous.

3) Containment of the resistant weed population with alternative residual herbicides or with a mixture of for example, simazine for general weed control plus an additional herbicide to control resistant groundsel or annual meadow grass. The objective would be to control triazine resistant species together with other species which were previously controlled just by the application of simazine. Ideally an alternative herbicide should have a long period of residual phytotoxicity.

Propyzamide would be an appropriate chemical for control of simazine-resistant P. annua in orchards, bush fruit and plant nurseries. A general low-cost weed control programme could be maintained with the general use of simazine, with propyzamide as an added cost. In plant nurseries, preliminary field experiments carried out by ADAS during 1982 indicate that napropamide might be an appropriate chemical which provides good residual control of triazine-resistant S. vulgaris (This is not a specific recommendation).

In the United States of America, napropamide in combination with oxadiazon has proved effective for control of triazine-resistant S. vulgaris. This combination may be appropriate for use in orchards, vineyards and plant nurseries. Oxyfluorfen is another chemical which could be used for control of triazine-resistant S. vulgaris in conifer nurseries. Further experimentation obviously will be required to establish which chemicals will combine good general annual weed control and a good residual life. Certain chemicals may need to be registered for use in new crop situations.

4) As an adjunct to containment of resistant weeds with chemical control measures. It will also be necessary for growers to take special precautions not to allow resistant seed to be exported to other trade growers via containerised stock, attached to bare rooted stock or even by pick-your-own members of the public. Clearly a resistant strain could spread quite rapidly via this route. Unless growers take sensible precautions they could establish an unfortunate reputation in the trade.

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REFERENCES

Anderson, R.N. (1969). A search for atrazine resistance in soybeans. Abstracts Meeting of the Weed Science Society of America, 157.

Chalef, R.S.; Parsons, M.F. (1979). Direct selection in vitro for herbicide-resistant mutants of Nicotiana tabacum. Proceedings of the National Academy of Sciences, U.S.A., 75, 5104-5107.

Cussans, G.W. (1970). A study of the competition between Agropyron repens (L) Beauv. and spring sown barley, wheat and field beans. Proceedings 10th British Weed Control Conference, 3, 337-343.

Gressel, J. (1979). Genetic herbicide resistance; projections on appearance in weeds and breeding for it in crops, In Plant Regulation and World Agriculture. Ed. T.K. Scott. Plenum Press.

Grignac, P. (1975). Deviation genetique de biotypes de plantes adventices sous l'action repetee de traitements herbicides, In Proceedings European Weed Research Society, Symposium on the Status and Control of Grassweeds in Europe, 340-348.

Holliday, R.J. (1978). The potential for evolution of herbicide resistance in annual weeds. Ph.D. thesis, University of Liverpool.

Holliday, R.J.; Putwain, P.D. (1977). Evolution of resistance to simazine in Senecio vulgaris L. Weed Research, 17, 291-296.

Holliday, R.J.; Putwain, P.D. (1980). Evolution of herbicide resistance in Senecio vulgaris: variation in susceptibility to simazine between and within populations. Journal of Applied Ecology, 17, 779-791.

Kung, S.D. (1977). Expression of chloroplast genomes in higher plants. Annual Review of Plant Physiology, 28, 401-437.

LeBaron, H.M.; Gressel, J. (1982). Herbicide Resistance in Plants - 401 pp. John Wiley, New York.

Scott, K.R.; Putwain, P.D. (1981). Maternal inheritance of simazine resistance in a population of Senecio vulgaris. Weed Research, 21, 137-140.

Sykes, S.R. (1980). Selection for herbicide resistance in cruciferous crop plants. Ph.D. thesis, University of Liverpool.

Zenk, M.H. (1974). Haploids in physiological and biochemical research - In Haploids in Higher Plants - Advances and Potential, M.J. Kasha (Ed.), University of Guelph, Guelph, Ontario, 339-354.

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WEEDS AND CROP YIELD

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Summary. The effects of weeds on crop yield are viewed in the context of weed control strategies and the economics of weed control. The mechanisms of crop-weed competition are considered, and the importance of below-ground competition for nutrients, and possibly for water, is stressed. Relationships between weed content and crop yield are reviewed. Relationships between weed density and crop yield show the greatest promise, for devising control strategies, but the effects of other factors, e.g. sowing date and fertilizer use, must also be defined. There is need for a more rational approach to defining weed control strategies, where the immediate effects of weeds on crop yield, and the direct effects of herbicides on crop yield, are considered. In addition, the long-term effects of herbicides and management on the population dynamics of weeds must be considered.

INTRODUCTION

Weed control and weed science have come of age in the past decade. The proliferation of herbicides and spraying equipment, on the one hand, and increasing knowledge of weed biology, weed control methods and the effects of weeds on crops, on the other hand, have given farmers and their advisors an unprecedented opportunity to limit, or even to eliminate, the effects of weeds on crop yield. This is therefore an opportune time to evaluate the present state of the art of weed control. I use the term "art", as opposed to "science", advisedly, for reasons that will soon become apparent.

In any evaluation it is important, first of all, to define the criteria by which success may be judged. All too often, in weed studies, the criterion of success is destruction of weeds, but this is only a means to an end, which is to increase crop yield or quality and so to increase profitability.

Previously, the importance of economic considerations was frequently forgotten in the obsession to destroy weeds, but there is now evidence of a return to more rational considerations.

The situation in weed control is quite analagous to warfare. A decisive battle has been won and the enemy (weeds) have been routed, though small groups have adopted guerilla tactics (fresh outbreaks of "old" weeds, herbicide resistant races, "new" weeds). These outbreaks can usually be controlled by moving up reserve forces or using new weapons (new herbicides), but total elimination is extremely costly and is economically justified only in special cases (e.g. in seed production). In most cases, containment is all that can be profitably achieved (Attwood, 1980). In weed control, the cost of control must be set against any benefits accrued, bearing in mind the opportunity cost of control measures, i.e. what else might be done with the money to increase crop yields (e.g. increased fertilizer use, increased use of fungicides, improved sowing or harvesting machinery).

At present, about £130 million is spent annually on herbicides in U.K.. The cost of herbicides applied to winter cereals averages about £80 ha^{-1} or about 30% of the variable costs (J. Elliott, pers.comm.). Is this expenditure economically justified? Could some of the cost be saved to pay for other inputs or to increase profits directly? How might optimum strategies for weed control be devised? These are obviously important questions. They are also complex questions, which I cannot hope to cover adequately in the available space. My intention here is to set the scene, and then to deal in more detail with one important aspect, i.e. the effect of weeds on crop yield.

In Fig.1. I have tried to show diagramatically the rational processes leading to the definition of optimum weed control strategies, and to the economic evaluation of these strategies. Such rational sequences are never followed at present, mainly because much of the essential information is not available. Instead, most weed control is carried out pragmatically, or, at best, empirically. The results of weed control are not often measured in terms of crop yield and rarely, if ever, in terms of economic analysis. When yield data have been collated (e.g. Friesen & Shebeski, 1960; Evans, 1969; Niemann, 1980; Wallgren, 1980) the results are depressing: in each of these cases the average yield response to herbicides was 2% or less, though the control of annual grass weeds (Baldwin, 1979) seems to have given greater responses (10-20%). Some of these values may be overestimated, since the trials tend to be carried out on heavily weed-infested crops; there is need for surveys of responses under typical farm conditions, instead of in trials. In addition, there is obviously a need to analyse the reasons for these rather poor responses to herbicides. More information is needed on the effects of weeds on crops (line 1, Fig.1), on how effective herbicides are in controlling weeds (line iii) and how damaging herbicides are to crops (line iv).

The present information concerning the main components in Fig.1. is very patchy. In general, the amount of information decreases sharply from left to right. It also varies vertically; there is extensive information on the effect of herbicide on weeds (iii), very much less on the effect of weeds on crops (i), even less on the effects of crops on weeds (ii), and little quantitative data on the effects of herbicides on crops (iv) (though see Munro et al., 1973). This balance of information bears little relationship to its probable importance in determining the economic outcome of using a particular weed control strategy.

My remit here is to deal with the effects of weeds on crops (i) and, to a lesser extent, the reverse effect (ii). These effects, and especially those of weeds on crops, are likely to greatly affect the outcome of weed control strategies, though this is not to belittle the importance of other components (e.g. the effect of herbicides on crops).

CROP-WEED COMPETITION

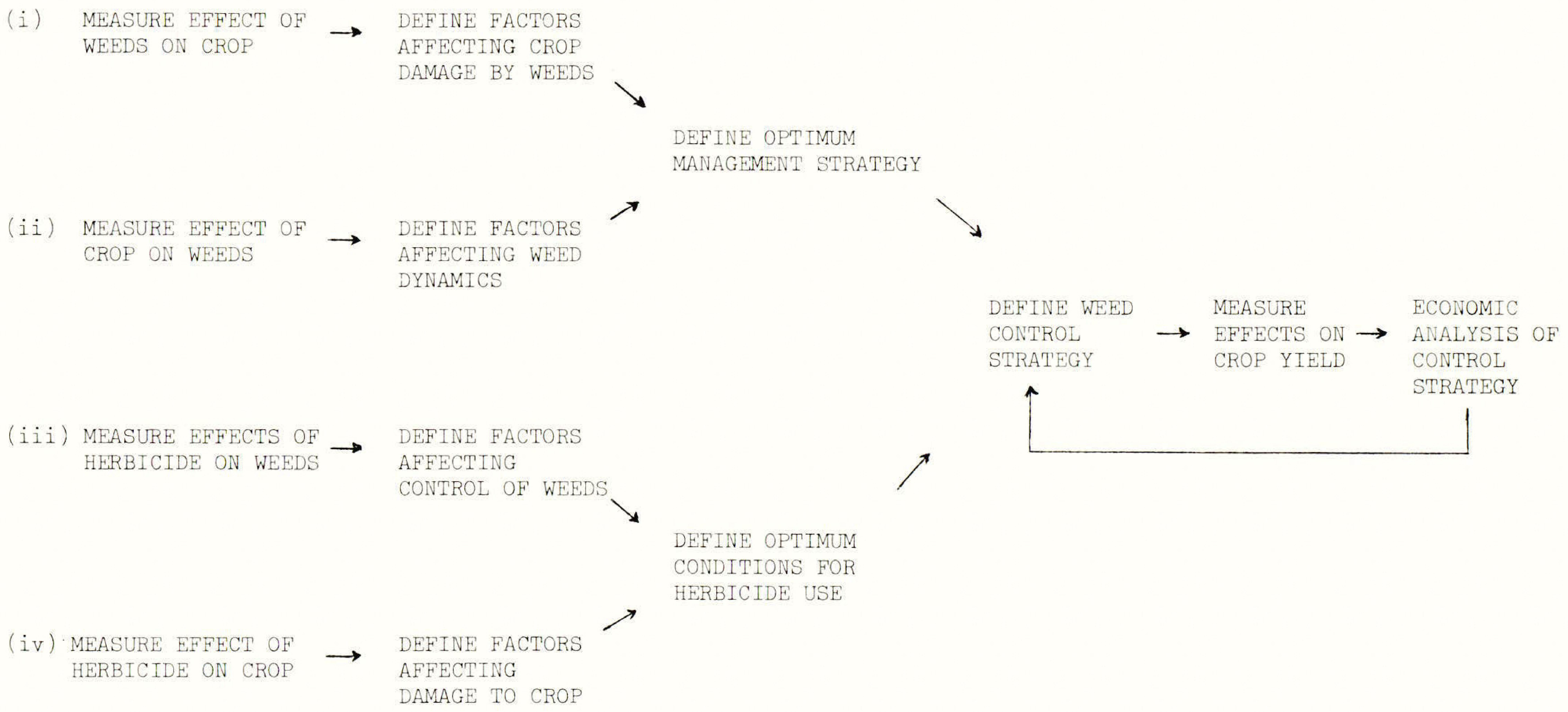
Crops and weeds use the same environmental resources (light, water and mineral nutrients), and therefore compete for those resources when they are in insufficient supply. As a result, the presence of weeds in the crop usually reduces the availability of light, water or nutrients to the crop and so reduces its yield.

In a given situation, with a given supply of environmental resources, it should be possible to relate the yield of the crop to that of the weed, providing the resources are fully used, and the crop and weed compete fully, i.e. the Relative Yield Total (de Wit & Vanden Bergh, 1965) is 1.0. In these circumstances, the total yield of the crop at various levels of weed infestation, when plotted against the total yield of weeds (Fig.2a), lies along a line joining the point for the pure stand of the crop and the point for the pure stand of the weeds (Hawton, 1980). Scott and Wilkockson (1976) have found that the relationship holds for different weed species sown at different times.

It would be agronomically more useful to have a similar relationship between grain yield and weed content. In theory, the relationship should also be linear as long as weed infestation does not affect the harvest index (i.e. the ratio of grain to total shoot weight). Unfortunately this is not the case, harvest index is commonly reduced by weed competition. In any case, even this relationship has limited agronomic value, because it is specific to a given set of conditions, and so

Fig. 1

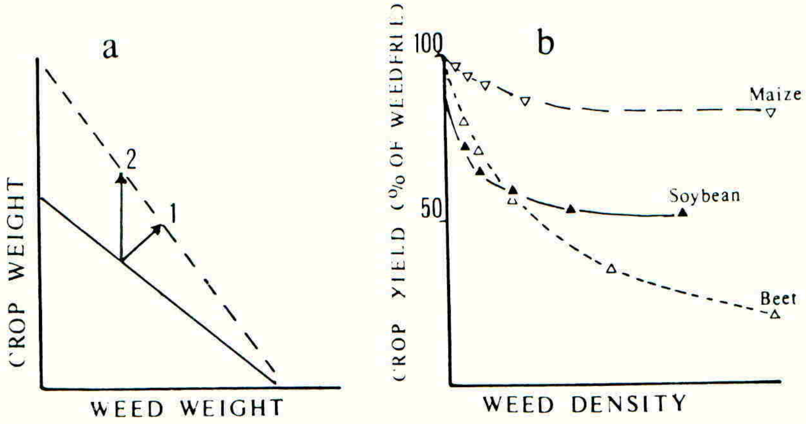
Pathway analysis for defining and assessing weed control strategies



has no predictive value, and because it is based on weed yield, which can only be determined after harvest.

Fig. 2

Relationships between crop performance and weed abundance. (a) Relationships between shoot weights of crop and weed (after Hawton, 1980); the dashed line represents a second set of conditions, giving greater crop growth (see text). (b) Relationships between crop yield and weed density (after Zimdahl, 1980).



WEED DENSITY AND CROP YIELD

Relationships between crop yield and weed density are much more useful than those involving weed yield, since they should allow predictions about subsequent yield loss to be made early in crop development. This, in turn, should allow decisions to be made on the likely effects and value of weed control.

Many attempts have been made to relate crop loss to weed density. Most of the examples cited in the review by Zimdahl (1980), and the extensive survey by Dew (1972), show relationships like those in Fig.2b. Increasing weed densities have their greatest effect on crop yield at low weed densities (Fig.2b). This is a rather sobering thought for farmers! Above a certain density, increasing weed density has less effect though, in many cases, crop yield continues to decline with increasing weed density.

The actual form of the relationship between weed density and crop yield depends on the crop species, the weed species and on environmental and management conditions. For example, crop species differ markedly in their response to a given weed density (Dew, 1972); barley is more affected than rye, wheat, oats and flax in that order (Zimdahl, 1980). There are also differences in susceptibility to weed damage within crop species; for example, there are differences between cultivars of wheat (Reeves & Brooke, 1978), soybean (Burnside, 1972), rice (Kawano et al., 1974), or maize (Staniforth, 1961). We know far too little about the competitive ability of crop cultivars in Britain.

Different weed species, at a given density, affect crop yield to different extents. For example, fat hen (*Chenopodium album*) reduced sugar beet yield more than did knotgrass (*Polygonum aviculare*) and scentless mayweed (*Tripleurospermum inodora*) (Scott & Willockson, 1976); Zimdahl (1980) lists field brome (*Bromus arvensis*), wild oats (*Avena fatua*) and penny cress (*Thlaspi arvense*) as being even more competitive than fat hen. No adequate studies seem to have been made to find whether the order of competitive ability for weed species is the same regardless of the crop in which they occur. Some differences might be expected; for example, there are almost certainly differences between autumn-sown and spring-sown crops, and there may be more subtle differences.

Obviously, any estimate of yield loss due to weeds would need to take into account not only weed density, but weed species, crop species, crop density and probably crop cultivar. To make the situation even more complex, it would seem that environmental conditions and crop management also affect the amount of weed damage; these factors will be considered later, after considering how weeds harm crops.

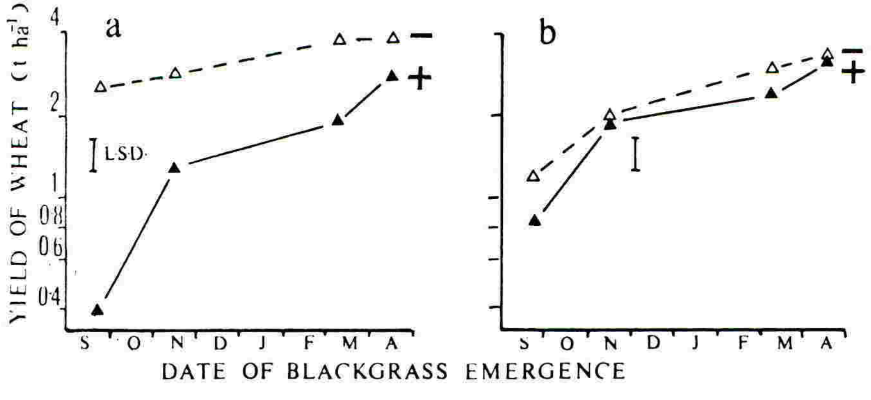
MECHANISMS OF CROP-WEED COMPETITION

The shading of crops by weeds is so apparent that it is often assumed that competition for light is most important (Donald, 1963). However, there is now considerable evidence, both direct and indirect, that competition between species below ground (i.e. for mineral nutrients and water) is normally greater than competition above ground for light (Snaydon & Harris, 1981). Most of this evidence is for competition between grassland species; surprisingly few studies have been made on crop-weed competition. In particular, very few direct comparisons of above-ground and below-ground competition have been made, for example, by using above-ground and below-ground partitions (Donald, 1958). However, Aspinall (1960) showed that below-ground competition between white persicaria (*Polygonum lapathifolium*) and barley was more important than above-ground competition, especially in the earlier stages of growth. A recent study (Fig.3) showed that below-ground competition from blackgrass (*Alopecurus myosuroides*) had a much greater effect on winter wheat than did above-ground competition, particularly when blackgrass germinated early. Above-ground competition, i.e. shading, had little effect on wheat yield and was not affected by the germination date of blackgrass.

It seems likely that the effects of root competition will be influenced by the availability of the resources for which competition occurs, especially nitrogen and perhaps water; these factors will therefore affect the extent to which weeds reduce crop yield (see below), and may give us the opportunity to alleviate the effects of competition.

Fig. 3

The effect of competition from blackgrass, emerging at different times, on the grain yield of winter wheat. (a) The effect of root competition; (b) the effect of shoot competition (+ = with competition; - = without competition)



FACTORS AFFECTING CROP LOSS

The effects of weed density, weed species and crop species in determining crop yield losses have already been briefly considered. The rather fragmentary evidence indicates that, with a given weed species in a particular crop, the effect of weed density on crop yield is extremely variable, but it is extremely difficult to isolate the factors responsible for this variation. However, if weed control is to be put on a sound rational and financial basis, these factors will have to be identified and their effects measured quantitatively.

It is fairly easy to list the probable factors, but much more difficult to assess their relative importance. Both the time of sowing of the crop and the time of germination of the weed are likely to determine the extent to which weeds reduce crop yield. In addition, such factors as crop density and the supply of limiting factors (e.g. mineral nutrients and water) are likely to affect competition between crops and weeds, and so affect crop yield.

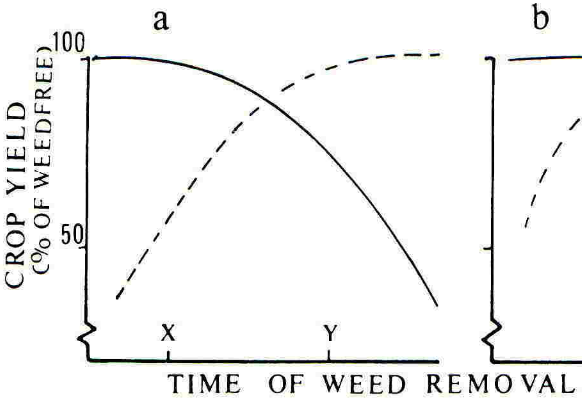
Time of establishment

We might expect that earlier establishment would confer competitive advantage on weed or crop; several studies have shown this. The effect of the germination date of blackgrass on winter wheat is clearly seen in Fig. 3; the earlier the germination date the greater the effect of the weed. In that study, the sowing date of wheat was also varied (October or November). Late sowing reduced wheat yields by about 15% but, more important, late sowing of wheat doubled the yield loss caused by blackgrass, regardless of the date of blackgrass germination.

The greater effect of early weed germination on crop yield would be expected, firstly because the weed is present in the crop for a longer time but also, more importantly, because early germinating weeds are likely to be much more competitive. These two factors together account for the results that have commonly been found when weeds have either been initially allowed to grow, but then removed at different times after crop emergence (continuous lines, Fig.4 a&b), or have been continuously removed at first, but subsequently allowed to grow unrestricted, after different times following crop emergence (dashed line, Fig.4 a&b).

Fig. 4

Schematic relationship between time of weed removal and crop yield. Weeds initially allowed to develop and then removed (—), or weeds initially removed but then allowed to develop (--) (after Nieto et al., 1968)



Initial infestations of weeds usually have little effect upon final crop yield (continuous line, Fig.4 a&b), provided they are removed before appreciable competition occurs, i.e. before time x (Fig.4 a&b). However, if they are left too long, they become highly competitive and use resources (mineral nutrients, water and light) which would otherwise be used by the crop, so that crop yield suffers. Conversely, if the crop is kept free of weeds for a sufficiently long time after sowing (dashed line, Fig.4 a&b), there is usually little effect on crop yield, because weeds which establish after time y (Fig.4) are very poor competitors.

Various people, following Nieto *et al*. (1968), have referred to a "critical period for competition". However, there is confusion as to what this period is, since Nieto *et al*. (1968) did not clearly define it. Some (e.g. Zimdahl, 1980) have used the term to describe the initial period (up to time x on the continuous line (Fig.4), when weeds have little effect on the crop as long as they are subsequently removed. Others (e.g. Roberts, 1976) have defined the period between x and y as the critical period; this is the period when too late removal of weeds (i.e. after time x (on the continuous line)) or too early relaxation of weed control (i.e. before time y on the dashed line) both lead to crop losses. On balance, it seems safer not to use the term "critical period", though the basic information obtained from studies of the timing of weed removal (Fig.4) certainly serves a useful purpose. The results from removing weeds at various times after sowing (dashed line) have particular relevance for post-emergence herbicides, though the results need to be viewed in the light of any constraints set by the need to use the herbicide at particular stages of development of the crop. Similarly, measurements of the effect of maintaining an initially weed-free crop (continuous line) have particular relevance to pre-emergence herbicides. Here the crucial factor is the period over which the herbicide remains active. So far, the available information on the time of weed removal, and information on the period of herbicide activity (both on weeds and crops), does not seem to have been fully integrated and assessed.

Fertilizer supply

Since competition for mineral nutrients seems to be one of the most important features of the effect of weeds on crops (see above), fertilizer supply should greatly affect crop-weed interactions. Most of the available evidence confirms this, though the effects are not all consistent.

One possible effect of applying a fertilizer would be to prevent a given nutrient from being a limiting factor, and so prevent or reduce competition for that factor. As a result, the yield of both the crop and the weed should increase, and the weed would usually have less effect on crop yield. This is most clearly seen in studies of the effects of N fertilizer on competition between maize and foxtail (*Setaria* spp.) by Nieto & Staniforth (1961). Other studies (e.g. Nakoneshny & Frieson, 1961) have also shown that applications of N reduced the effects of weeds on crop yield, though without information on the yield of weeds. These incomplete results might have alternative interpretations; for example, applications of N fertilizer might reduce the competitive ability of weeds, so that weed yield decreased as crop yield increased. In some circumstances, fertilizer applications can increase the competitive ability of weeds, relative to the crop, and so increase the effect of weeds on crop yield. This has been demonstrated, for example, with Italian ryegrass (*Lolium multiflorum*) growing as a weed in winter wheat (Appleby *et al*., 1976).

The various ways in which factors, such as fertilizer supply, can affect crop-weed interactions is perhaps best seen by reference to the relationship between crop yield and weed yield, already considered (Fig.2a). Any practice which does not affect the performance of the weed-free crops or the pure weed stand, e.g. removal of weeds at different times or to different extents, will simply increase the yield of the crop as the weed yield decreases, or vice versa, so the various points will lie along a straight line (solid line). Some other practices may affect the weed-free crop yield (e.g. early sowing of the crop in spring), but not affect weed yield. A new relationship now exists (dotted line). The yield of weed infested crops under the new set of conditions will depend upon how the conditions affect the relative competitive ability of crop and weed. If the competitive ability of the crop, relative to the weed, is constant (arrow 1), then the yield of the crop will increase slightly. If the competitive ability of the crop increases (arrow 3) then crop yield will increase more. Other practices may increase the pure stand yield of the weed but not the crop (line not shown) or may affect the competitive ability of the weed. These practices will tend to reduce crop yield.

The available results indicate that we cannot assume that additional fertilizer will always reduce the effects of weeds. The effect apparently depends on the relative response of crop and weed to the fertilizer. There is obviously scope to study the way in which N, and perhaps other nutrients (e.g. P and K) influence the relationship between weed density and crop yield. Such information will be important in trying to predict crop losses, and so in determining the potential economic outcome of weed control.

Crop density

Several studies (e.g. Nieto & Staniforth, 1961; Gruenhagen & Nalewaja, 1969; Felton, 1976) have shown that increasing crop density reduced crop losses caused by weeds. Many other studies (see Zimdahl, 1980) have demonstrated that greater crop density controls weeds, though without necessarily increasing crop yield. The value of manipulating crop density, as a means of weed control, will depend upon whether the crop density required to control weeds is within the range giving greatest yield of the crop. Once again, the paucity of information prevents any general conclusions being drawn, though, at present, it seems that the choice of crop density is determined more by maximisation of yield than by considerations of weed control.

FACTORS AFFECTING WEED PERFORMANCE

In general, the growth of weeds is only important in so far as it affects crop yield, crop quality or ease of harvesting (Elliott, 1980),though some might consider weed growth unsightly and argue for cosmetic weed control. Increased reproductive capacity (seed production and vegetative spread) must also be considered, since this determines the future abundance of weeds.

Each of the factors so far considered in the context of crop yield will also affect weed growth and reproductive capacity. Usually those conditions which lead to greater crop growth and yield will lead to reduced weed growth and seed production (or vegetative spread). However, in some cases improved conditions, such as increased N supply (Nieto & Staniforth, 1961), increase the growth of both crop and weed (see above).

Although the effects of various factors on weed reproduction (seed production or vegetative spread) are so important, in the long-term, relatively few studies have been made on effects of various treatments on weed reproduction. It is not safe to assume that seed production is proportional to total yield of a weed. For example, competition with wheat reduced the seed yield of blackgrass more than total shoot yield, so that the "harvest index" of blackgrass (i.e. seed weight/total shoot weight) was reduced from 0.34 to 0.26.

Information on the seed production of weeds will be increasingly important if predictions are to be made concerning the effect of control measures on subsequent weed density, i.e. the population dynamics of weeds. Weed control strategies will need to be based on predictions of the likely build-up of weed infestations, when, for example, herbicides are witheld for one or two years, or if other management strategies (e.g. straw-burning, rotation or occasional deep ploughing) are used (e.g. Moss, 1980; Wilson, 1981; Jarvis & Clapp, 1981).

CONCLUSIONS

Crop-weed interactions are only one component, though an important component, in defining weed control strategies (Fig.1). If herbicides are to be used profitably then their use must be based upon a sound knowledge of likely crop losses, at given weed densities and other specified conditions.

In future, it may be possible to estimate the effect of a herbicide on crop yield by taking into account: (a) the expected effect of the herbicide on the weed content of the crop, (b) the expected effect of this reduction in weed content on crop yield, (c) the direct effect of the herbicide on the crop. At the moment, each of these relationships is so uncertain that it would be simpler, and probably more accurate, to predict the effect of herbicides on crop yield directly from results of trials (e.g. Friesen & Shebaski, 1960; Evans, 1969; Baldwin, 1979; Neimann,1980; Wallgren, 1980). However, the empirical results so far provide only inaccurate predictions of yield increases, because they do not take into account weed density. Each of these reviews gives little or no information on the weed densities occurring in the trials, and make no attempt to measure the response to herbicide at various levels of weed infestation. In general, the trials tend to be carried out in crops with heavy weed infestations, and the results probably over-estimate the response likely to occur at lower infestations.

In the short term, the most useful criterion for deciding whether to spray would be threshold densities, based on an economic analysis of many trials. In the longer term, empirical relationships between yield response to herbicide treatment and weed density may be refined by taking into account other factors, e.g. fertilizer use, crop sowing date, and timing of herbicide applications. Large numbers of trials have been carried out; for example, Baldwin (1977) cites 108 trials on wild oat control, and involving yield evaluation, carried out by ADAS alone. Some attempt must now be made to detect statistical patterns in yield response, especially in relation to weed density and other major controlling factors.

Although empirical relationships between yield response to herbicides and weed density and other factors may prove useful in the short term, they are not a substitute for analysing the components of the response to herbicides. More information is still required on the effects of weeds on crop yield, and on the factors which affect this response. More information is also required on the direct effects of herbicides on the yield of weed-free crops.

The practice of weed control has advanced spectacularly over the past three decades and, in general, the changing pattern of the weed flora (Cussons, 1976; Chancellor, 1979) only presents temporary problems for weed scientists. The real problem in weed control, it seems to me, is in deriving weed control strategies that are economically justifiable. We have the necessary armoury of chemicals and management techniques, the problem is to know when and how to use them in the most profitable manner. This is a question which has so far only been superficially considered by weed scientists, who have generally been more concerned with means, rather than ends.

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REFERENCES

Appleby, A.P.; Beson, P.D.; Colbert, D.R. (1976). Winter wheat yield reduction from interference by Italian ryegrass. Agronomy Journal, 68, 463-466.

Attwood, P.J. (1980). Strategic planning for weed control: eradication or containment. Proceedings 1980 British Crop Protection Conference - Weeds, 833-838.

Baldwin, J.H. (1979). The chemical control of wild oats and blackgrass. A.D.A.S. Quarterly Review, 33, 69-101.

Burnside, O.C. (1972). Tolerance of soybean cultivars to weed competition and herbicides. Weed Science, 20, 254-297.

Chancellor, R.J. (1979). The long-term effects of herbicides on weed populations. Annals of Applied Biology, 91, 141-144.

Cussans, G.W. (1976). The influence of changing husbandry on weeds and weed control in arable crops. Proceedings of the British Crop Protection Conference - Weeds, 1001-1008.

Dew, D.A. (1972). An index of competition for estimating crop loss due to weeds. Canadian Journal of Plant Science, 52, 921-927.

De Wit, C.T.; Van den Burgh, J.P. (1965). Competition between herbage plants. Netherlands Journal of Agricultural Science, 13, 212-221.

Donald, C.M. (1958). The interaction of competition for light and nutrients. Australian Journal of Agricultural Research, 9, 421-435.

Donald, C.M. (1963). Competition among crops and pasture plants. Advances in Agronomy, 15, 1-118.

Elliott, J. (1980). The economic significance of weeds in harvesting grain. Proceedings of the British Crop Protection Conference - Weeds. 787-797.

Evans, S.A. (1969). Spraying of cereals for the control of weeds. Experimental Husbandry, 18, 102-109.

Felton, W.L. (1976). The influence of row spacing and plant population on the effect of weed competition in soybeans. Australian Journal of Experimental Agriculture and Animal Husbandry, 16, 926-931.

Friesen, G.; Shebeski, L.H. (1960). Economic losses caused by weed competition in Manitoba grain fields. I. Canadian Journal of Plant Science, 40, 457-467.

Gruenhagen, R.D.; Nalewaja, J.D. (1969). Competition between flax and wild buckwheat. Weed Science, 17, 380-384.

Hawton, D. (1980). Yield effects of herbicides on competition between crops and weed communities. Australian Journal of Agricultural Research, 31, 1075-1081.

Jarvis, R.H.; Clapp, J.T. (1981). Effect of different herbicides and cropping sequences on the population dynamics of wild oats. Experimental Husbandry, 37, 133-143.

Kawano, K.; Gonzalez, H.; Lucene, M. (1974). Intraspecific competition with weeds and spacing response in rice. Crop Science, 14, 841-845.

Moss, S.R. (1980). Some effects of burning cereal straw on seed viability, seedling establishment and control of Alopecurus myosuroides. Weed Research, 20, 271-276.

Munro, I.A.; Hubbard, K.R.; Scourey, L.R. (1973). Spraying winter wheat with herbicides. Experimental Husbandry, 23, 82-85.

Nakoneshny, N.; Friesen, G. (1961). The influence of commercial fertilizer treatment on weed competition in spring-sown wheat. Canadian Journal of Plant Science, 41, 231-238.

Niemann, P. (1980). Evaluation of long-term trials for control of weeds in spring barley (1970-9). Gesunde Pflanzen, 32, 239-240.

Nieto, J.H.; Brondo, M.A.; Gonzalez, J.T. (1968). Critical periods of the crop growth cycle for competition from weeds. Pest Articles and News Summaries, 14, 159-166.

Nieto, J.H.; Staniforth, D.W. (1961). Corn-foxtail competition under various production conditions. Agronomy Journal, 53, 1-5.

Reeves, T.G.; Brooke, H.D. (1978). The effect of genotype and phenotype on the competition between wheat and annual ryegrass. Proceedings of 6th Asian-Pacific Weed Conference, 166-171.

Roberts, H.A. (1976). Weed competition in vegetable crops. Annals of Applied Biology, 83, 321-324.

Scott, R.K.; Willockson, S.J. (1976). Weed biology and the growth of sugar beet. Annals of Applied Biology, 83, 331-335.

Snaydon, R.W.; Harris, P.M. (1981). Interactions below ground - the use of nutrients and water. In: International Workshop on Intercropping, 188-201. ICRISAT, Hyderabad.

Staniforth, D.W. (1961). Responses of corn hybrids to yellow foxtail competition. Weeds, 9, 132-136.

Wallgren, B. (1950). Weed control in spring cereals. 21st Swedish Weed Conference, 18-23.

Wilson, B.J. (1981). The influence of reduced cultivation and direct drilling on the long-term decline of a population of *Avena fatua* in spring barley. Weed Research, 21, 23-28.

Zimdahl, R.L. (1980). Weed-crop competition - a review. International Plant Protection Centre, Corvallis.

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BIOLOGICAL AND FINANCIAL CRITERIA OF LONG-TERM CONTROL STRATEGIES FOR ANNUAL WEEDS

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Summary. The alternative strategies for the control of annual weeds are either eradication or containment, but eradication is difficult mainly because of the longevity of weed seeds in the soil. From studies of buried seeds of *Chenopodium album* and *Avena fatua*, germination appeared to be the principal means of seed loss, but losses were limited by seed dormancy. Because of its dormancy characteristics, the depletion of *C. album* is slow, except at the soil surface. This, combined with a considerable possibility of influx of new seeds, precludes eradication and containment is necessary. Depletion of *A. fatua*, although slow, was uniform throughout the profile, and was limited by low soil nitrate levels. More rapid depletion of *A. fatua* is likely if nitrate is applied in the early spring. Since this weed can be removed by hand at low population levels and the potential influx is comparatively low, eradication seems both practicable and economic. *Avena fatua, Chenopodium album,* population dynamics, economics, germination, dormancy.

INTRODUCTION

The long-term control strategy for any weed problem will either aim for eradication, or where this is impossible, containment at some specified level. The choice depends on the answers to two questions:

1. Is eradication biologically feasible? A positive answer leading to the further question:
2. Is eradication economic relative to containment?

Annual weeds are necessarily short-lived plants, and eradication would be simple but for the longevity of their seeds in the soil. The feasibility of eradication thus depends on two aspects of their seed population dynamics:

1. the rate of decline of the existing seed population in the soil, offset by
2. the rate of influx of new seeds.

Since seed populations of many annual weeds decline slowly (typically by 25 to 30% p.a., Roberts and Dawkins, 1967), and the potential seed influx is often large (Sagar and Mortimer, 1976), the feasibility of containment, let alone eradication, may be questioned. Nevertheless, the influx of seeds of most species can be restricted by herbicides, and the main biological constraint is depletion of the existing seed population.

The biology of depletion, that is to say, the means - germination, loss of viability, or predation - and environmental effects on these, is thus the background to control strategies for annual weeds. Current evidence suggests that germination is the principal means of seed loss though few detailed studies are available (Roberts 1972; Murdoch, 1982). To provide information relevant to the development of weed control strategies, seeds of *Avena fatua* and *Chenopodium album* were buried in soil, and recovered at intervals to assess both the losses and the viability and dormancy of surviving seeds. Laboratory experiments were also carried out to investigate dormancy characteristics.

MATERIALS AND METHODS

Seeds of *C. album* were collected from fallow ground at Sonning Farm, Berkshire in September, 1974, and *A. fatua* from an infestation in barley at Blewbury, Oxfordshire in August, 1974. The seeds were spread out to dry on a greenhouse bench for less than three weeks, rubbed gently, cleaned and then stored prior to use in polythene or glass containers at c. -20°C, (a procedure which maintains both viability and dormancy).

Before burying, seeds were placed in terylene mesh packets (of approximately 275 µm aperture size and 55% open area) with 2.65 g of *C. album* in 140 x 64 mm packets and 24.42 g of *A. fatua* in 140 x 140 mm packets.

In December 1974, packets were placed at the soil surface or buried at depths of 25, 75 and 230 mm in a stoneless, loamy coarse sand at Sonning, Berkshire. Packets were usually recovered in daylight (*A. fatua*) or at night (*C. album*), wrapped immediately in aluminium foil and transferred to the laboratory where the initial processing was carried out in a dark room equipped with Ilford green safelights. The minimum definition of germination in dormancy/viability tests and also for *in situ* germination at recovery, was 2 mm radicle emergence.

A similar trial was established in December, 1975 using fewer seeds, the packet sizes being reduced in proportion. Seeds placed at the surface in 1974 were predated and predators were excluded in 1975 by enclosing the surface packets in three staggered layers of 13 mm mesh galvanized wire netting.

RESULTS

Depletion of *C. album* seeds after 19 months was greatest near the soil surface, with losses of 68%, 47% 39% and 36% at 0, 25, 75 and 230 mm respectively. The largest numbers of seedlings were also observed in packets recovered from the surface, but *in situ* germination could not be measured due to the deterioration of seedlings.

The dormancy of these seeds prior to burial was such that substantial germination only occurred if alternating temperatures, light and potassium nitrate were all available (table 1), a requirement which could only be satisfied at the soil surface. Nevertheless, when samples were recovered after 12 to 19 months at the soil surface, only about 50% of the undecayed, and hence apparently viable seeds would germinate *in vitro* in these conditions. Transferring the ungerminated seeds to 0.01 M gibberellic acid had little effect.

Table 1

Percentage germiantion of fresh seed of *Chenopodium album* after six weeks in different treatments. Each value is the mean of four replicates of 50 seeds.

Temperature	Dark		Light	
	Water	Nitrate*	Water	Nitrate*
30°C	1.0	2.0	1.0	4.5
30°/10°C (16h/8h)	2.0	45.0	8.0	99.0

* 0.01 M potassium nitrate

Seeds of *A. fatua* placed at the soil surface in 1974 were predated and very few full seeds remained in any packet after April or May, 1975. Most seeds were retained in the packets, which had been torn open and the caryopses were extracted leaving the pales intact. In one unpredated packet retrieved in March, 1975, 992 full seeds (84%) were recovered and a further 51 (4.3%) had germinated. Germination was similar in two predated packets recovered at the same time, but only 85 and 41 full seeds were found. Undetected germination or loss of viability could not account for losses exceeding 80%, and this was confirmed in the second experiment when predators were excluded. Without predation, only 24% of *A. fatua* seeds were lost from the soil surface over seven months, of which less than 2% appeared to have germinated, 12% were inviable, and the remaining 10% were empty seeds not otherwise accounted for.

By contrast, losses of buried seeds were largely through *in situ* germination, and after 19 months, the depletion was similar at each depth (figure 1). The losses between July, 1975 and July, 1976 were very low (figure 1) especially when compared with the germination of seeds retrieved from the field at the time when *in situ* germination was occurring (table 2). The data are not presented here but high germination was recorded for other samples retrieved between late October and late March. Samples retrieved during the summer gave low germination.

Extensive monitoring of the soil environment at each depth during these trials indicated that neither soil temperature, moisture or atmosphere (oxygen and carbon dioxide), nor the darkness of 25 to 230 mm (cf. table 2) were likely to limit *in situ* germination.

Fig. 1

Cumulative losses of *Avena fatua* seeds placed at different depths in the soil in December, 1974.
Values are means of three replicates and expressed as percentages of the initial number.

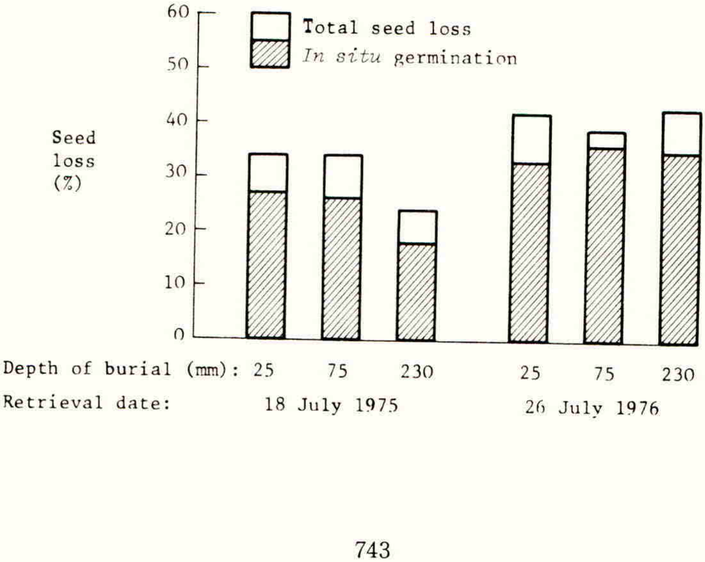


Table 2

Percentage germination of *Avena fatua* after c. 12 weeks in different treatments after retrieval from various depths in the soil. The seeds were buried in December, 1974 and recovered in February, 1976. Each value is the mean of three replicates of c. 70 seeds.

Depth	10°C				3°C	20°C
	Dark		Light		Dark	Dark
(mm)	Water	Nitrate*	Water	Nitrate*	Nitrate*	Nitrate*
25	1.3	29.1	0	14.2	47.3	0.5
75	2.4	36.6	1.7	10.7	57.5	0
230	15.5	55.1	5.6	26.3	78.0	0

* 0.01 M potassium nitrate

The germination of retrieved seeds *in vitro* was increased by nitrate levels of 0.01 M potassium nitrate (table 2), whereas the soil nitrate concentrations during this experiment were about 0.002 M at each depth. *In situ* germination was comparable to the germination of retrieved seeds in water (cf. figure 1, table 2), so the main limitation to germination in the field appeared to be the low concentration of nitrate in the soil water. This accords with the optima for fresh seed reported by Fykse, 1970, (0.03 M) and Murdoch, 1982, (0.01 M).

Over much longer periods of burial, this limiting effect of nitrate appeared to decline, and for seeds recovered on 1st March, 1979 (after 4.2 years), mean germination *in vitro* at 10°C in water with light was 39.8%, 52.0% and 69.6% after 2½ weeks for seeds retrieved from 25, 75 and 230 mm respectively.

DISCUSSION

The complex germination requirements described for *C. album* are typical of many annual weeds (Vincent and Roberts, 1977; Roberts, 1981), and make rapid depletion of seed populations unlikely except at the soil surface. However, the low germination of the apparently viable seeds which were recovered from the soil surface after 12 to 19 months suggests that substantial increases in the rate of depletion by the use of dormancy-breaking treatments may be difficult, and for example, with four cultivations per annum Roberts and Dawkins (1967) only increased depletion of *C. album* to 33% p.a. from 21% p.a. in undisturbed soil. Moreover, assuming 33% depletion p.a. and 100% efficient weed control, an initial population of 10 plants m^{-2} would take 23 years to drop to 10 plants ha^{-1}. It is not surprising, therefore, that elimination of annual weeds such as *C. album* has not been achieved after decades of herbicide use. Elimination is improbable because of seed survival in the soil, and only occasional omission or failure of herbicide control would be needed to replenish seed stocks.

The dormancy of *A. fatua* has different characteristics from *C. album* and this led to fairly uniform depletion through the soil profile for, unlike *C. album*, neither fluctuating temperatures nor light were required for germination *in vitro*. Depletion was nevertheless slow, and soil nitrate levels were apparently limiting. Several pieces of evidence supporting this role of nitrate are found in the literature.

The depletion of *A. fatua* reported here is compatible with the year to year variations and slow rate of decline (25% p.a.) observed in a ley pasture (Thurston, 1966), but contrasts with that for continuous spring barley cropping in both direct-drilled and ploughed land where the average annual seed losses were 94% and 87%

respectively during the second to fourth years of the trial (Wilson, 1981). Because of the germination characteristics of *A. fatua* it is not surprising that Wilson's results were largely independent of the degree of cultivation. It is interesting to note, however, that he always applied some nitrogen before the end of March (87 kg N ha^{-1} in the second and third years, 20 to 30 kg in the first and fourth, B. J. Wilson, personal communication), whereas Thurston only once applied nitrogen to her grass leys in the early spring (50 kg N ha^{-1} in the fifth year). While other differences between tilled soil and soil under ley cannot be excluded, nitrate does appear to limit depletion, and for example, up to fivefold increases in the emergence of *A. fatua* have been observed when nitrate fertilisers were applied to the soil in early Spring (Sexsmith and Pittman, 1963; Fay, 1975).

Since the amounts of nitrogen required may not be large (table 3), the present results together with Wilson's (1981) data suggest that seed populations of *A. fatua* decline rapidly given early spring applications of nitrogenous fertilisers (for example, in combine-drilled spring barley). *A. fatua* seeds are therefore potentially short-lived in the soil, suggesting that eradication is feasible; but is it an economic proposition?

Table 3

Nitrate fertiliser application giving 0.01 M nitrate in the top 230 mm of the profile at two soil moisture levels.

Soil moisture content %	Weight of soil to 230 mm* t ha^{-1}	Volume of soil water to 230 mm $\ell\ ha^{-1} (x\ 10^3)$	Existing soil nitrate$^{\phi}$ g ℓ^{-1}	Fertiliser application giving 0.01 M nitrate g $NO_3\ell^{-1}$	kg N ha^{-1}
15	3220	483	0.124	0.496	54
30	3220	966	0.124	0.496	108

* Assumes a bulk density of 1.4

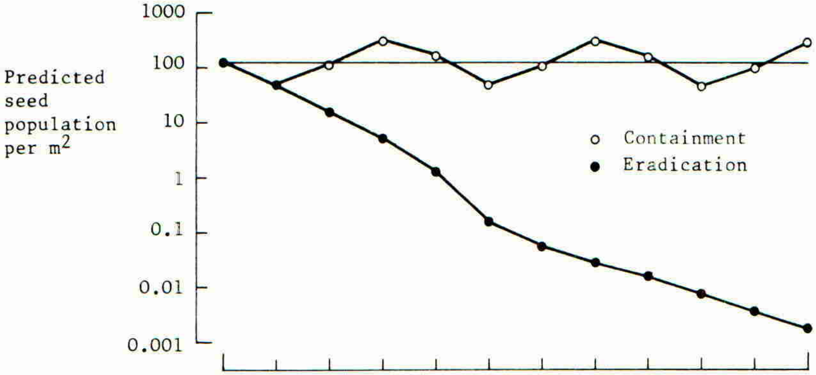
ϕ Assumes 0.002 M

Using population models to predict the consequences of different control strategies (cf. Cussans, 1980), a simple comparison of containment and eradication for *A. fatua* in spring barley is possible. The following assumptions are made here with all costings relating to the 1982 UK harvest.

1. Uncontrolled *A. fatua* plants each produce 45 seeds (cf. Wilson, Cussans and Ayres, 1974) of which less that 40% enter the soil (cf. Wilson, 1972). Of seeds entering the soil, 50% survive the first year of burial and 10% each subsequent year (Wilson, 1981). 12% of seeds in the soil give rise to seedlings in each crop (Cussans, 1976).
2. The application of herbicides for *A. fatua* costs £40 ha^{-1} for chemicals and £10 ha^{-1} for spraying (Nix, 1981).
3. Infestations < 1 plant per 30 m^2 are rogued, taking two man-hours per hectare (Anon, 1976) at a cost of £2.50 per hour (cf. Nix, 1981).
4. Fifteen *A. fatua* plants m^{-2} reduce crop yield by an amount equal in value to the cost of chemical control (£50 ha^{-1}, equivalent to 0.47 t ha^{-1} or 11% of a potential crop yield of 4.2 t ha^{-1} valued at £451 ha^{-1}, Nix, 1981; cf. Chancellor and Peters, 1976).
5. Chemical weed control is 95% efficient (cf. Chancellor and Peters, 1976) and a notional efficiency for roguing is 90%.
6. No allowances are made for the following: yield reductions caused by uncontrolled weeds or crop damage during spraying; the extra costs of harvesting and cleaning a weedy crop; the higher prices obtained for seed and malting barley; inflation; and the interest charges on any loans required.

Fig. 2

Predicted buried seed populations of *Avena fatua* in continuous spring barley for two long-term control strategies. The horizontal line denotes the economic threshold for the use of herbicides. The underlying assumptions are described in the text.



		1	2	3	4	5	6	7	8	9	10	11	12
Time (years):		1	2	3	4	5	6	7	8	9	10	11	12
Eradication	Spray	+	+	+	+	+	−	−	−	−	−	−	−
	Rogue	−	−	−	+	+	+	+	+	+	+	+	+
Containment	Spray	+	−	−	+	+	−	−	+	+	−	−	+
	Rogue	−	−	−	−	−	−	−	−	−	−	−	−
Cumulative costs (£ ha^{-1})	Eradication	50	100	150	205	260	265	270	275	280	285	290	295
	Containment	50	50	50	100	150	150	150	200	250	250	250	300

For a hypothetical initial infestation at the economic threshold for chemical control (15 plants m^{-2}, assumption (4) above), control would be justified in the first year regardless of strategy. The model shows that spraying for a further four consecutive years is predicted to reduce the infestation to a density at which roguing would be the only control needed (figure 2). The cumulative costs of the control measures for eradication and containment are predicted to be the same after approximately 12 years (£300 ha^{-1}). After the population is reduced to levels at which roguing only is required, the average annual savings on spraying costs alone, when adopting the eradication policy, would be about £20 ha^{-1} at 1981 prices. (On average, spraying in alternate years is required for containment (figure 2; cf. Selman, 1970). The actual savings will be reduced by the interest charges on any loans required; but on balance, the advantages of eradication will be much greater because of the following risks attached to the containment strategy:

1. The probable reduction in crop yields a) in those years when control would be uneconomical and b) due to weeds which survive control measures.
2. The costs of harvesting and cleaning weedy crops.
3. The unlikelihood of gaining quality premiums. For example, seed crops could never be grown.

It could be argued that it would be safer to use a containment policy which aimed at maintaining the infestation well below the short-term economic threshold for the use of herbicides - say at 1 to 2 plants m^{-2} (Selman,1970). This would decrease the risks mentioned above. However, such a containment policy would be initially more expensive, and would cost as much as an eradication policy after 8 years (instead of 12 years as calculated in the previous example).

Successful eradication will, however, depend on careful attention to one critical factor - minimising the influx of seeds during each year of the programme. Although the potential influx by *A. fatua* is much lower that that of most annual weeds (Sagar and Mortimer, 1976), uncontrolled infestations increase rapidly. Since seed populations decline approximately exponentially, a limited requirement for roguing must therefore be expected for some years. Moreover, the risks of introducing *A. fatua* seeds during drilling are well known, and while the use of HVS cereal seed is preferable, once a seed population has dropped to very low levels (0.1 seeds m^{-2}), crop seed must be obtained from crops known to be completely free of wild oats.

Eradication would thus appear to be both practical and economic for *A. fatua* in cropping systems involving early spring applications of nitrate fertilisers since *A. fatua* seeds should then be short-lived in the soil. Nevertheless, we would stress that these few simple calculations only show what might be achieved. The assumed values will vary and an analysis of the financial risks is needed before firm recommendations are possible.

A. fatua is, however, atypical. The seed populations of most annual weed species, typified by *C. album* decline more slowly and have a greater potential for increase. Hence, the elimination of important species such as *C. album* is currently impractical and the containment of these species at or below economic threshold levels is necessary.

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REFERENCES

Anon, 1976. Guide to wild oat roguing. UK Ministry of Agriculture, Fisheries and Food leaflet, 4pp.

Chancellor, R. J., Peters, N. C. B. (1976). Competition between wild oats and crops. In: Jones, D. P. (ed), *Wild Oats in World Agriculture*. London: Agricultural Research Council, pp. 99-112.

Cussans, G. W. (1976). Population studies. In: Jones, D. P. (ed), *Wild Oats in World Agriculture*. London: Agricultural Research Council, pp. 119-125.

Cussans, G. W. (1980). Strategic planning for weed control - a researcher's view. *Proceedings 1980 British Crop Protection Conference - Weeds*, 823-831.

Fay, P. K. (1975). The effect of germination stimulators on wild oat (*Avena fatua* L.) emergence in the field. *Proceedings North Central Weed Control Conference*, 30, 110-111.

Fykse, H. (1970). (Investigations into the germination, dormancy and longevity of wild oat seeds.) *Meldinger fra Norges Landbrukshøgskole*, 49 (15), 1-120.

Murdoch, A. J. (1982). Factors influencing the depletion of annual weed seeds in the soil. PhD Thesis, Reading University, 222pp.

Nix, J. (1981). *Farm Management Pocketbook*. 12th ed. Ashford: Wye College, 160pp.

Roberts, E. H. (1972). Dormancy: a factor affecting seed survival in the soil. In: Roberts, E. H. (ed), *Viability of Seeds*. London: Chapman and Hall, pp. 321-359.

Roberts, E. H. (1981). The interaction of environmental factors controlling loss of dormancy in seeds. *Annals of Applied Biology*, 98, 552-555.

Roberts, H. A., Dawkins, P. A. (1967). Effect of cultivation on the numbers of viable weed seeds in soil. *Weed Research*, 7, 290-301.

Sagar, G. R., Mortimer, A. M. (1976). An approach to the study of the population dynamics of plants with special reference to weeds. *Applied Biology*, 1, 1-47.

Selman, M. (1970). The population dynamics of *Avena fatua* (wild oats) in continuous spring barley. Desirable frequency of spraying with tri-allate. *Proceedings 10th British Weed Control Conference*, 1176-1188.

Sexsmith, J. J., Pittman, U. J. (1963). Effect of nitrogen fertilisers on germination and stand of wild oats. *Weeds*, 11, 99-101.

Thurston, J. M. (1966). Survival of seeds of wild oats (*Avena fatua* L. and *Avena ludoviciana* Dur.) and charlock (*Sinapis arvensis* L.) in soil under leys. *Weed Research*, 6, 67-80.

Vincent, E. M., Roberts, E. H. (1977). The interaction of light, nitrate and alternating temperature in promoting the germination of dormant seeds of common weed species. *Seed Science and Technology*, 5, 659-670.

Wilson, B. J. (1972). Studies of the fate of *Avena fatua* seeds on cereal stubble, as influenced by autumn treatment. *Proceedings 11th British Weed Control Conference*, 242-247.

Wilson, B. J. (1981). The influence of reduced cultivations and direct drilling on the long-term decline of a population of *Avena fatua* L. in spring barley. *Weed Research*, 21, 23-28.

Wilson, B. J., Cussans, G. W., Ayres, P. (1974). The effects of tri-allate and barban on the control of *Avena fatua* in spring barley, on the yield of barley and the presence of *A. fatua* seeds in the harvested grain. *Proceedings 12th British Weed Control Conference*, 25-32.

Proceedings 1982 British Crop Protection Conference - Weeds

MODELLING WILD OAT POPULATIONS AND THEIR CONTROL

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Summary. Demographic data are presented for populations of wild oats growing under various agricultural/experimental regimes. The data are used to demonstrate the application and utility of population modelling to annual weed problems.

INTRODUCTION

Wild oats, *Avena* spp., are still widespread and serious weeds of cereals despite the availability of effective selective herbicides and the accumulated knowledge of over a quarter of a century of research into their biology and control. Constructing a quantitative assessment of the damage function (Conway,1978) of wild oats to cereal crops demands knowledge of contributions to weed biomass, as affecting yield loss, matter other than grain (MOG) (Elliot,1980) and to seed return of the emergence groups (cohorts) of the weed within specific cropping regimes. For spring barley, Peters (1978) has shown that the contributions of early cohorts are of greatest significance to cereal yield loss and harvest index and it has been argued that at some levels of infestation the contribution of late emergence cohorts to population increase is minimal.

In order to plan cost-effective control strategies it is necessary to predict levels of infestation and the effects of various agricultural practices, including specific control measures, on population processes. In an earlier paper (Mortimer *et al.*,1980) a population model was introduced for a monocarpic annual species with discrete non-overlapping generations, such as *Avena fatua* L., in which the finite rate of change in the population size, λ, is given by:-

$$\lambda = N_{t+1} / N_t = \sum_{i=1}^{Z} k_i p_i F_i + b \qquad \text{...Equ. 1}$$

where N_t = total seed population at the start of season t

N_{t+1} = " " " " " " " " t+1

b = the proportion of the seed bank, N_t, remaining viable and dormant in the soil at the start of season t+1

and, for an individual time period, i, in a consecutive series (i = 1,2,3..Z).

k_i = the proportion of the seed bank, N_t, which emerges during the 'i'th period.

p_i = the probability of a plant which emerged in the 'i'th period surviving to set seed.

F_i = the mean seed number (per surviving plant) produced by plants which emerged in the 'i'th period.

In this paper we present a preliminary analysis of selected data from a study of the population dynamics of *Avena fatua* and explore the utility of the model.

METHOD

Data for the model were collected from a field experiment conducted on a sandy loam site with no history of wild oat infestations at the University of Liverpool Botanic Gardens, Ness, Wirral. The experiment comprised 180 2m x 2m plots arranged in a split plot, randomised block, factorial design (Table 1). Cultivation and management practices applied during the course of the experiment are given in Table 2. Emergence and death of wild oat plants in the central 1m x 1m area of each of the plots were monitored at fortnightly census through the growing season. At each census newly emerged plants were tagged with a number and the identity of dead plants recorded. At the harvest in August 1981 counts were made on each plant of tiller and panicle number, panicles being saved from plants occurring in treatments requiring no seed return. These were then air-dried and weighed. Spikelets were counted on a random sub-sample of 50 plants and linearly regressed against panicle weight. (Ln spikelet number = 0.75 Ln panicle weight (g.) + 4.33, $P \leq 0.01$). It was assumed that two viable seeds were produced per spikelet. Mean seed numbers obtained in this way for plants in different cohorts and from different treatment combinations were used to estimate seed return of *A. fatua* in those plots where shedding was allowed.

Table 1

a) The design of the field experiment

Factor	Levels	Description	Comments
Replication	3	1 2 3	Randomised blocks
Crop	3	Winter Wheat Spring Barley No-crop control	Main plots
Seed return in 1981	2	Prevented Allowed	Sub-plots
Sown density of wild oats (seeds m^{-2})	5	20 50 250 500 1000	Fully randomised sub-sub-plots
Application of post-emergence wild oat herbicide	2	- +	

b) A comparison of effective densities and sown densities

Sowing density seeds/m^2	Mean density at 1981 harvest plants/m^2	Range plants/m^2
20	1	
50	3	0 - 6
250	14	5 - 28
500	21	9 - 33
1000	42	17 - 80

Depletion of a buried seed population of *A. fatua* for September 1980 to November 1981 was estimated at 70% (b = 0.3) on the basis of an independent experiment in which seeds buried in nylon mesh bags were systematically removed and tested for viability by staining with a 1% tetrazolium chloride solution.

Table 2

Summary of husbandry operations

Date	Event
15. 9. 80	Seed bed preparations.
18. 9. 80	*A. fatua* seed broadcast
4.11. 80	Winter wheat (cv. Bounty) drilled at 0.16 tonnes ha^{-1} and plots fertilised *
24. 3. 81	Spring barley (cv. Athos) direct drilled at 0.16 tonnes ha^{-1} Spring barley and control plots fertilised *
24. 5. 81	Application of L-flamprop-isopropyl, 3 $l.ha^{-1}$ in 220 $l.ha^{-1}$ water
10. 8. to 30. 8. 81	Harvest
18.10. 81	Seed bed preparations
9.11. 81	Winter wheat (cv. Bounty) drilled at 0.16 tonnes ha^{-1} and plots fertilised *
25. 3. 82	Seed bed preparations for spring barley plots. Spring barley (cv. Athos) drilled at 0.16 tonnes ha^{-1} Spring barley and control plots fertilised *
26. 5. 82	Application of L-flamprop-isopropyl, 3 $l.ha^{-1}$ in 450 $l.ha^{-1}$ water
1. 8. to 14. 8. 82	Harvest

* Fertiliser rate : 0.38 tonnes ha^{-1} (20:8:13).

RESULTS AND DISCUSSION

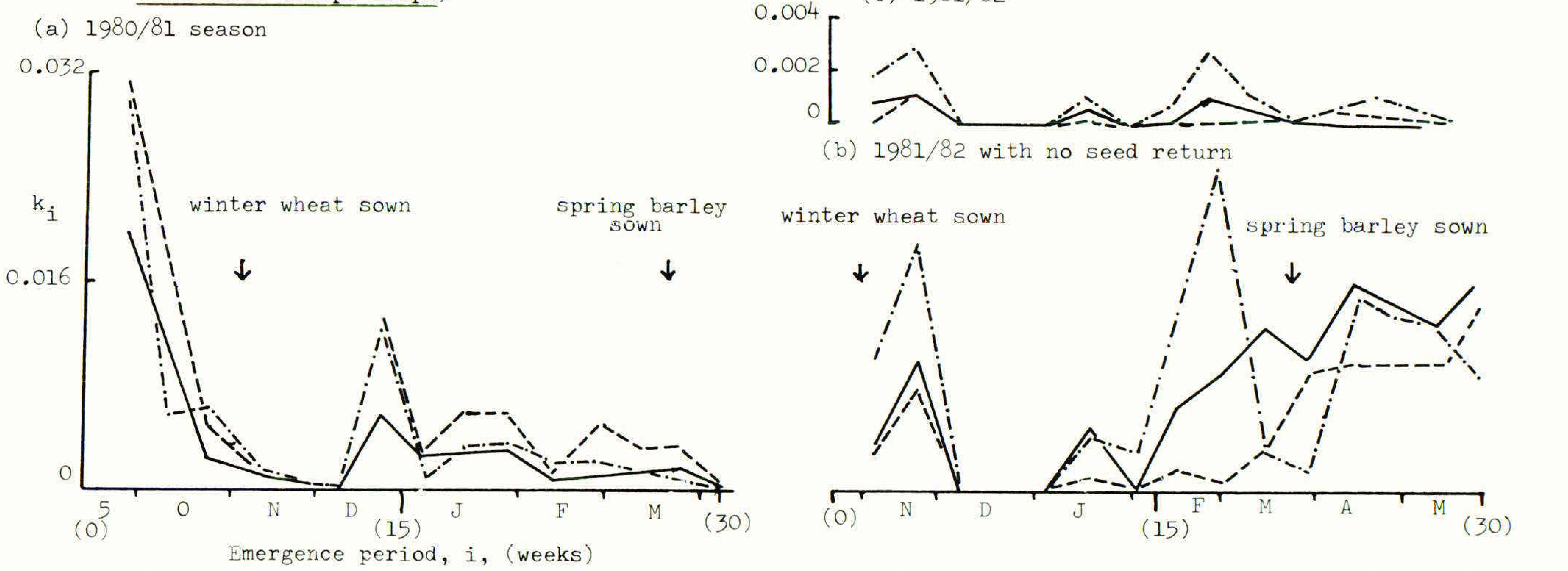
The proportions of wild oats (k_i) emerging in successive two-week time intervals are presented in Fig. 1. Although the overall pattern of emergence for both seasons follows the familiar autumn and spring flushes described originally by Thurston (1951) there was considerable variation both between and within seasons. We have not yet attempted a rigorous correlation of the emergence pattern with meteorological data for the site, but initial inspection suggests that within season variation reflects in part climatic control of germination. Thus in the 1980/81 season the second flush of emergence began during a warm period in December following ground frosts at the end of November, whilst in the next season snow throughout December delayed the onset of the spring flush until January.

The cumulative fraction of the seed bank emerging as seedlings throughout a season (Σk_i) is comparable to those reported by other workers (Thurston,1961: Tingey,1961)[1]. In 1980-81 this ranged between 4.7% in the uncropped plots to 8.8% in winter wheat. Spring emergence of wild oats in 1981 was generally highest in winter wheat sown plots, which for some emergence cohorts may be a consequence of soil perturbation during crop drilling and fertilising.

Seasonal differences in the proportions of seedlings emerging are more difficult to interpret. It was noticeable that emergence of wild oats in 1981 was not observed after early April contrasting with the findings in 1982. In plots sown with spring barley this could be attributable to the 1982 spring cultivations that were not practised in 1981. But the emergence functions for uncropped and barley sown plots show greater similarity within years than between years tending to discount this.

There are a number of possible explanations for increased emergence of wild oat seedlings from the original sowing, in the plots where 1981 seed return was prevented (Figs. 1b,1c). 1. dormancy of seed from the original sowing was less than that of newly shed seed, as found by Peters (1978) and others. (The former would

Fig. 1. k_i, The proportion of A. fatua seed giving rise to seedlings in successive 2-week intervals (meaned over treatments except crops)


(a) 1980/81 season

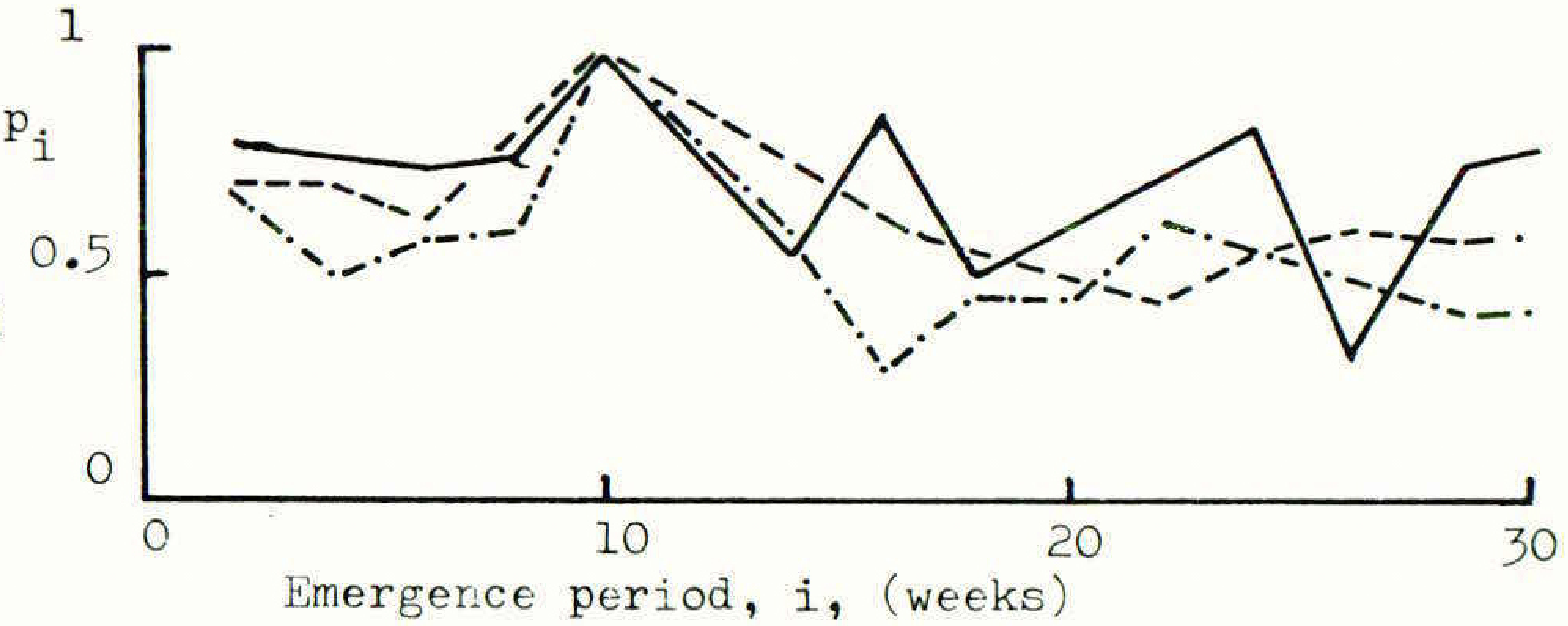
(c) 1981/82

(b) 1981/82 with no seed return

Key to figs.1 & 2

▬▬▬	Uncropped plots
– – –	Winter wheat
–·–·–	Spring barley

Fig. 2. p_i, the probability of A.fatua plants in successive cohorts surviving to set seed (meaned over treatments except crops)



form only a small fraction of the total seed bank in plots where shedding was allowed); 2. seed dispersal into the plots due to poor experimental practice,though this is highly unlikely; 3. the fraction of seed remaining in the soil,b,may have been underestimated.

Survivorship probabilities, p_i, for cohorts emerging throughout the 1980/81 season are presented in Fig.2. meaned over all treatments except crops. Survivorship was defined by the presence of any externally-visible green tissues in plants at the time of harvest. There was no evidence of density-dependent mortality at the range of densities which occurred in the first season(Table 1a). Neither was survivorship consistently reduced by the herbicide. Conditions of application in 1981,however, were not ideal, rain falling shortly after spraying.

Values of p_i were generally lowest in spring barley. This level of mortality probably resulted from direct drilling of the crop. Conversely survivorship was highest in the control plots where crop competition was absent. It should be noted however, that, in 1981, the barley was direct drilled and that a considerable proportion of autumn emerging wild oats survived in the crop in contrast to standard 'good farming' practice.

Mean seed fecundities, F_i, at the 1981 harvest are presented in Fig. 3 for three of the original sowing densities (250, 500, 1000 seeds m^{-2}) and over the range of treatments. In general, successive cohorts showed a progressive decline in fecundity though not in every case. F_i values are generally lowest in the highest density plots but at the two lower densities results are less consistent, possibly because the actual densities which occurred in the plots did not always exactly reflect the original sowing densities. In the absence of herbicide application seed production was least in winter wheat, F_i values being about half those in the control plots, but seed production was not suppressed in spring barley. Reductions in F_i resulting from herbicide application, however, were greatest in spring barley. Practically all the seed production in barley plots came from germination before crop sowing.

In the sprayed uncropped plots early emergence cohorts maintained fecundities of between c.400 and 3700 seeds plant^{-1}, illustrating the importance of crop competition to the efficacy of L-flamprop-isopropyl. The absence of any reduction by the herbicide in seed production of wild oats in winter wheat may have been due to poor spray penetration since the volume of water in which the herbicide was applied was standardised at the lower limit (220l.ha^{-1}) in 1981 across all crop treatments, but the winter wheat crop at the time of spraying was at the 3 node stage (Zadoks 33) and was quite dense. F_i values were in fact slightly higher, possibly due to an adverse effect of the herbicide on the crop leaf canopy, though no scorch was observed.

Application of the model (Equ. 1) provides estimates of the finite rate of change, λ, in populations under the various experimental regimes. These are shown for just one of the original sowing densities (500 seeds.m^{-2})(Figure 4)

The relative contributions to λ of successive cohorts are given by the individual $k_i p_i F_i$ terms in the model (Fig. 4). Cohorts which make the largest contributions to population growth, and are therefore prime targets for control, can be immediately identified. This is a particular strength of the model. Although contributions from some cohorts may be relatively small, they may still be significant to population growth, and a value for λ of one will, by definition, maintain the population size. The combined contributions of the seed bank (0.3) and just one or two of the later emerging groups of seedlings would maintain the population size in many of the cases. It has been argued (e.g. by Chancellor and Peters, 1972) that later emerging A. fatua plants can generally be ignored but whilst this might be true in spring sown cereals from a yield loss point of view if decline of the weed population over a number of years is an objective of control the contributions of all cohorts must be taken into account.

At present we are unable to present population growth rates and relative contributions in relation to groups of plants classified according to growth stages since at the time of writing fecundity data for the 1981/82 season, when growth stage data were collected, are not available. However the use of stage- as opposed

Fig. 3. F_i, the mean seed fecundity of *A. fatua* plants in successive cohorts (meaned over the 1981 shedding/non-shedding treatment)

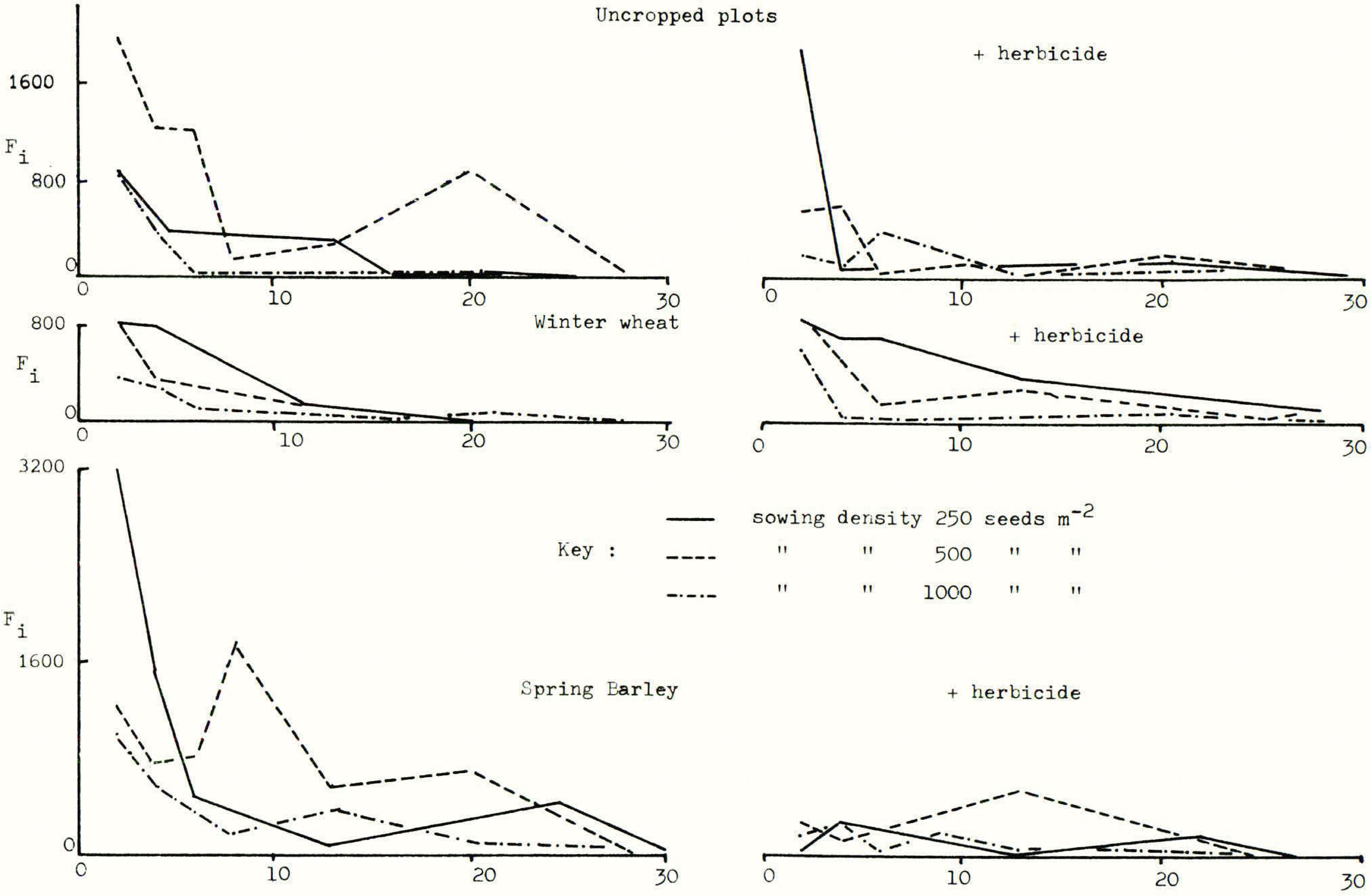
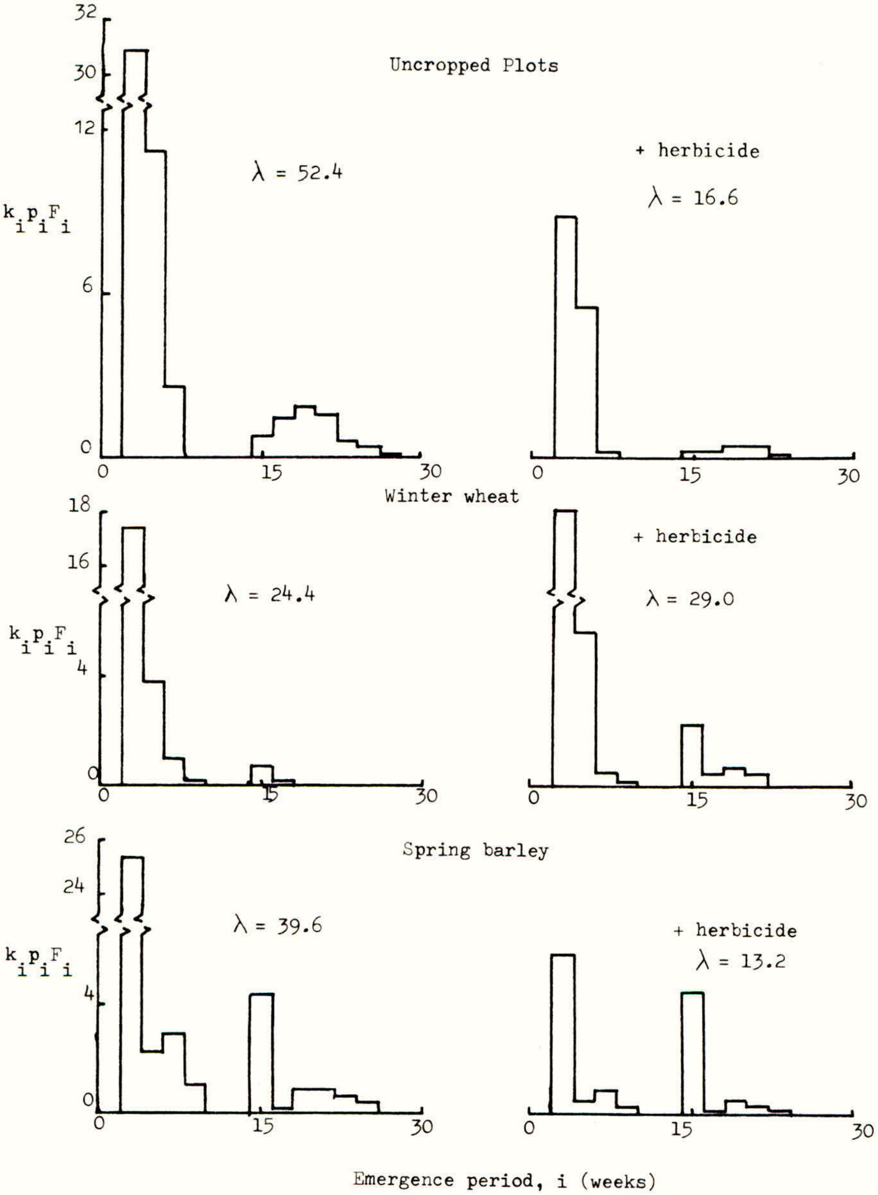


Fig.4. $k_i p_i F_i$, the relative contributions of cohorts of *A. fatua* plants to population growth (measured over the 1981 shedding/non shedding treatment).



to age-classes as units in the model has a number of theoretical and practical advantages; in one of the few comparisons which have been reported, a model based on growth stages of teasel, Dipsacus sylvestris Huds, was a better predictor of population behaviour than one based on age classes (Werner and Caswell, 1977). It seems more likely that a differential response to herbicide application would be shown by plants at different growth stages than by plants at the same growth stage, but not necessarily the same age. Whilst farmers are unlikely to be prepared to tag and monitor weed plants at regular intervals, it would not be unreasonable to take occasional censuses of growth stage in a few quadrats in an infested field.

We emphasise that this is a preliminary report using selected information from a large field experiment, and is intended to demonstrate the utility of a modelling approach in tackling weed problems. The data were characterised by quite high levels of variation, not least that inherent in populations of species such as A. fatua. Further analysis of the data may modify our estimates of various parameters but does not alter the principles or reduce the validity of the modelling approach, the value of which has been recognised for several years (Cussans, 1976).

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References

CHANCELLOR, R.J.and PETERS, N.C.B.(1972). Germination periodicity, plant survival and seed production in populations of Avena fatua L. growing in spring barley. Proceedings 11th British Weed Control Conference, 7-11.

CONWAY, G.(1976). Man versus pests. In Theoretical Ecology Principles and Applications, Ed. May, R. M., Blackwells.

CUSSANS, G.W.(1976). Population Studies. In Wild Oats in World Agriculture. Ed. Price-Jones, D. ARC London.

ELLIOTT, J.C.(1980). The economic significance of weeds in the harvesting of grain. Proceedings British Crop Protection Conference - Weeds 787-797.

MORTIMER, A.M., PUTWAIN, P.D., and McMAHON, D.J. (1978). A theoretical approach to the prediction of weed population sizes. Proceedings British Crop Protection Conference - Weeds.

MORTIMER, A.M., McMAHON, D.J., MANLOVE, R.J., and PUTWAIN, P.D. (1980). The prediction of weed infestations and cost of differing control strategies. Proceedings British Crop Protection Conference - Weeds. 415-422.

PETERS, N.C.B. (1978). Ph.D. Thesis, University of Reading.

THURSTON, J.M. (1951). Some experiments and field observations on the germination of wild oat (Avena fatua and A. ludoviciana) seed in soil and the emergence of seedlings. Ann. Appl. Biol. 38. 289-302.

THURSTON, J.M. (1961). The effect of depth of burying and frequency of cultivation on survival and germination of seeds of wild oats (Avena fatua L. and A. ludoviciana Dur.) Weed Res. 1. 19-31.

TINGEY, D.C. (1961). Longevity of seeds of wild oats, winter rye and wheat in cultivated soils. Weeds. 9. 607-611.

TOTTMAN, D.R. and MAKEPEACE, R.J. (1979). An explanation of the demical code for the growth stages of cereals, with illustrations. Ann. Appl. Biol. 93. 221-234.

WERNER, P.A. and CASWELL, H. (1977). Population growth rates and age versus stage-distribution models for teasel (Dipsacus sylvestris Huds) Ecology. 58. 1103-1111.

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EFFECTS OF BEAN (*Vicia faba* L.) PLANTING DATES ON BROOMRAPE (*Orobanche crenata* Forsk) PHENOLOGY AND COMPETITION

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Summary. Field experiments were conducted at Córdoba (Spain) to determine the influence of bean planting dates on bean and broomrape phenology and competition intensity. Broomrape attachment and emergence occurred more intensively and at an earlier bean stage of growth for the early planting date (November, 13) than for the medium (December, 15) and late (January, 15) planting dates. However time differences in broomrape emergence among the three planting dates tested were shorter than among broomrape attachment dates. As a consequence the broomrape cycle becomes longer with earlier planting dates. These observations may explain the need for repeated glyphosate applications to control the broomrape infections at early bean planting dates. Bean yields decreased as planting dates were delayed on plots free from broomrape. On the contrary, broomrape-bean competition intensity increased in the early planting date as compared with medium or late planting dates.

INTRODUCTION

The parasitic weed broomrape (*Orobanche crenata* Forsk) is one of the main problems of beans (*Vicia faba* L.) in Andalusia (south of Spain). The lack of an effective and suitable method to control broomrape has considerably reduced the area sown to beans in the past decades. Late planting dates have been recommended in Andalusia to decrease broomrape infections (Moreno-Marques, 1947). However no research has been done on the effect on planting dates on crop-parasite phenology and competition. This is now important in order to clarify not only the potential of late planting but its impact on the recently developed technique to control broomrape with herbicides (Kasasian, 1973; Schmitt et. al. 1979; Zahran et. al. 1980; Jacobson and Kelman, 1980). The purposes of this study were to determine the influence of bean planting dates on a/ bean and broomrape phenology; and b/ bean yield at different broomrape seed rates.

METHODS AND MATERIAL

Field experiments were conducted at Alameda, INIA, Córdoba, on a sandy loam soil, ph= 7.8, on 1981-82.

Phenology study. Bean cv. Alameda and broomrape seeds collected in the spring 1981 were used. Planting dates were Nov. 13, 1981 (early), Dec. 15, 1981 (medium) and Jan. 15, 1982 (late). Plant spacing was 1 m. between rows. Two bean seeds were seeded each 25 cm. apart in the row. Broomrape seeds were seeded for all bean planting dates prior to the first planting date. A mixture of 100 mg. of broomrape seeds (about 15,000 seeds) with 50 g. of soil, were placed in the row, in a hole 8 cm. deep, every 25 cm. near the bean seeds. Bean planting depth was 4 cm.

The experiment consisted of a completely random design of planting dates, with 4 replications. The experimental unit was a row 5 m. long. Plants were sampled every 10-15 days, starting Jan. 18, 1982. Two bean plants were randomly selected for replication each sampling date. Plants were removed carefully in order to keep as much root system as possible attached to the aerial part. Then roots were washed to separate soil particles and facilitate broomrape counting.

Bean growth stages were determined by counting on uninfected control plants the vegetative, flowering and pod-bearing nodes of each plant, according to the method described by Drennan (1980). The apical vegetatives nodes which appear when flowering is over were not taken into account. The average number of nodes per plant at the vegetative, flowering and pod-bearing stages were then calculated for each sampling date. Infections were determined by counting the number of attached broomrapes per plant at each of the following developmental stages: a) nodule*; b) nodules with short degenerated roots; c) sprout already visible; d) sprout and degenerated roots well developed; e) shoot development from the sprout; f) shoot emergence from the soil surface. The average number of total broomrape per bean plant and the percentages of occurrencein the mentioned development stages were also calculated for each sampling date.

Competition study. The experiment consisted of a randomized complete block design with a factorial arrangement of planting dates and broomrape seed rates. The experimental unit was a row 2 m. long. Treatments were replicated 6 times. Broomrape

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* These are swellings of the haustorial attached to the bean roots not to be confused with the root nodules caused by the nitrogen fixing Rhizobium

seed rates were achieved with 0 (uninfected control), 2.5 (low), 25 (medium) and 125 (high) mg. of broomrape seeds per bean plant, as described previously. Bean planting dates and seeding were the same as in the previous study. The number of broomrape emerged from the soil and the seed weight per bean plant were determined at the end of the experiment. Harvesting took place late May 1982.

RESULTS

Phenology study. The bean and broomrape growth stages resulting from the three planting times at different observation dates are shown in Table 1.

Attachment of broomrape to the bean plants was first observed by 18th January for the earlier planting and much later, on the 10 th and 18 th March respectively for the medium and late planting dates.

There were no consistent relationships between growth stages of the host plant and attachment or any subsequent growth stage of the parasite. Thus, first attachment of broomrape coincided with the vegetative (8 vegetative nodes, 0 flowering node, 0 pod-bearing nodes), flowering (6,5,0) and early flowering (5,1,0) stages of beans planted at the three successive dates. Similarly, at the bean onset of flowering predominant broomrape stages were d and e, c and a, and c and a for the first, second and third planting dates, respectively.

The duration of the underground stage of broomrape decreased as the bean planting was delayed. The time between first attachment and shoot emergence from the soil was approximately 66, 35 and 34 days respectively for the early, medium and late planting dates. Thus the differences between emergence dates were much less than the differences between dates of first attachment.

The number of broomrape plants succesfully attached decreased as planting date was delayed. From the same numbers of seed planted in November the maximum number of attached plants was 65.0, 41.7 and 28.9 respectively for the November, December and January sowings of beans.

Competition study. The final number of broomrapes emerged per bean plant as affected by planting dates and broomrape rates are shown in Table 2. Late planting dates significantly decreased the number of broomrapes emerged per plant compared with the early and medium planting dates, when averaged over infection levels and

Table 1

Crop-parasite phenologic relationship and infection intensity evolution for the three planting dates essayed.

Plantig dates		Observation dates (month/day)										
		1/18	1/27	2/8	2/19	3/1	3/10	3/24	4/4	4/15	4/28	5/7
Nov. 13, 1981	F.B.1/	8,0,0	8,0,0	8,0,0	5,3,0	6,6,0	5,6,0	6,7,2	5,5,13	4,5,12	4,8,14	4,4,12
	B.N:	7.51	21.0	21.4	33.8	65.0	50.9	54.5	34.2	27.6	13.5	20.3
	S.d.	12.12	5.4	7.0	7.6	12.9	12.8	10.5	6.9	8.0	7.8	7.1
	B.G.S.	a(100)	a(64)	a(41)	d(32)	d(45)	d(37)	e(50)	f(44)	f(75)	f(78)	f(73)
		-	b(22)	c(33)	c(27)	e(23)	e(35)	d(27)	d(30)	e(21)	e(22)	e(24)
		-	c(14)	b(22)	a(22)	c(14)	c(21)	f(11)	e(15)	d(14)	-	-
Dec. 15, 1981	F.B.	(3,0,0)	(4,0,0)	(5,0,0)	(7,0,0)	(8,0,0)	(6,5,0)	(5,6,7)	(4,7,6)	(4,6,10)	(3,3,13)	(4,8,8)
	B.No.	-	-	-	-	-	1.1	12.8	48.7	9.2	8.4	12.8
	S.d.	-	-	-	-	-	0.9	5.7	7.1	3.4	2.4	2.3
	B.G.S.	-	-	-	-	-	c(64)	c(60)	d(72)	d(58)	f(50)	f(85)
		-	-	-	-	-	a(36)	d(29)	c(14)	e(23)	c(43)	e(15)
		-	-	-	-	-	-	a(6)	c(19)	f(12)	d(15)	-
Jan. 15, 1982	F.B.	-	-	-	3,0,0	4,0,0	5,0,0	5,1,0	6,5,2	5,5,5	4,5,9	7,5,9
	B.No.	-	-	-	-	-	-	1.1	8.7	10.5	21.8	28.9
	S.d.	-	-	-	-	-	-	0.9	6.7	7.0	7.7	7.2
	B.G.S.	-	-	-	-	-	-	c(64)	c(74)	d(59)	d(46)	e(45)
		-	-	-	-	-	-	a(36)	b(12)	c(30)	e(36)	f(34)
		-	-	-	-	-	-	-	d(11)	b(11)	f(9)	d(5)

1/ Abbreviations F.B.: Faba bean stages expressed by the averaged number of nodes per plant at the vegetative, flowering and pod-bearing stages, respectively. B.No. and S.d.: number of broomrape per two faba bean plant and its standard deviation. B.G.S.: Broomrape growth stages expressed by the percentages of occurrence of parasites at the three more frequent stages (in parenthesis).

at the low and medium levels essayed. Medium and high broomrape seed rates increased the broomrapes number per plant as compared to the low seed rates for the second planting and when averaged over planting dates.

Table 2

Broomrape number per bean plant as affected by planting dates and broomrape seed rates

Planting dates	Control	Broomrape seed rates Low	Medium	High	Means
Nov. 13, 1981	0.1	4.2	6.4	4.4	4.0
Dec. 15, 1981	0.05	3.6	6.8	5.6	4.0
Jan. 15, 1982	0.05	1.3	1.6	3.7	1.6
Means	0.05	3.2	4.9	4.7	
	L.s.d.$_{.05}$=1.5a/;	L.s.d.$_{.05}$=0.85b/ d/		L.s.d.$_{.05}$=0.85 c/ d/	

a/ L.s.d.$_{.05}$ for planting dates X infection levels b/ L.s.d. $_{.05}$ for planting dates, averaged over infection levels. c/ L.s.d.$_{.05}$ for infection levels averaged over planting dates. d/ The broomrape seed rates X planting dates interaction is significant at P=0.01

Bean seed yield as affected by planting dates and broomrape seed rates are indicated on Table 3. Seed yield significantly decreased as broomrape seed rates increased and as planting date was delayed, when averaged over planting times and over broomrape seed rates, respectively. Bean yield was drastically reduced as planting date was delayed on plots free from broomrape. Bean seed yield without broomrape competition were 118, 53 and 18 g. per plant respectively for the November, December and January sowing of beans. However, bean-broomrape competition for a given broomrape seed rate was more intense for the early than for the medium or late planting dates. For example, bean seed yield planted on Nov. 13, 1981, were 38%, 31% and 6% of the control for the low, medium and high broomrape seed rates, respectively, and were 74%, 44% and 34% of the control, for similar seed rates, respectively, planted on Dec. 15, 1981.

Table 3

Bean yield (g. per plant) as affected by planting dates and broomrape seed density

Planting dates	Broomrape seed rates Control	Low	Medium	High	Means
Nov. 13, 1981	118	45 (38%)a/	36 (31%)	6 (8%)	51
Dec. 15, 1981	53	40 (74%)	23 (44%)	18 (34%)	33
Jan. 15, 1982	19	16 (85%)	7 (37%)	4 (22%)	11
Means	63	34	22	9	
	L.s.d.$_{.05}$= 16b/;	L.s.d.$_{.05}$=8c/ e/;		L.s.d.$_{.05}$=9.5.d/ e/	

a/ In parenthesis; seed yield percentages of the control for each planting dates. b/ L.s.d.$_{.05}$ for planting dates x infection levels. c/ L.s.d.$_{.05}$ for planting dates, averaged over infection levels d/L.s.d.$_{.05}$ for infection levels averaged over planting dates. e/ The broomrape seed rates x planting dates interaction is significant at P=0.01

DISCUSSION

The results whow that planting dates influences the bean growth stages in which broomrape is first attached. In our study, the first broomrape attachment for the medium and late planting dates occurred after onset of flowering in the bean. This is in agreement with the observations of Schluter and Aber (1980) in Morocco. However, in our early planting date, broomrape gegan to be attached when the bean plant was still in the vegetative phase, one month before flowering approximately As a consequence, it can be concluded that broomrape attachment does not always occur at the same stage of bean development. So that, to base the recommedations for the timing of postmergence herbicides application to control broomrape on a certain crop development stage may not be adequate.

Final number of broomrape emerged per bean plant is much influenced by the broomrape seed population and planting dates. Low broomrape seed rates can result in high broomrape emergence in early bean planting dates. On the contrary, a high broomrape emergence in late faba bean planting will occur only on a soil with a very high seed population.

The number of broomrape attached in the bean plant increases with the time up to a maximum and then decreases. It has also been observed that at the early and medium planting dates essayed the final number of broomrape emerged at the high broomrape seed rate is lower than at the medium seed rate. These observations can probably be explained by the interbroomrape competition, which normally occurs when the number of broomrapes attached per bean plant is too high, preventing futher development of some of them.

Broomrape-bean competition was more intense, for a given broomrape seed population, at the early than at the medium or late planting dates. This is probably due to the earlier and more intense broomrape attachment which occurred in the early planting date as compared to the others essayed.

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REFERENCES

Drennan D.S.H. (1980). A suggestion for classification of *Vicia faba* growth stages. *Fabis*, 2, 15 .

Jacobson, R.; Kelman, Y. (1980). Effectiveness of glyphosate in broomrape (*Orobanche* spp.) control in four crops. *Weed Science* 28, 692-697 .

Kasasian, L. (1973). Control of *Orobanche*. *Pans*, 19, 368-371 .

Moreno-Marquez, V. (1947). El Jopo (*Orobanche crenata* Forsk) y las siembras tardías de habas. *Boletín Patología Vegetal* y *Entomología Agrícola*, 15, 97-108 .

Schmitt, M.; Schluter, K.; Boorsma, P.A. (1979). Control químico de *Orobanche* crenata en habas. Boletín Fitosanitario FAO, 27, 88-91.

Schluter, K.; Aber, M. (1980). Chemical control of Orobanche crenata on commercial culture of broad beans in Morocco. Journal Plant Diseases and Protection, 87, 433-438.

Zahran, M.K.; Ibarahin, T.S.E.N.; Farag, F.H.; Korollos, Margrette A. (1980). Chemical control of Orobanche crenata in Vicia faba. Fabis, 2, 47

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BROOMRAPE (*Orobanche crenata* Forsk) CONTROL IN BEAN (*Vicia faba* L.) WITH GLYPHOSATE AS AFFECTED BY INFECTION INTENSITY

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Summary. A field experiment was conducted at Córdoba (Andalusia, southern Spain) to determine the efficiency of glyphosate applications in the control of broomrape at several infection levels in the bean crop. Glyphosate applications on infected bean fields delayed broomrape emergence and increased bean yield. However, at early bean planting dates and with very high broomrape infection levels even two applications of glyphosate at 120 g/ha a.i. did not reduce the final number of broomrape per bean plant as compared to the uninfected control, although yield was increased. In such cases, a higher number of glyphosate applications may be required to achieve complete control of broomrape. Infection intensity does not seem to influence glyphosate efficiency while timing of application seems to be critical.

INTRODUCTION

Broomrape (*Orobanche crenata* Forsk) is a serious and widespread root parasite affecting mostly legume crops in the mediterranean area. Infections of broomrape on bean (*Vicia faba* L.) can be controlled by postmergence glyphosate (N-phosphonomethylglycine) applications (Kasasian 1973; Zahran et. al. 1978; Schluter and Aber 1980; Jacobson and Kelaman, 1980). Broomrape growth stages influences glyphosate efficiency (Schmitt and al. 1979; Schlutter and Aber, 1980), the treatments being more effective before broomrape shoot formation. Infection levels my also affect glyphosate efficiency. Application of 2,4-D to bean plants parasitized by broomrape led to a much higher concentration of the herbicide in the immature parasite than in the bean roots (Whitney, 1972), and similar behaviour could be expected for the glyphosate. As a consequence, glyphosate applied to highly infected beans plants could be less effective since herbicide concentration on each immature parasite would probably be lower. Broomrape attachment occurs more intensively and its cycle is longer at early than at normal or late bean planting dates (Mesa-García and

García-Torres 1982 a). Glyphosate at low rate, 60 g/ha a.i., were effective in the control of broomrape regardless of the intensity of the attack when applied to bean planted at normal or late dates (Schluter and Aber, 1980; Mesa-García and García-Torres, 1982 b). The purpose of this study was to determined the efficiency of glyphosate applied to early planting bean at several infection levels.

METHODS AND MATERIAL

The field study was conducted at Alameda, INIA, Córdoba, on a sandy-loam soil, pH= 7.8, on 1981-82. Bean cv. Alameda and broomrape seeds collected at the spring 1981 were the plant material used. Bean planting date was Nov. 13, 1981. Plant spacing was 1 m. between rows. Two faba bean seeds were hand planted 25 cm. apart in the row. Bean planting depth was 4 cm. Experimental unit was a row 2 m. long. Broomrape seeds were seeded before bean planting at a rates of 0 (control), 2.5 (low) and 25 (high) mg. per bean plant. The fix amount of broomrape seeds per plant were previously mixed with 50 gr. of soil, and then placed in the rows, in a hole 8 cm. deep every 25 cm. near the bean seeds. Glyphosate was applied at 120 g/ha a. i. with a AZO experimental sprayer delivering 175 l/ha at 3 Kg/cm^2. Nozzle type used was Teejet SS 8001. Glyphosate applications took place on February, 4 1981 (single application) and on the same date and 20 days later (double application).

The experiment consisted of a randomizad complete bloock with a factorial arrangement of broomrape seed rates and number of glyphosate applications. Treatments were replicated six times. The number of broomrape emerged from the soil surface were determined for each experimental unit on April 1, April 18 and May 15, 1982. The bean seed weight of each plot was determined at the end of the experiment. The broomrape number and seed weight data were also expressed as percent of the control for each seed level.

RESULTS

The effect of the treatments on broomrape emergence are expresed on Table 1. The number of emerged broomrape was higher at the high than at the low broomrape seed density. Glyphosate delayed emergence of Orobanche in all cases. Double applications of glyphosate were more effective than single applications at reducing emergence of Orobanche but the difference were only stastically significant at the

Table 1

Broomrape emergence[a] as affected by glyphosate applications and seed density

Seed density	Observation dates											
	April 1, 82				April 18, 82				May 15, 82			
	Untreated control	single applic.	double applic	Means	Untreated control	Single applic.	double applic.	Means	Untreated control	single applic.	double applic.	Means
Low	4 (100%)	0 (0%)	0 (0%)	1.3	44 (100%)	22 (43%)	10 (20%)	25.3	60 (100%)	61 (103%)	46 (72%)	55.6
High	21 (100%)	0 (0%)	0 (0%)	7.0	104 (100%)	60 (59.7%)	26 (25.2%)	63.3	97 (100%)	104 (111%)	96 (98%)	99.0
Means	12.5 (100%)	0 (0%)	0 (0%)		74 (100%)	41 (55%)	18 (24%)		78.5 (100%)	82.5 (105%)	71 (90%)	

April 1, 82: L.s.d.$_{.05}$=6.3[b]; L.s.d.$_{.05}$=3.6[c]; L.s.d.$_{.05}$=3.6[d]

April 18, 82: L.s.d.$_{.05}$=22.9[b]; L.s.d.$_{.05}$=13.2[c][e]; L.s.d.$_{.05}$=13.2[d][e]

May 15, 82: L.s.d.$_{.05}$=24.6[b]; L.s.d.$_{.05}$=14.2[c]; L.s.d.$_{.05}$=14.2[d]

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a/ Expressed in number of broomrape per experimental units and as percentage (in parenthesis) of the untreated control for each infection level. b/ L.s.d.$_{.05}$ for infection levels x herbicides application. c/ L.s.d.$_{.05}$ for infection levels averaged herbicide application. d/ L.s.d.$_{.05}$ for herbicides application averaged over infection levels. e/ the seed density x number of glyphosate applications interaction were significant at P=0.01

second date of observation. Moreover, double applications of glyphosate only reduced the final broomrape emergence by 28% of the untreated control at the low infection level and this reduction was negligible at the high infection level.

Treatments seed yields are indicated on Table 2. High infection level significantly reduced seed yield as compared to the low infection. Two applications of glyphosate at the high infection level increased seed yield compared to the untreated control and the glyphosate single application, but only the former difference was statisticaly significant. However, at the high infection level glyphosate double application treatment yield was only 43.3% of the uninfected control.

Table 2

Seed yield expressed as percent of the broomrape free control as influenced by infection levels and glyphosate applications.

Infection levels	Glyphosate applications Untreated Control	single	double	Means
Low	58.2	69.6	64.0	63.9
High	12.3	27.6	43.3	27.7
Means	35.2	48.6	53.6	

L.s.d.$_{.05}$= 21.35$\underline{a/}$ L.s.d.$_{.05}$= 12.3$\underline{b/}$

L.s.d.$_{.05}$= 12.3$\underline{c/}$

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a/ L.s.d.$_{.05}$ for infection levels x herbicides applications. b/ L.s.d.$_{.05}$ for infectiom levels averaged over herbicide applications. c/ L.s.d.$_{.05}$ for herbicides applications averaged over infection levels.

DISCUSSION

In this study glyphosate applications produced a delay in broomrape emergence rather than a broomrape control. The increase in yield with two applications of glyphosate as compared with a single application and the untreated control at the high infection level could have been due to the reduced competition in time produced by the delay in broomrape development.

To explain the low efficiency of glyphosate obtained in this experiment it should be noted that the bean planting date was Nov. 13, 1981, which can be considered an early planting date. In this condition it is known that broomrape attachment on bean plants occurred much earlier and with higher intensity than at normal or late planting dates (Mesa-García and García-Torres, 1982 a). As a consequence, it seems that at early crop planting dates more glyphosate applications are necessary in order to get high efficiency in broomrape control.

It has been shown that 2,4-D applied on parasitized bean plants mainly accumulated on the parasites (Whitney, 1972) and is possible that it occurs similarly with glyphosate. Thus, at high infection level the herbicide rates accumulated at each parasite could be lower and therefore of little efficiency. This hypothesis may probably help to explain the slighly higher broomrape control percentages obtained with double glyphosate applications at the low than at the high infection levels. However, differences in broomrape emergence percentages between single applications of glyphosate at the high and low infection level were negligible. Furthermore, experiment conducted at Andalusia have repeatedly shown that at normal bean planting dates, (December, 10-20), when the broomrape cycle is shorter, even a single glyphosate application at 60 g/ha a.i. on highly infected bean resulted in a very high broomrape control (Mesa-García and García-Torres, 1982 b). Therefore, it seems that infection intensity does not play a such an important role in determining the timing and number of glyphosate applications in order to get a high herbicide efficiency while bean planting date does.

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REFERENCES

Jacobson, R; Kelman, Y., (1980). Effectiveness of glyphosate in broomrape

(*Orobanche* spp.) Control in four crops. *Weed Science*, 28, 692-298.

Kasasian. L. Control of *Orobanche* (1973). *Pans*, 19 368-671

Mesa-García, J; García Torres, L. (1982a).Effects of bean (*Vicia faba* L) planting dates on broomrape (*Orobanche crenata* Forsk) phenology and competition. *Proceedings 1982 British Crop Protection Conference-Weeds* (in this volume)

Mesa-García, J.; García-Torres, L. (1982 b).Unpublished data.

Schluter, K.; Aber, M. (1979).Chemical control of *Orobanche crenata* in commercial culture of broad beans in Morocco, *Journal of Plant Diseases and Protection* 87, 433-438.

Schmitt, M.; Schluter, K; Broorsma, P.A. (1979) Control químico de *Orobanche crenata* en habas. *Boletín Fitosanitario FAO* 27, 88-91.

Zahran, M.K.; Ibrahim, T.S.; Farag, M.F.; Korollos, M.A. (1980) Chemical control of *Orobanche crenata* in *Vicia faba*. Fabis, 2, 47-49.

Whitney, P J (1972).The translocation of herbicide from bean (*Vicia faba*) to broomrape (*Orobanche crenata*). *Annals of Applied Biology*, 72, 205-210.

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TIME, SPACE AND THE GROWTH OF COUCH GRASS

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Summary. An analysis of the spatial dynamics of Agropyron repens in pure stand and winter wheat showed that in dense infestations regular placement of shoot complexes occurred at several scales of pattern. The causes of this were investigated by experimental observation and computer simulation. Small scale pattern was explained by morphological expression during rhizome growth. A hypothesis of fine grained environmental sensing by rhizome apices for growth resources in the soil is considered to explain pattern at larger scales. The consequences to weed-crop interactions are discussed.

INTRODUCTION

Time and space are the dimensions of the theatre in which weed-crop interactions occur. In Agropyron repens L. Beauv. (couch grass), considered by Håkansson (1975) to be the major perennial weed of Northern Europe, biological control of population size through presumptive interspecific competition has been suggested (Cussans, 1970; Mortimer, 1983). The precise mechanism(s) by which such control is achieved have yet to be elucidated, competition for light within the crop canopy (Williams, 1970) being an obvious candidate. During demographic studies on this species (McMahon and Mortimer 1980), we made the chance observation that the spatial arrangement of shoots in pure stand was apparently regular. This prompted the hypothesis that either underlying morphological constraints or demographic processes might be operative in ramet positioning and hence the process of resource exploitation,with consequences to competition with a companion crop. This paper describes the original observations and an analysis of the spatial dynamics of A.repens and considers the potential implications for the control of the weed.

GROWTH FORM

Clones of A.repens comprise a series of tillers morphologically interrelated at two levels; proximally within the shoot complex (White, 1979) of primary shoot (from erected rhizome apex) and subtending tillers and distally amongst shoot complexes interconnected by rhizomes. Reiteration is seen at both these levels in a sympodial structure. Shoot complexes may appear perennial due to successive seasonal tillering and the death of parent shoots since branches are dwarf. Plagiotropic rhizomes arising from buds in the transition zone (Palmer, 1958) beneath shoots and from lateral buds upon parent rhizomes constitute long branches amongst shoot complexes. Buds are borne in alternate manner on these branches which may vary in internode number and length. The phenology of the species and the erection of shoots from plagiotropic rhizomes has been described by Palmer (1958). Fragmentation of rhizomes often results in the development of a primary shoot from segments and hence multiplication of separate ramets. Throughout this paper the terminology used follows the definitions given above. Rhizomes are classified as primary if they originate from the base of a shoot complex or secondary if they occur as growth extensions from buds on a parent rhizome. No classification by order is used.

MATERIALS & METHODS

The structure of individual clones

Three clones of A. repens were grown at Ness Botanic Gardens, Wirral from single node fragments in wooden sided boxes (1m x 1m x 0.5m) containing a sand:peat (90%: 10%) mix to which 1.6 Kg of Vitax -Q4 fertiliser (5.3%N, 7.5%P, 10%K and trace elements) was added. The boxes were horizontally divided at depths of 5,10,20,30 and 40 cm with layers of plastic netting (1.27 cm square Netlon). After a season's growth (1978-1979) clones were excavated, rhizomes being held in place by the netting. The growth of each rhizome in turn was mapped by recording the three dimensional coordinates of rhizome passage through each layer of netting; measurement of all internode lengths and the position of branches in relation to depth; and within each section of the soil profile, the number of buds, the number of primary and secondary rhizomes that produced a primary shoot and the angle of growth between secondary (lateral) and primary (parent) rhizomes.

Pattern in aerial shoots

The spatial pattern of shoot complexes was mapped in three sites : i) a mature monoculture of couch (see McMahon and Mortimer, 1980 for details), ii) the edge of a stand of winter wheat which had been grown on tine cultivated land and iii) within winter wheat grown under minimal cultivation in a plot in which couch control by glyphosate spraying was omitted by accident. In each of these sites,density estimates of shoot complexes in 16 parallel transects each containing 32 contiguous 9 cm^2 quadrats were made. Spatial pattern was analysed by block size analysis of variance (Grieg-Smith, 1961).

Rhizome development in the field

Observations were made on material from the excavation of the rhizome mat underneath a replicate of the mature monoculture of couch assessed for aerial shoot pattern. Nine clones originally planted in 1977 as single bud fragments were dissected in addition to twelve plants which had fragmented from original plantings. The time of emergence and hence age of shoot complexes was determined by tagging (McMahon and Mortimer, 1980). Diagrammatic maps were constructed of each clone showing internode number and length, positions of branching rhizomes and shoot complexes.

Fates of rhizome buds

To assess the survivorship of dormant buds on couch rhizomes, plants were grown for a season (1978-1979) in pots buried in the field. Systematic, destructive harvests of rhizomes were made and individual dormant buds tested for viability using tetrazolium chloride,if sprouting of single node fragments had not occurred on moist filter paper after three weeks in alternating temperature (15°C/25°C on a 12 hour cycle).

RESULTS

The structure of individual clones

Table 1 summarizes the growth of clones of A.repens grown as spaced plants. The three clones showed considerable variation in shoot and primary rhizome growth. Clone 3 produced 6-7 fold more shoots, primary rhizomes and buds than clone 1, clone 2 being intermediary. Approximately 50% of the buds in two clones (2 and 3) occurred in the top 10cm of the soil profile, none being found below 20cm in clone 3. This pattern was not repeated in the least productive plant (1) in which a significant number of buds were placed at greater depths (24% below 20cm), the majority being found in the 10-20cm. layer. In no cases were rhizomes found below 40 cm.

In general most shoots emerged from secondary rhizome apices,this being a direct consequence of the proportion of secondary rhizomes produced. No consistent pattern of shoot emergence in relation to depth of rhizome occurrence was discerned. Overall 3.7-8.3% of buds produced secondary rhizomes. The potential for increase by vegetative reproduction is illustrated by the prolificacy in bud production, the range encompassing 443-2584 buds season^{-1} beneath a surface area of $1m^2$.

Shoot complexes arising from rhizome apices were on average 23.5cm distant from the original planting and were orientated in all directions of the compass. Analysis of the spatial pattern of these complexes by nearest neighbour analysis (Clark and Evans, 1954) indicated a random arrangement. The distribution of branch angles of secondary rhizomes was positively skewed with a mean of 5.2° from the primary axis.

Pattern in aerial shoots

Figure 1 illustrates that significant departures below unity in variance/mean ratios (indicating regularity in spatial arrangement) were found at scales of 3-24 cm in shoot complex densities greater than 500 m^{-2}. This evenness occurred within one cropping season in winter wheat whether the infestation encroached from headlands at the crop boundary or from rhizomes in the soil profile within the crop. At densities below 500 m^{-2} a significant clumping of complexes was detected on the crop

Table 1. Quantitative description of the structure of individual clones of _Agropyron repens_. Measurements were recorded after one season's growth in the field in $0.46 m^3$ soil.

CLONE	NUMBER OF PRIMARY RHIZOMES ARISING FROM THE PARENT SHOOT	NUMBER OF SHOOT COMPLEXES (EXCLUSIVE OF PARENT SHOOT)	DEPTH cm.	NUMBER OF SHOOT COMPLEXES ARISING FROM PRIMARY RHIZOMES	NUMBER OF SHOOT COMPLEXES ARISING FROM SECONDARY RHIZOMES	NUMBER OF BUDS	DISTRIBUTION OF BUDS (%)	PROBABILITY OF A RHIZOME BUD EXTENDING TO FORM A BRANCH
1	9	9	0-5	0	1	68	32.4	0.023
			5-10			64		
			10-20	0	7	176	43.1	0.057
			20-30	0	0	84	20.6	0
			30-40	0	1	16	3.9	0.125
			Total	0	9	408	100.0	
2	15	28	0-5	7	5	173	52.8	0.071
			5-10			178		
			10-20	0	12	232	34.8	0.103
			20-30	0	4	68	10.2	0.074
			30-40	0	0	14	2.2	0.071
			Total	7	21	665	100.0	
3	64	54	0-5	17	20	269	57.8	0.075 *
			5-10			1107		
			10-20	0	16	1005	42.2	0.074
			20-30	0	0	0	0.0	0
			30-40	0	0	0	0.0	0
			Total	17	36	2381	100.0	

* One shoot of unidentified origin was recovered for this section of the profile.

boundary (Fig.1B).

Rhizome development in the field

Inspection of the maps of excavated clones from a pure stand of couch showed that shoot complexes arising from single node fragments bore on average 8 primary rhizomes after 2½ years growth, the number ranging between 3 and 18. These rhizomes arose by extension growth of axillary buds at basal nodes of aerial shoots and nodes in the transition zones between aerial shoot and plagiotropic rhizome. Whilst some complexes had the potential to be immortal (perennating by successive tillering and showing annual rhizome production) others were barren. Age-specific primary rhizome production by shoot complexes differed substantially amongst clones. It was common for new primary shoots to be recruited from the cohort of the preceeding year although recruitment from 'parental' shoots in the same season and from shoot complexes two years old was evident. Some rhizomes however remained plagiotropic. Inspection of the pattern of emergence of shoot complexes and of recruitment in the two birth pulses (May and October, McMahon and Mortimer, 1980) suggested an absence of any discrete behaviour amongst cohorts. Primary shoots also arose from secondary rhizomes and contributions from this source accounted for up to 35% of annual arrivals.

Fates of rhizome buds

The fates of buds on rhizomes were to die, to remain dormant, or to form branch extension growths. Despite extensive statistical analysis no correlation could be found between the age of a bud and its subsequent fate. Generally it was rare for buds to die in situ and it was not uncommon for successive buds to branch. Linear projections of both primary and secondary rhizomes showed oscillations in internode lengths (Fig.2). Troughs identified by the progressive shortening of three internode lengths were found to be significantly correlated ($P=0.016$) with periods of soil moisture deficit ($\leqslant -10$mm), measured at the meteorological station at Ness Botanic Gardens.

SIMULATION

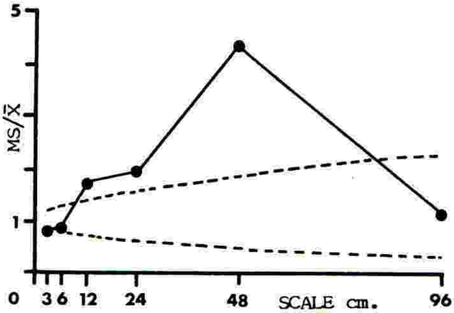
A computer simulation of the growth of individual clones was made in order to search for underlying causes of pattern. Two premises were central to the construction of the model : firstly that many of the underlying variables were *a priori* stochastic but varying according to a definable probability distribution; and secondly that there was no density dependent mortality of shoot complexes. The hypothesis under test was that simulated clonal growth at the level of the individual or the population did not result in pattern at any scale. Eight driving variables formed the basis of the model: primary rhizome production (1); angle (2) and rate (3) of growth of primary rhizomes; bud fate-branching (4) and mortality (5); rate of growth of secondary rhizomes (6); branching angle of secondary rhizomes (7) and probability of rhizome erection (8). Data on these variables were collected from the pure stand observations in spaced plant trials, from examination of bud survivorship, and from field excavations, in the latter case only data from the first growing season (1977-1978) being utilised.

The results from an individual simulation are shown in Figure 3. It is immediately discernable that local pattern is the result of secondary rhizome growth and apex erection along primary axes (for example see cluster at 25, -50). Analysis of pattern at higher block sizes in a simulated population of clones giving an overall density of 924 complexes m^{-2} (in comparison to 762 m^{-2} accumulated shoot complexes in the field) indicated aggregation at scales of 12-48 cm (Figure 4).

DISCUSSION

The results reported here indicate that within the time span of one cropping season, infestations of couch grass can arise which show a regular spatial arrangement of shoot complexes. In winter wheat, these dense infestations of evenly spaced plants arose where the biological reservoir from which aerial shoots were recruited was either intact clones from headlands, partially fragmented clones surviving beneath tine depth or rhizome mats escaping herbicide treatment. In field experiments with pure stands of couch initiated from single node fragments, the development of evenness was apparent after two years development during which there was no segregation of shoot complexes according to time of emergence and natural mortality

Figure 4. The analysis of spatial pattern of shoot complexes in a simulated clonal population of couch. - - - - - 95% confidence limits.



of shoot complexes was low (McMahon, pers comm). It is highly likely that in the sites chosen for assessment in winter wheat crops that very low natural or man-induced mortality also occurred.

Two hypotheses may be proposed in explanation for the observed pattern. Either there are inherent morphological rules determining clonal architecture or density-dependent mortality of shoot complexes occurs, which is distance related. The latter is unlikely in view of the low level of mortality. The former appears in contradiction to reports by many workers on the variability and apparent 'random nature' of rhizome growth. Yet the simulation study reveals that there are levels of architectural control in couch clones. The alternate arrangement of buds at rhizome nodes is a systematic arrangement which affords the potential of equilateral exploitation of resources around the parent rhizome axis, but the acuteness of branching angle of secondary rhizomes precludes this. It is achieved however by primary rhizome growth from the base of shoot complexes which can occur in all compass directions. Freedom from the constraints of an alternate phylotaxy and consequent planar rhizome outgrowth is achieved during the expression of plagiotropy by extending axillary buds. The immediate direction of growth is influenced by spatial restrictions imposed by the packing of buds closely together along the vertical shoot axis which results in indeterminate radial growth during plagiotropic expression. The overall pattern of growth in couch therefore does not morphologically allow a systematic conservative, two-dimensional placement of shoot complexes; rather the principal level of architectural construction ensures the opportunity to position primary shoots at any locus on a circumference surrounding the parent shoot complex, whilst the second level has the potential to amplify colonisation in the direction of the parental rhizome axis.

This second level may explain local scales of pattern (3-6cm) but does not give an adequate explanation of evenness at higher block sizes (12 and 24cm) which the model failed to generate.The variation in the length of internodes on rhizomes may constitute an historical record of resource availability during the growth of the plant and possibly the availability of photosynthetic assimilates for rhizome extension growth.Yet this <u>per se</u> cannot account for the generation of evenness in spatial pattern. The correlation between internode shortening and periods of drought reported here and more importantly the work of Leakey (1974) and McIntyre (1976) suggests that rhizome apices may sense the environment in a fine grained manner.The expression of orthotropy by rhizomes and hence position of shoot complexes may in part be determined by the levels of soil nitrogen which may become locally depleted by extant shoot complexes.If threshold levels are a prerequisite for apex erection, this may lead to a statistically even shoot complex distribution. This hypothesis envisages rhizomes actively exploiting soil resources during growth, possibly through the extensive rooting systems at nodes.

The cost of inherent mechanisms determing clonal architecture in couch may be interpreted as an evolutionary compromise to the risk of intercomplex competition that might otherwise occur if growth was truly at random. Systematic two dimensional exploitation of soil resources is a further consequence of the primary level of architecture and supports the arguments of Welbank (1961) that depression of crop growth may be due to interference with soil moisture and nitrogen acquisition. The

Figure 1. Pattern analyses of the spatial arrangement of shoot complexes of *A.repens* in pure stand and winter wheat. $MS/\bar{x} = 1$ indicates randomness, <1 regularity, >1 contagion. - - -95% confidence limits.

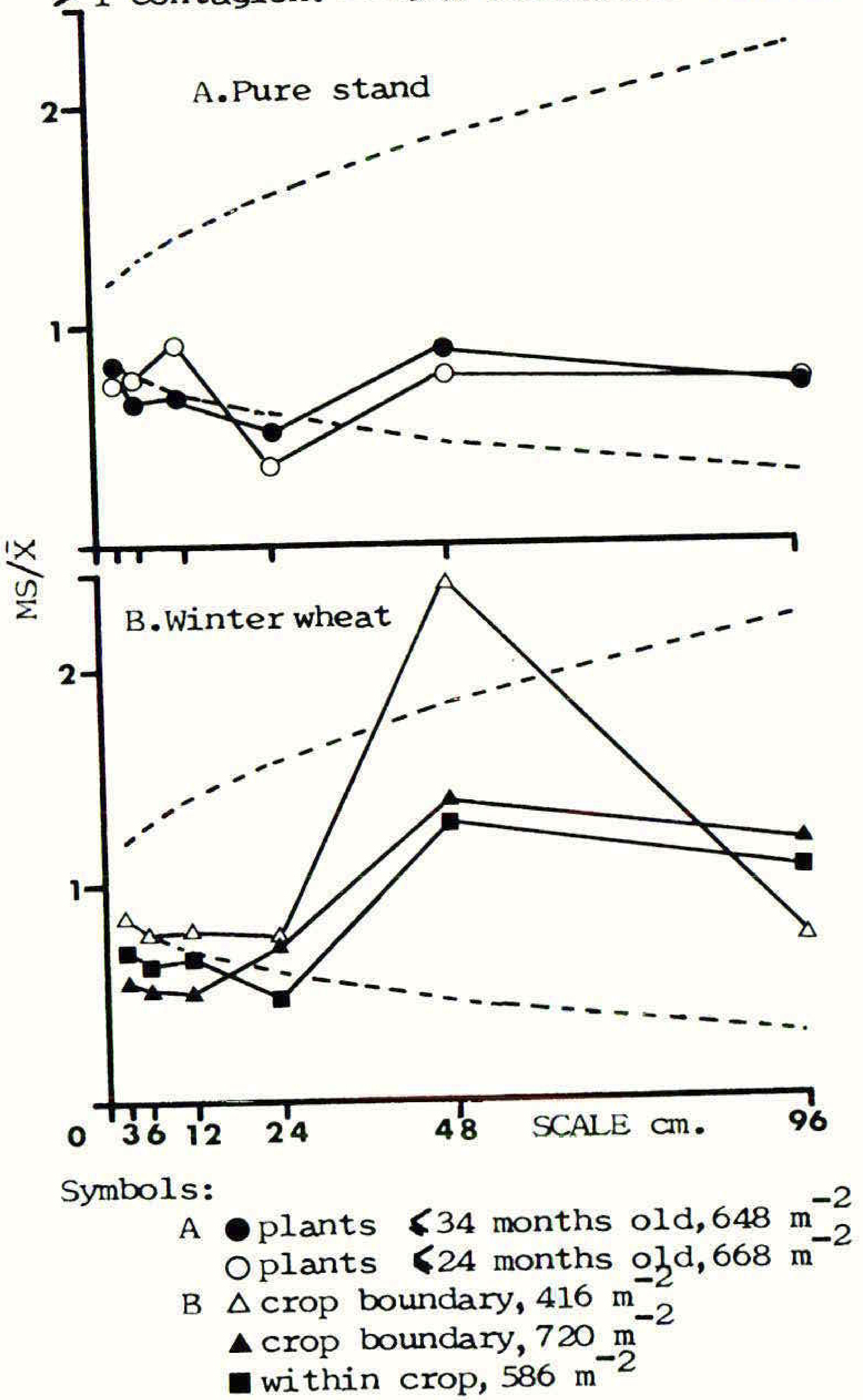


Figure 2. Linear projections of primary rhizomes of *A.repens*. — indicates a sequence of 3 internodes progressively shortening. ● a dormant viable bud. ▲ an inviable bud ○ a rhizome branch.

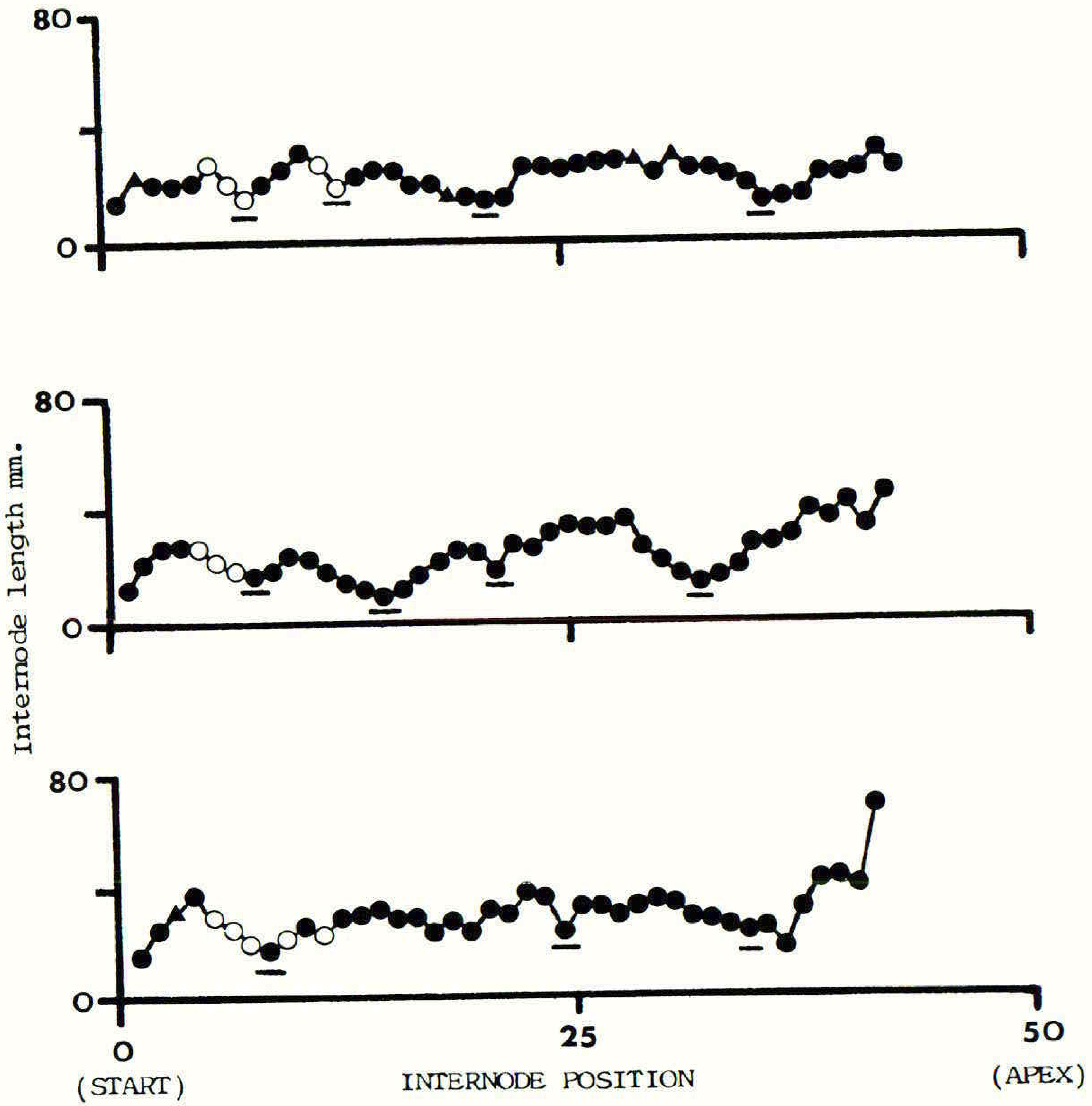
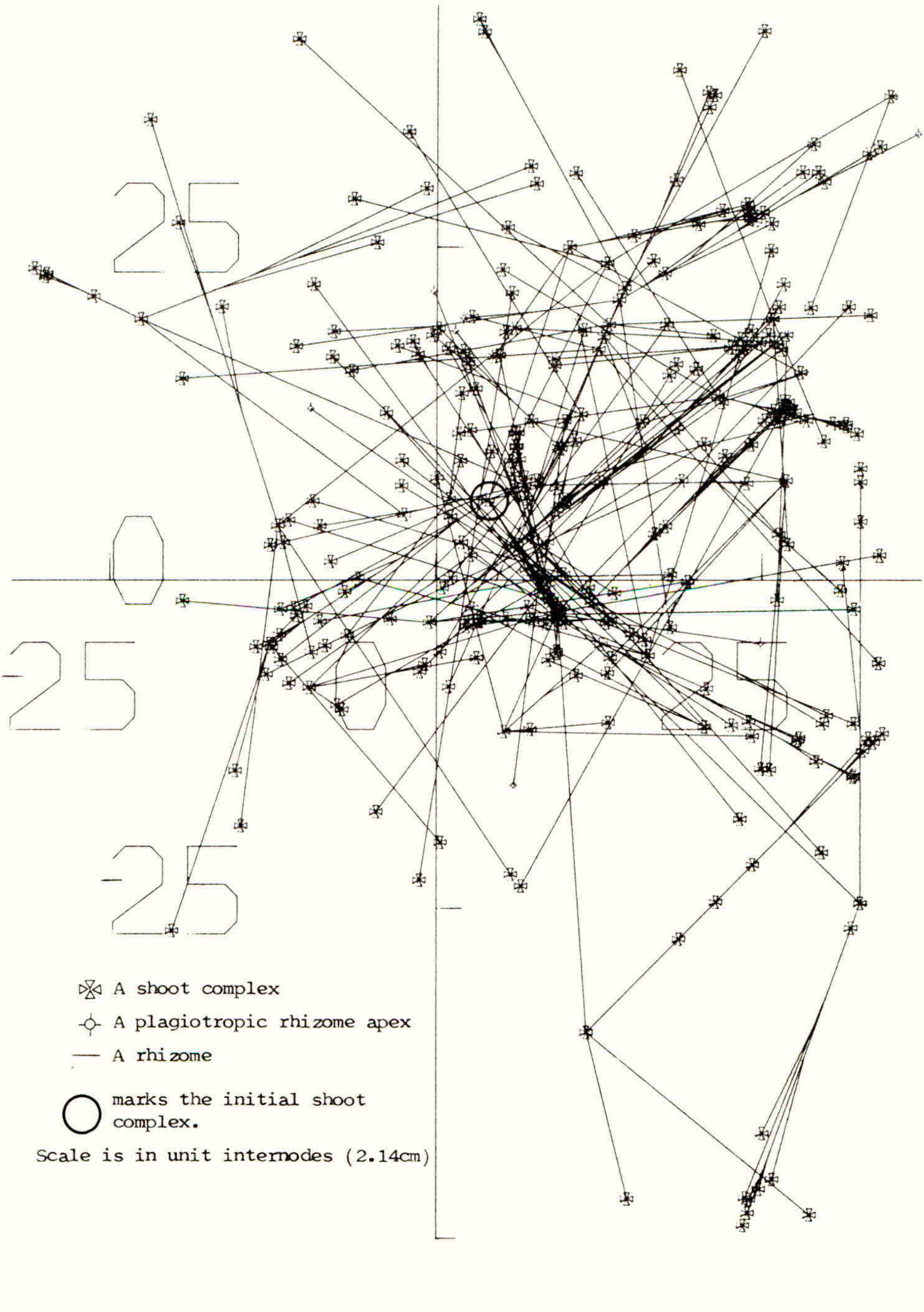


Figure 3. A detail from a simulation of the growth of a single clone of *A.repens.*



secondary level potentially results in even packing of shoot complexes along lines of primary colonisation with the consequence of localised monocultures of couch. Depending on the time and sequence of rhizome erection in a cereal, this may constitute a phalanx of shoots interfering with light interception by the crop.

The demonstration of physiological cooperation amongst photosynthetic units (Fiveland et al, 1972) coupled with integrated morphological growth form is suggestive of a strategy of growth adapted to minimising intraspecific interference and in so doing showing aggresivity to companion species. Yet A. repens is itself susceptible to crop competition (Cussans and Ayres, 1975). Echoing Robinson (1978) the extent to which phytotoxicity of chemical control measures may be enhanced by biological control in the form of competitively-induced stress from the companion crop would appear to deserve further study in A. repens. Understanding the mechanisms will however require careful experimentation. In the meantime the model used here is undergoing further development to enable prediction of rates of invasion of couch into cereal crops.

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BIBLIOGRAPHY

Clark, P.J. and Evans F.C. 1954. Distance to nearest neighbour as a measure of spatial relationships in populations. Ecology 35 : 445-453.

Cussans, G.W. 1970. Biological background to the control of rhizomatous grasses. Proc. 10th Brit. Weed Control Conf. 3 : 1101-1107.

Cussans, G.W. and Ayres, P. 1975. The influence of chemical treatments and autumn cover crops of brassicae, following spring barley, upon the growth of Agropyron repens (L) Beauv. Proc EWRS Symp. Status, biology and control of grassweeds in Europe 1 :314-321.

Fiveland, T.J., Erickson, L.C. and Seely, C.I. 1973. Translocation of ^{14}C-assimilates and 3-amino-1,2,4-triazole and its metabolites in Agropyron repens. Weed Res. 12 : 155-163.

Grieg-Smith, P. 1961. Data on pattern within plant communities I. The analysis of pattern. J. Ecol. 49 : 695-702.

Håkansson, S. 1975 General survey on perennial grass-weeds. Proc EWRS Symp on Status, biology and control of grassweeds in Europe 2 : 71-84.

Leakey, R.R.B. 1974. Factors affecting the growth of shoots from fragmented rhizomes of Agropyron repens (L.) Beauv. Ph.D thesis. Univ. Reading.

McIntyre, G.I. 1976. Apical dominance in the rhizome of Agropyron repens : the influence of water stress on bud activity. Can. J. Bot 54 2747-2754.

McMahon, D.J. and Mortimer, A.M. 1980. The prediction of couch infestations - a modelling approach. Proc. 15th Brit. Weed Control Conf. 2 : 601-608.

Mortimer, A.M. 1983. On weed demography. In Recent advances in weed research. Ed W.W. Fletcher CAB. In press.

Palmer, J.H. 1958. Studies on the behaviour of the rhizome of Agropyron repens (L) Beauv. I. The seasonal development and growth of the parent plant and rhizome. New Phytol. 57 : 145-159.

Robinson, D.W. 1978. The challenge of the next generation of weed problems. Proc. 14th Brit. Crop Prot. Conf. - Weeds 3 : 799-823.

Welbank, P.J. 1961. A study of the nitrogen and water factor in competition with Agropyron repens (L.) Beauv. Ann. Bot. 25 116-137.

White, J. 1979. The plant as a meta-population. Ann. Rev. Ecol. Syst. 10 : 109-145.

Williams, E.D. 1970. Effect of decreasing light intensity on the growth of Agropyron repens (L.) Beauv. in the field. Weed Res. 10 : 360-366.

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PRIORITIES IN THE SELECTION OF AGENTS FOR THE BIOLOGICAL CONTROL OF WEEDS

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Summary. Quarantine safety and effectiveness are the principal factors used in selecting agents for biological control studies. Effectiveness is the prospective ability of a biocontrol agent to control a weed in a habitat where the agent does not occur at present. Assessment of effectiveness has been made by observing the agent's effect on the weed in ecoclimatic situations within its native range which most closely resemble the infested regions where it is being considered for release. This method was applied to the selection of biological control agents for *Chondrilla*, *Echium* and *Heliotropium*. The manner in which assessments of both effectiveness and preliminary safety are used to establish priorities for further study and quarantine safety testing are discussed.

INTRODUCTION

Weed species are often attacked in their native range by a large number of insects, pathogens and other phytophagous organisms. The priorities for detailed study and quarantine safety testing of the agents used for the classical biological control of weeds are established by 2 principal factors;
(1) known restriction to the host, indicating quarantine safety which consists of a demonstration, on the one hand of specificity to the host and on the other of immunity of crop and other important plants to attack by the agent;
(2) effectiveness under field conditions. Enough information to select sufficiently restricted agents can often be obtained from the literature, from a background knowledge of the taxonomic group to which the agent belongs and from preliminary field observations. The initial estimation of effectiveness, which is the prospective ability of the agent to control the weed in the new habitat, has been found to be the more difficult task.

One of the ways used to estimate effectiveness has been to observe the effect of the agent on the weed and in some cases on weed populations in regions within its native range which are ecoclimatically similar to the weed infested regions. Such assessments are adjusted for possible differences in predation, parasitisation and any other ecological disparities between the two regions (Wapshere, 1970). This method was used to estimate the effectiveness of the agents attacking the weeds *Chondrilla juncea*, *Echium plantagineum* and *Heliotropium europaeum*.The manner in which these assessments of effectiveness, taken together with the initial assessments of quarantine safety, established priorities for detailed study and safety testing of these weeds, is discussed below.

Chondrilla juncea (compositae)

This is a perennial weed of wheat/fallow cultivations on sandy soils in dry Mediterranean climatic regions of eastern Australia. It appears as rosettes regenerating from the rootstocks and as germinating seedlings in autumn after the seasons first rains. The rosettes from both sources grow in size and compete with the wheat crop for nitrogen until the rosette foliage dies in late spring shortly after the flower shoots bolt from their central buds. The plant flowers and seeds during summer, the shoot dying off in early autumn. Regenerating buds then appear on the perennating rootstock beneath the ground.

A study of the effect of the various organisms attacking the weed in the drier parts of Mediterranean Europe which are regions ecoclimatically similar to the regions infested in Australia indicated that those playing the principal role in controlling populations of the plant were, in order of decreasing importance :

1) *Puccinia chondrillina*. This rust fungus destroys a considerable proportion of seedlings and rosette plants in the field and reduces flower shoot development each season and this despite a common infestation of the rust by the fungal parasite *Darluca filum*. *P. chondrillina* occurs throughout the home range of *C. juncea* and like many other monoecious rusts was considered specific to *Chondrilla*.

2) *Erysiphe cichoracearum*. This powdery mildew destroys a number of more mature seedlings and damages rosettes and flower shoots. *E. cichoracearum* exists in many forms, some attacking a wide range of cultivated plants but others restricted to a single genus or group of species. Although subsequent studies showed that the *Chondrilla* form was restricted to that genus it was not considered safe enough by the Australian Plant Quarantine authorities for introduction. It was felt by them that the taxonomy of powdery mildews was too uncertain at present and that the introduction of an additional form of *E. cichoracearum* into Australia would increase the genetic pool of the mildew there.

3) *Cystiphora schmidti*. This cecidomyiid gall midge occurs in the eastern part of the native range of *C. juncea* and infests seedlings, rosettes and flower shoots considerably reducing growth. Despite heavy parasitisation it was often abundant. It has been recorded only on *Chondrilla*.

4) *Leveillula taurica*. This powdery mildew also infests rosettes but is particularly damaging to the flower shoot. Like *E. cichoracearum* it occurs in several forms, each more of less restricted to certain hosts or host groups. The *Chondrilla* form is considered to be specific but rejection of the earlier proposals to introduce a powdery mildew indicated that the Australian Pant Quarantine authorities would not have permitted its introduction.

5) *Bradyrrhoa gilveolella*. The larvae of this phycitid moth attack the perennating rootstock of the weed below soil level. Individually this insect is the most damaging organism on *Chondrilla* and quite

common in the drier regions of Mediterranean climate. It had only been recorded on *Chondrilla* and is found only in the eastern part of the home range of the weed.
6) *Aceria chondrilla*. The main effect of this eriophyid gall mite is to reduce seeding by replacing flowers by leafy galls. Like many gall-forming eriophyids it was considered highly specific to its host.
7) *Oporopsamma wertheimsteini*. The larvae of this tortricid attack the collar region of *C. juncea*. However, the moth does not occur in Mediterranean climatic regions but in areas with continental climates, further east, with very cold winters and very hot summers. It has also been recorded only on *Chondrilla* species.
8) Several other apparently specific insects are also limited to regions further east with continental climates and for this reason amongst others only preliminary investigations were made on them. (Wapsher, 1970; Hasan, 1972a, 1972b, 1974; Hasan & Wapshere, 1973, 1977; Caresche & Wapshere, 1974, 1975a, 1975b; Wapshere *et al.*, 1974, 1976).

Taking the above description of the situation for each organism on *C. juncea* into account detailed work on the agents should have been carried out in the following order of priority. 1. *P. chondrillina*, 2. *C. schmidti*, 3. *B. gilveolella*, 4. *A. chondrillae*, 5. *O. wertheimsteini* with the two powdery mildews and other agents put on one side.

Echium plantagineum (Boraginaceae)

This annual plant is a weed of high rainfall Mediterranean pastures in Australia, where its rosettes compete with other pasture plants. Studies were concentrated on those organisms which attack the plant early in the season in its native range in the higher rainfall regions of the western Mediterranean area of Europe. These agents would limit rosette development and reduce the storage of food in the tap root, thereby diminishing later flower production.

The principal organisms in these regions in order of decreasing effect on plants, were as follows :
1) *Ceuthorrhynchus geographicus* and *Ceuthorrhynchus larvatus*. The larvae of these weevils destroy the root and the collar regions respectively of the late rosette stage of *Echium* spp. Individually they are the most damaging organisms on *Echium* but are sometimes heavily parasitised. Both weevils considered to be restricted to *Echium* spp. as larvae.

2) *Longitarsus echii* and *Longitarsus aeneus*. The larvae of the halticine flea beetles damage the root and rootlets respectively of the early rosette stage of *Echium*, and are both very common. The larvae are considered in the literature to be restricted to *Echium* spp.
3) *Dialectica scalariella*. The larvae of this gracillariid moth produce large blotch mines in both rosette and cauline leaves of *Echium* and thereby act as partial defoliators. Attacks commence early in the season and continue on subsequent stages of the plant. The moth attacks a range of Boraginaceae as well as *Echium* but as no boraginaceous plant has any commercial value in Australia it can be selected as an agent.
4) *Erysiphe horridula*. This powdery mildew heavily infests late rosettes and early flower shoots. Like *D. scalariella* its recorded host range is restricted to various Boraginaceae. Although, as

damaging at times as the moth species, it could not be considered as an agent after the Australian Plant Quarantine authorities had refused to allow the introduction of the *Chondrilla* powdery mildew.
5) *Dictyla echii* and *Dictyla nassata*. These tingid bugs build up their most damaging populations on *Echium* flower shoots and are probably the insects causing the greatest reduction in seeding of this annual weed. Although frequently abundant the fact that their effect on the plant occurs late in the season reduces their importance to established plants compared with the organisms already considered. They have also been recorded only from various Boraginaceae.
6) *Ethmia bipunctella*. The larvae of this moth destroy the buds of *Echium* and are most important when they attack the central flower shoot but in spring. However, the moth is never very abundant despite having more than one generation yearly. It is mainly restricted to *Echium* spp., but has occasionally been recorded from other Boraginaceae.
7) *Phytoecia coerulescens*. The larvae of this common cerambycid bores out the flower shoots of *Echium* and attack even later in the season than do the *Dictyla* spp. The beetle is also restricted to a group of boraginaceous plants.
8) Many other insects attack *Echium* in the western Mediterranean region, but are either less damaging, less abundant or more restricted in occurrence than those mentioned above.
(Wapshere & Kirk, 1977; Kirk & Wapshere, 1979; Wapshere, 1981, 1982; Vayssières, 1983; Vayssières & Wapshere, 1983).

It is evident from the reasons given above for each agent on *E. plantagineum* that the priorities for further work should be in that same order except for *E. horridula* which, as a powdery mildew, has to be put on one side despite its effectiveness.

Heliotropium europaeum (Boraginaceae)

This summer annual is a weed of semi-desertic sheep pastures in Australia. Seeds first germinate with any late spring or early summer rains and the plants rapidly produce flowering cymes. Growth, flower production and seedling continue throughout the summer, the plants dying off in autumn. The seeds then remain dormant in the soil until temperatures reach late spring levels again.

Surveys in semi-desertic areas in the native range of the weed in the Middle East, North Africa and the driest areas of the Mediterranean region led to the discovery of the following organisms, listed in order of importance :
1) *Longitarsus albineus*. The larva of this halticine flea beetle attacks the rootlets of the weed. Both adults and larvae infest the plant immediately after germination and continue to do so during the summer. The species occurs abundantly throughout the native range of *H. europaeum*. It has been recorded only from *Heliotropium* spp.
2) *Pachycerus madidus*. The larva of this weevil attacks the root of *Heliotropium* spp. shortly after germination. It occurs and is often abundant in the eastern part of the native range of *H. europaeum*. Its larvae are considered specific to *Heliotropium* spp.
3) *Ethmia distigmatella*. The larvae of this moth feed within the floral cymes of *Heliotropium* destroying the seeds. It is the only seed feeder discovered on annual *Heliotropium* spp. and occurs frequently throughout the eastern part of the range of the weed. It has been found only on *Heliotropium* spp.
4) *Utetheisa pulchella*. The larvae of this arctiid moth defoliate heliotrope in late summer, usually after considerable seeding has

taken place. A very closely related species, *Utetheisa pulchelloides*, occurs in Australia and causes similar damage in the same season. It thus already fills the ecological niche that would otherwise be available to *U. pulchella*. Both species are largely restricted to heliotrope with occasional records on other Boraginaceae.

5) *Cercospora* spp. These fungi cause partial defoliation of *Heliotropium* by leaf blotching. Although attack occurs fairly early in the season the pathogens are abundant only on the wetter Mediterranean coast in North Africa and are rare in the more inland, semi-desert, indicating lack of adaptation to Australian regions infested by heliotrope. They also occur in colder, continental regions of the Middle East. These fungi also pose quarantine problems since they are the asexual stage of imperfect fungi whose sexual stage is not known and the host range of *Cercospora* spp. has rarely been reliably examined experimentally.

6) *Uromyces heliotropii*. This rust fungus has only been found on 4 occasions despite many observations of a large number of *H. europaeum* sites over several years. However, when the rust occurs it produces a virulent infection. The rust is too rare to consider that plant resistance can have developed to the rust to the extent to explain it's rarity. This is more likely due to a lack of adaptation to the environment of the semi-desertic regions surveyed. Like many monoecious rusts, it is considered to be specific to its host.

7) Several other insect species attack the later stages of annual *Heliotropium* but most belong to groups which are, in general, less specific or pose other quarantine problems.

(Chupp, 1953; Gaumann, 1959; Huber, 1981; Huber *et al.*, 1982).

The priorities for further detailed work on the *H. europaeum* agents are the same as the order given above for the first three agents. Doubts concerning the safety of *Cercospora* spp. will have to be dispelled before work commences on these and *U. pulchella* also has a low priority for the reasons stated thus *U. heliotropii* becomes priority among the organisms whose specificity is not considered in doubt.

DISCUSSION

The brief accounts given of the various biological control agents occurring in the native ranges of *C. juncea*, *E. plantagineum* and *H. europaeum* illustrate how priorities for further detailed study and quarantine safety should have been, or were, set. Priorities represent compromises between the observed effect of the agents on the weed or, in one case, populations in the field situations as closely similar ecoclimatically to those in the infested regions, adjusted for various mitigating circumstances peculiar to the agent concerned, and presumed safety or otherwise. Under these circumstances each organism is considered on its merits as a safe and effective agent for its particular weed.

In the case of *Chondrilla* there was little doubt that the fungal pathogens were the main agents controlling *C. juncea* under field conditions. Adding to the effect of the fungi on the weed were several different types of insects, a cecidomyiid fly, phycitid and tortricid moths as well as an eriophyid mite.

In the case of *Echium*, however, the insect species both in number and in effect, outweighed the single fungus which, being a powdery mildew could not at present be introduced into Australia. A very wide range of different insects are available for *Echium* control including weevils, halticine flea beetles, gracillariid leaf mining and ethmiid bud moths, tingid bugs and a cerambycid borer with many others available for consideration.

The agents on *Heliotropium* are more equally divided between insects and fungi but because of the rarity of the rust, and the doubts concerning the host range of *Cercospora* spp. there is an initial priority for the principal insect species.

Thus the agents for each weed must be considered with an open mind and selected according to the initial observations on their effect on the plant populations and to a knowledge of their probable safety.

REFERENCES

Caresche, L.A.; Wapshere, A.J. (1974). Biology and host specificity of the *Chondrilla* gall mite *Aceria chondrillae* (G. Can.) (Acarina, Eriophyidae). *Bulletin of Entomological Research* 64 : 183-192.

Caresche, L.A.; Wapshere, A.J. (1975a). The *Chondrilla* gall mite *Cystiphora schmidti* Rübsaamen (Diptera, Cecidomyidae). II. Biology and host specificity. *Bulletin of Entomological Research* 65 : 55-64.

Caresche, L.A.; Wapshere, A.J. (1975b). Biology and host specificity of the *Chondrilla* root moth *Bradyrrhoa gilveolella* (Tr.). *Bulletin of Entomological Research* 65 : 171-185.

Chupp, C. (1953). A monograph of the fungus genus *Cercospora*. Ithaca, New York p. 667.

Gaumann, E. (1959). Die Rostpilze Mitteleuropas mit besonderer Berücksichtigung der Schweiz. *Beitr. Kryptogamenflora Schweiz.* 12 : p. 1407.

Hasan, S. (1972a). Behaviour of the powdery mildews of *Chondrilla juncea* L. in the Mediterranean. *Actas III Congresso da Uniao Fitopatologia Mediterranea*, Oeiras. 1972. 171-176.

Hasan, S. (1972b). Specificity and host specialization of *Puccinia chondrillina*. *Annals of Applied Biology* 72 : 257-263.

Hasan, S. (1974). Host specialization of a powdery mildew, *Erysiphe cichoracearum* from *Chondrilla juncea*. *Australian Journal of Agricultural Research* 25 (3) : 459-465.

Hasan, S.; Wapshere, A.J. (1973). The biology of *Puccinia chondrillina*, a potential biological control agent of skeleton weed. *Annals of Applied Biology* 74 : 325-332.

Hasan, S.; Wapshere, A.J. (1977). Biology and host specificity of the *Chondrilla* crown moth, *Oporopsamma wertheimsteini* (Rebel) (Lepidoptera : Tortricidae). *Bulletin of Entomology Research* 67 : 619-625.

Huber, J.T. (1981). Observations on the heliotrope flea beetle *Longitarsus albineus* (Foudras) (Coleoptera : Chrysomelidae) with tests on host specificity. *Entomophaga* 26 (3) 265-273.

Huber, J.T.; Vayssières, J.F.; Wapshere, A.J. (1982). Case to Australian quarantine for introduction of the *Heliotropium* weevil *Pachycerus madidus* (Col. : Curculionidae).

Kirk, A.A.; Wapshere, A.J. (1979). The life history and host specificity of the borer, *Phytoecia coerulescens* (Col. : Cerambycidae) *Entomophaga* 24 (4) 1979, 423-430.

Vayssières, J.F. (1983). Life histories and host specificities of the *Echium* bugs *Dictyla echii* Schr. and *Dictyla nassata* Put. (Hemiptera : Tingidae) (in manuscript).

Vayssières, J.F.; Wapshere, A.J. (1983). Life histories and host specificities of the *Echium* weevils *Ceuthorrhynchus geographicus* Goeze and *Ceuthorrhynchus larvatus* Schultze (Col. : Curculionidae) (in manuscript).

Wapshere, A.J. (1970). The assessment of the biological control potential of organisms attacking *Chondrilla juncea* L. Proceedings 1st International Symposium Biological Control of Weeds. *Commonwealth Institute of Biological Control. Miscellaneous Publication* N° 1 : 81-89.

Wapshere, A.J. (1981). Biological control of Paterson's curse, *Echium plantagineum* : northern hemisphere studies. Proc. V. Int. Symp. Biol. Contr. Weeds, Brisbane : 599-602. *CSIRO Melbourne*.

Wapshere, A.J. (1982). Life histories and host specificities of the *Echium* flea beetles, *Longitarsus echii* Koch and *Longitarsus aeneus* Kutsch (Col. : Chrysomelidae). *Entomophaga* 27 (in press).

Wapshere, A.J.; Caresche, L.A.; Hasan, S. (1976). The ecology of *Chondrilla* in the eastern Mediterranean. *Journal of Applied Ecology* 13 : 545-553.

Wapshere, A.J.; Hasan, S.; Wahba, W.K.; Caresche, L.A. (1974). The ecology of *Chondrilla juncea* in the western Mediterranean. *Journal of Applied Ecology* 11 (2) : 783-799.

Wapshere, A.J.; Kirk, A.A. (1977). The biology and host specificity of the *Echium* leaf miner *Dialectica scalariella* (Zeller) (Lepidoptera : Gracillariidae). *Bulletin of Entomological Research* 67 : 627-633.

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RECENT WORK ON THE ASSESSMENT OF THE BIOLOGICAL CONTROL AGENTS OF EUROPEAN BLACKBERRY (*RUBUS FRUTICOSUS*)

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Summary. European Blackberry (*Rubus fruticosus* aggregate) has become naturalised in many parts of the world and is a particularly persistant weed in both agricultural and non-agricultural areas of southern Australia. Assessment of the biological control potential and the specificity of three candidate organisms is being carried out in Europe.

Rubus fruticosus, biological control.

INTRODUCTION

European blackberry (*Rubus fruticosus* aggregate) has become naturalised in many parts of the world climatically similar to its native habitat in Europe. It is regarded as a serious weed in western U.S.A., Chile, New Zealand and southern Australia (Amor and Richardson, 1980).

In southern Australia, nine species of the European blackberry aggregate have become persistant weeds in both agricultural and non-agricultural areas where the annual rainfall exceeds 760 mm (Amor and Miles, 1974). Control of the weed by chemical and cultural methods is a lengthy and expensive process and can only be carried out in accessible areas.

An Australian program to investigate the possibility of biological control of European blackberry was started in 1977. Surveys conducted in Europe by the Commonwealth Institute of Biological Control (C.I.B.C.) recorded 38 arthropods and 15 fungal pathogens restricted to the genus *Rubus* (C.I.B.C. unpublished report). Most of these attacked cultivated *Rubus* species or did not cause sufficient damage to the weedy species and were therefore not further considered. Field observations indicated that three organisms had a certain potential for the biological control of European blackberry. These are the rust fungus *Phragmidium violaceum*, the stem-boring sawfly *Hartigia albomaculatus* and the purple blotch fungus *Septocyta ruborum*.

This article describes recent work in Europe on the assessment of the biological control potential and the specificity of these organisms.

THE ORGANISMS ATTACKING EUROPEAN BLACKBERRY

The blackberry rust fungus *Phragmidium violaceum*.

The Australian project to investigate the potential of this rust fungus was encouraged by its successful introduction into Chile in 1973 (Oehrens and Gonzalez, 1974). There, a strain of the rust was released after limited specificity testing and only one of the two European blackberry species present in that country has been controlled (Oehrens and Gonzalez, 1977).

P. violaceum is an autoecious and macrocyclic rust, commonly found throughout Europe attacking the leaves, flower parts and unripe fruit of blackberry. The epidemic begins with the inoculation of the emerging leaves in spring by the overwintering teleutospores. After the sexual phase, several generations of asexual uredospores are produced throughout late spring and summer. The windborne uredospores are responsible for the dispersal of the pathogen. In autumn, the pustules produce the overwintering teleutospores. Under favourable climatic conditions, the pathogen causes severe defoliation of the brambles, dieback of the first-year canes (primocanes) and the second-year canes (floricanes) and decreases both the vegetative propagation and the seed production of the weed.

During 1978-79, 40 strains of the rust were collected throughout Europe from European blackberry species which have become weeds in Australia. The 40 strains were then screened individually for virulence to *Rubus procerus*, the most widespread species of European blackberry in Australia. Out of the 40 strains, the 15 most virulent to *R. procerus* were selected and multiplied. These strains were then screened for virulence on the other 8 species of European blackberry present in Australia.

A total of 100 test plants of the family Rosaceae were selected to ensure that the fungus is specific to European blackberry. The test plants were selected because of their importance to Australia, New Zealand and Papua-New Guinea. The specificity tests on these plants are currently under way. They are being carried out with a mixture of equal parts of the 15 strains selected as being the most virulent to *R. procerus*. Since the strains originated from widely separated areas, there is a wide margin of genetic variability in the spore mixture used in the specificity tests. Results of the tests will thus give a more accurate idea of the specificity of the rust fungus.

The blackberry stem-boring sawfly *Hartigia albomaculatus*.

This univoltine and parthenogenetic sawfly oviposits into succulent primocanes as they emerge from the rootstock in spring. The larvae tunnel into the pith of the primocanes. Preliminary observations throughout Mediterranean Europe showed that at high levels of attack, the pith was completely destroyed and the primocanes collapsed. Dieback of the primocanes occurred and there was no formation of daughter plants at their tips in autumn. (C.I.B.C. unpublished report).

The biological control potential of this insect was studied in the Montpellier area of southern France (Bruzzese, 1982), an area which is climatically similar to areas infested by the weed in Australia. Results showed that although most primocanes were attacked, there were insufficient numbers of larvae in each primocane to cause severe damage.

The specificity of this insect depends on the oviposition behaviour of the adult. Tests were carried out on 35 plant species comprising 11 families, selected using the centrifugal phylogenetic strategy and with reference to the safeguards suggested by Wapshere (1974). Although in Mediterranean Europe the insect is found only on a few species of European blackberry, the larvae were able to feed on a numer of cultivated brambleberry and rose varieties under the testing conditions. Raspberry (*Rubus idaeus*), the most important *Rubus* crop, was not attacked (Bruzzese, 1982).

The blackberry purple blotch fungus, *Septocyta ruborum*.

This fungus attacks the base of succulent, young primocanes in late spring and summer. At the end of summer, the infection appears as reddish-purple areas, 2-3 cm in diameter, at the base of the primocanes. The pathogen remains inactive during winter but in early spring the infection recommences, progressing towards the tip of the primocane (Punithalingam, 1980). The primocane is killed, thus stopping the formation of the floricanes which bear the flowers, fruits and seeds. The daughter plants at the tips of infected primocanes are also killed before they become independent from the mother plant. Loss of over 80% of fruit production has been recorded in Switzerland on a cultivated variety of *R. procerus* (Koellreuter, 1950).

Preliminary field surveys have shown that this pathogen causes serious dieback of a number of species of European blackberry in areas climatically similar to areas where the weed is a problem in Australia. A literature survey and a search in the fungal collection of the Commonwealth Mycological Institute has shown that the fungus is recorded only on species of the European blackberry aggregate (Punithalingam, pers. comm.).

DISCUSSION

European blackberry is a difficult candidate weed for biological control, due to the large number of closely related cultivated plants. An additional difficulty is that only three out of the 53 organisms which are specific to *Rubus* spp. in Europe were considered to be both sufficiently specific and damaging to the weed to warrant further studies.

Of the three organisms, the rust fungus *P. violaceum* has the greatest potential for the biological control of European blackberry. It weakens the thickets by continual defoliation throughout spring and summer, attacks the flower parts and fruits and decreases the vegetative propagation of the plant. The spores of the pathogen are windborne, thus enabling it to spread rapidly throughout the weed infestation. Furthermore, strains highly virulent to the Australian species of European blackberry have been found and selected for further study. Results of the specificity tests will indicate whether the rust is suitable for introduction to Australia.

Assessment of the blackberry stem-boring sawfly, *H. albomaculatus*, has shown that in Mediterranean Europe its potential for reduction of blackberry thickets is low. The insect has no significant detrimental effect on the vegetative reproduction of its host, one of the most important weedy characteristics of the plant. It could however, build up important populations on another continent, where it would be free from its own parasites. Because *H. albomaculatus* has the potential of attacking some brambleberry crops and some rose varieties, permission to introduce it to Australia is unlikely to be granted. It could however be of interest to other countries where these plants are not commercially important.

No assessment has yet been made of the potential of the blackberry purple blotch fungus *S. ruborum*. Field observations and a literature review indicate that this pathogen seriously damages the weed and may be specific. Since this fungus is easily cultured on artificial media (Koellreuter, 1950), it has potential for development as a bioherbicide specific to European blackberry.

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REFERENCES

Amor, R.L.; Miles, B.A. (1974). Taxonomy and distribution of *Rubus fruticosus* L. agg. (Rosaceae) naturalised in Victoria. *Muelleria*, 3, 37-62.

Amor, R.L.; Richardson, R.G. (1980). The biology of Australian weeds. 2. *Rubus fruticosus* L. agg. *Journal of the Australian Institute of Agricultural Science*, 46, 87-97.

Bruzzese, E. (1982). The host specificity of *Hartigia albomaculatus* (Stein) (Hym.: Cephidae) and its potential effectiveness in the biological control of European blackberry. *Entomophaga*, in press.

Koellreuter, J. (1950). Morphologie und biologie von *Rhabdospora ramealis* (Desm. et Rob.) Sacc. *Phytopathologische Zeitschrift*, 17, 129-160.

Oehrens, E.B.; Gonzalez, S.M. (1974). Introduccion de *Phragmidium violaceum* (Schulz) Winter como factor de control biologico de zarzamora (*Rubus constrictus* Lef. et M. y *R. ulmifolius* Schott.). *Agro Sur*, 2, 30-33.

Oehrens, E.B.; Gonzalez, S.M. (1977). Dispersion, ciclo biologico y danos causados par *Phragmidium violaceum* (Schulz) Winter en zarzamora (*Rubus constrictus* Lef. et M. y *R. ulmifolius* Schott.) en la zonas centro-sur y sur de Chile. *Agro Sur*, 5, 73-85.

Punithalingam, E. (1980). *Septocyta ruborum. C.M.I. Descriptions of Pathogenic Fungi and Bacteria* No. 667.

Wapshere, A.J. (1974). A strategy for evaluating the safety of organisms for biological weed control. *Annals of Applied Biology*, 77, 201-211.