SESSION 9A

POTENTIAL FOR REDUCING HERBICIDE INPUTS/RATES – DEFINING SITUATIONS AND TECHNIQUES

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POLITICAL AND PRACTICAL APPROACHES IN SCANDINAVIA TO REDUCE HERBICIDE INPUTS

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ABSTRACT

In the Scandinavian countries Norway, Sweden and Denmark political attempts are being made to reduce pesticide input in order to avoid contamination of water resources and foodstuffs and undesireable effects on flora and fauna. In Sweden in 1986 a political demand of a 50% reduction before 1990 was adopted. In that same year the Danish Parliament passed a Plan of Action stipulating a 25% reduction before 1990 and a further 25% reduction before 1997. Norway in 1989 got their Plan of Action with the objective of reducing the use of pesticide as much as agriculturally defensible. Means to achive these goals were substantially similar: An extended advisory service on the use and handling of pesticides, obligatory training of spray applicators, intensified research on chemical and non-chemical control methods, and standards for and tests of field sprayers' performance.

Sweden managed to half their pesticide use mainly through reducing dosages and partly by shifting to highly active pesticides. In Denmark a 25% reduction of active ingredient was obtained, but a desired reduction of treatment frequencies failed. Furthermore, with the reevaluation of pesticides used in the 1980's a great number are being withdrawn from the market.

Sweden in 1990 decided on another halving of the pesticide use. In Denmark a political debate is in progress concerning the governmental plan of "Creating a Sustainable Agriculture", stipulating a 25% reduction of active ingredient before 1997. The demand in the original plan of reducing also treatment frequencies was omitted.

Continued efforts in areas of advising, education, and research are major means to fulfill the new goals, but in future weed control must be an integrated part of an economic husbandry system. This calls for new approaches to weed research.

INTRODUCTION

There has been a growing concern in the Scandinavian countries about the environment and environmental problems since the mid-1980´s. Agriculture is involved in the ongoing environmental debate; especially in the domains of fertilizer and pesticide usage. The foremost consideration is to prevent the pollution with nitrate and pesticide residues of the aquatic environment, specifically groundwater resources, but also of streams, lakes and the sea. In the case of pesticides there is also the concerns that foodstuffs should not contain residues, and of avoiding harmfull effects on wildlife flora and fauna. In the following paper an analysis will be presented of the political and practical measures so far adopted in Norway, Sweden and Denmark.

In Norway and Sweden the fundamentals of agricultural policy has been to preserve the national self-sufficiency of agricultural products, at the same time maintaining the continued habitation of rural districts; even in regions with adverse climate and soil conditions. In recent years this policy has entailed an agricultural overproduction, necessitating the opening of an export of surplus produce to the world market. The costs of the state subsidizing this export has pressed for a general reduction of prices on agricultural produce in both countries. Especially in Sweden transitional arrangements has been introduced which in few years will bring down prices to a level comparable to that of the European Community.

Danish agriculture has for long had a large export trade and this has contributed considerably to the foreign exchange income. As Denmark has been a member of the European Community since 1972, Danish agriculture is subordinate to those price and quota policies laid down by the Community. There is currently an attempt to drastically revise these policies. The conclusions of the GATT negotiations of a world-wide agreement on free trade of agricultural produce will be expected to will play a dominant role. So far, however, the scenario has not required a policy of intentionally reducing the Danish agricultural production through extensification by introducing restrictions on the use of pesticides and fertilizers.

Norwegian pesticide policy in principle differs from that of Sweden and Denmark, in that figures have not been stipulated by how much the use of pesticide is to be reduced. In February 1989 the Norwegian Parliament decided to "urge the Government to produce a five-year plan of action with the objective of reducing as much as defensible the use of pesticides in agriculture". An inter-ministerial work party drew up a Plan of Action, which officially came into force by January 1991 (Stubsjøen, 1991). The plan contains the following measures:

- Improvements of information through a campaign titled "Focus on the Environment"
- Research projects: Control thresholds, prognoses, forecasting
- Monitoring and mapping of pesticide residues in the hydro-sphere
- monitoring of pesticide residues in plant products
- functional tests of spray application equipments
- compulsory authorization of dealers and users of pesticides
- control system for the trade and use of pesticide at the farm-level.

The last three initiatives are exptected to come into force this year (Stubsjøen, 1991).

Furthermore it is presupposed that a range of development projects will be initiated concerning plant protection.

The Norwegian government appropriated 22.6 million NK (c. 2 million sterling) in 1991 towards the fulfillment of the plan. It was stated in the recommandations underlying the Plan of Action that a regulation of pesticide consumption through legislation is difficult, and that the objectives of the plan should be reached through motivating and improving the knowledge of the pesticide user. These measures are partly financed through the environmental taxes introduced in 1988 on fertilizer and pesticides.

The Swedish government in 1986 passed a five-year plan aiming at reducing the use of pesticides to 50% of the average amount used during the years 1981-1985, measured as million kg of active ingredient. Measures to reach this objective were detailed by a working party comprising the National Agricultural Board, the Environmental Protection Board and the National Chemicals Inspectorate, and they included:

- an extended advisory service concerning specifically the potential of using reduced dosages, and extended services of forecasting pest and disease levels
- intensified research in chemical as well as non-chemical control methods
- development of standards for spray application equipment and voluntary access to official tests of field sprayers
- introduction of a price regulating tax on each single pesticide fixed in accordance with the recommended dose ha^{-1}.

It must be noted that Sweden had already in the 1960's introduced users' courses as a precondition for the buying and use of pesticides from the highest toxicity class. Effective from 1990 this was intensified such that a 3-day course must be taken as a prerequisite for buying and using for occupational purposes pesticides of the second toxicity class, and a further one-day course for permission to use the chemicals from the first toxicity class. Validity of permissions issued are limited to five years.

It has not been possible to calculate the total costs of these initiatives. In Sweden two types of taxes are imposed on pesticides: the aforementioned price regulating tax amounting to 29 SK per hectare dosage, bringing in some 80-90 million SK annually; and an environmental tax which for pesticides has been fixed at 8 SK per kg active ingredient since 1988, and annually brings in 25 million SK. The yield of the environmental tax is allocated to the programme of halving pesticide use, whilst the price regulating tax is primarily linked to subsidies for the export of surplus production of cereals. In a report from 1990 it was concluded, that the consumption reducing effect of these taxes was negligible, merely counting for a calculated 2% of fungicides and insecticides.

The Danish government in 1986 also passed a Plan of Action with the objective of reducing the pesticide use to 75% by 1990 and further down to 50% by 1997 relative to the average consumption during the years 1981-1985. These reduction figures must be reached both in terms of million kg of active ingredient used nationally and in terms of treatment frequencies. The treatment frequency is defined as the number of standard recommended dosages with which the total agricultural area is treated annually. It is calculated by converting the registered sale of each pesticide to a corresponding area potentially to be treated with the standard dosage; the summation of area-figures for all pesticides divided by total agricultural area, then, produces the treatment frequency. It was indicated in the Danish Plan of Action that in evaluating the pesticide consumption considerations should be given to alterations taking place in crop rotations, to natural oscillations in the need for combatting pests and diseases, and also to the possibility of less harmful chemicals gradually being introduced.

To pursue those aims established the following measures was indicated:

- advisory service to the farmers
- research on the exploitation of preventive measures, forecasting and control thresholds, on the optimized use of pesticides and on biological and mechanical control techniques
- obligatory training of applicators
- obligatory spray records
- obligatory approval of spray application equipments
- extension and differentiation of the existing taxing system
- establisment of acceptable limits to the environmental loading.

Of these measures only the first three mentioned were implemented, whilst the remaining four were postponed or relinquished following negotiations in parliamentary committees.

To finance this plan a 3% tax was impelled on the sale of pesticides to yield 30-40 million DKK annually. The intention is that roughly 1/3 shall accrue to education and advisory service, 1/3 to research, and 1/3 to the reevaluation of pesticides on the market.

RESULTS

Developments in the consumption of pesticides (million kg of active ingredient) in the three countries are shown in Table 1. Norwegian figures only shows the present level. In Sweden the 50% reduction aimed at has been reached. Consumption figures for 1990 showed a reduction of 47 % of active ingredient used achieved through the use of reduced dosages and improved spray application equipment, as well as by changing to the use of highly active chemicals.

TABLE 1. Consumption of pesticides in Norway, Sweden and Denmark in the years 1981-1990 is stated in million kg A.I. (1) Fykse, 1991 2) Lantbruksstyrelsen, 1991 3) Miljøstyrelsen, 1990 4) Bendiksen, 1991)

	81-85	86	87	88	89	90
Norway[1)]						
Total						
Pesticides	1.46	1.51	1.32	1.19	1.03	1.18
Herbicides	1.24	1.19	1.06	0.92	0.86	0.96
Sweden[2)]						
Total						
Pesticides	4.53	5.68	2.52	2.98	2.52	2.45
Herbicides	3.54	4.21	1.78	2.03	1.78	1.66
Denmark[3)]						
Total						
Pesticides	6.69	6.46	5.82	5.74	6.32	6.03[4)]
Herbicides	4.35	4.03	4.08	3.96	4.28	3.49

Danish figures show that a 20% reduction in kg active ingredient was reached. In a report adressed to the government it is claimed, that if actual changes in crop rotation are considered, the 25 % aim has in fact been reached (Miljøministeriet, 1990). From Table 2, showing the development measured as treatment frequencies, it is apparent, however, that no reduction was attained; even taking changes in crop rotation into account.

TABLE 2. Frequency of treatment calculated as number of treatments with recommended dosage (Kjølholt, 1985 and 1989).

Year	Herbicide	Growth regulator	Fungicide	Insecticide	Total
74	0.95	0	0.10	0.25	1.30
81	1.07	0.05	0.30	0.22	1.64
82	1.20	0.08	0.55	0.37	2.20
83	1.36	0.15	0.97	0.50	2.98
84	1.40	0.23	1.34	0.59	3.46
85	1.33	0.18	0.98	0.58	3.06
86	1.27	0.20	0.63	0.58	2.68
87	1.35	0.16	0.54	0.42	2.47
88	1.43	0.14	0.56	0.46	2.60
89	1.61	0.17	0.73	0.76	3.26

Future goals

In Denmark, as well as Sweden, work has been carried out in recent years to set up goals for the future development of pesticide usage. The Swedish government in 1990 decided that another halving of the active ingredient consumption in agriculture be carried out. Mesasures to reach this goal are generally a continuation of the activities already implemented. The Danish government produced a plan for creating a sustainable agriculture (Landbrugsministeriet, 1991). Preconditional to this Plan of Action is the government's desire that the agricultural industry will continue to produce high-quality foodstuffs, for home consumption as well as for export, by environmentally and ethically defensible methods, that production can be carried out without public subsidies, and that the trade within the framework of the EEC agricultural policy can produce working conditions and earning powers comparable to other trades. It is also established, that the competitive ability internationally of the agricultural industry must be considered when unilateral Danish environmental measures are taken.

In the field of pesticides the stage has been set for a further 25% reduction by 1997 of active ingredient used, thereby maintaining goals of the original Plan of Action. However, a cancellation of the original demand of similar reductions of treatment frequencies is proposed. What will be the outcome of the ongoing negotiations in

Parliament is rather uncertain, especially noting that these is presently a minority government. Reasons produced for cancelling a reduction in treatment frequencies are that the pesticides in current use are less toxic, implying a reduced pollution risk, and are effective in lower amounts.

Re-evaluation of pesticides in respect of toxicity and environmental loading

A re-evaluation of toxicity and environmental effects of older pesticides together with the desire of a reduced level of pesticide consumption has played a major role in the policies staked out in the mid-1980's. Approval for sale of pesticides in Norway are given from the Toxicology Jury under the Ministry of Agriculture, in Sweden from the National Chemicals Inspectorate under the Ministry of Environment, and in Denmark from the National Agency of Environmental Protection under the Ministry of Environment. In Norway and Sweden a concerted evaluation is made of the risk of each single pesticide, old as well as new. In Denmark the Agency of Environmental Protection set up thresholds for ten criteria not to be exceeded by any pesticide. Criteria are mainly toxicological, but also characteristics like persistency, leaching and bio-accumulation are included.

In Sweden and Denmark it was decided politically that all pesticides marketed before 1986 be re-evaluated. The re-evaluation in Sweden must be finalized by 1991 and in Denmark by 1993. In Sweden the reevaluation so far resulted in the withdrawal of around 200 pesticides, mainly on the ground that agrochemical companies did not want to produce the new evidence demanded, but also some chemicals were withdrawn having been found too hazardous or relatively ineffective. In Denmark the re-evaluation of herbicides will soon be concluded. A withdrawal of around 30% of the active ingredients is expected, again mainly the premises being, that sufficient evidence was not produced for older chemicals with a limited application anyway. But also the prohibition of further sale of some herbicides of wide application was announced. These prohibition have not been executed yet, as decisions have been taken to a board of appeal. It is to be expected that Danish policy will gradually be adapted to the EEC Council of Ministers' directive on "EEC accepted plant protection products".

DISCUSSION AND CONCLUSION

Irrespective of the approval only of toxicologically and environmentally "safe" herbicides by the Scandinavian authorities, the political demands are maintained of a continued reduction of pesticide use. As herbicides make up 70-80% of the total pesticide use in Scandinavia a reduction cannot be fulfilled without herbicide use being drastically reduced. The continuous development in the chemical industry of novel low-dose chemicals and a shift to chemicals composed of active isomers only will contribute substantially to such reduction in the years to follow. Political initiatives to reduce plant production through fallowing and afforestation of former agricultural areas, and the subsidizing of transitions to organic farming, will in Denmark presumably lead to a 10% reduction of the pesticide treated area within 5-10 years. An even larger reduction is expected in Norway and Sweden. The remaining part of the intended reduction of herbicide usage will have to be met through:

- intensive dissimination of our present knowledge on preventive measures, crop rotation, varieties, and cultivation techniques,
- establishment through research of the control requirements in relation to differing crop and weeds,
- guidance in the use of reduced dosages and split application,
- dissemination of the potentials of implementing mechanical weed control.

In Sweden, as well as Denmark, the advisory service worked to provide farmers with this knowledge. In Sweden the State Agricultural Board in 1990 and 1991 placed 100-150 cereal demonstration fields in all parts of the country. In each field the full, half and quarter of normal recommended treatment dosage was applied. Through such demonstrations the Advisory Service intended to show that reduced dosages are possible, when herbicide and weed flora match. In Denmark dissemination was carried out by the formation of a number of groups of eight farmers who, guided by an agricultural consultant, during the growth season meet to discuss actual potential for reducing the use of fertilizer and pesticide, thereby reducing production costs. In 1991 eighty such groups were formed, and for many this meant a drastic reduction in the use of pesticides. It is hoped, that the good example of these farmers can procure a change in attitude generally to the use of pesticides. The economically difficult conditions for plant production is a key factor in motivating farmers to gain the knowledge needed to handle a reduction of herbicide use without negative consequences for yield and cultivation reliability. The knowledge available in the weed domain is of proportions difficult to handle and up-date for the practical farmer. It is therefore urgent to develop computorized advisory tools accesible to farmers. "PC-Planteværn" a computericed advisory system developed in Denmark (Baandrup, 1989) and testet in cooperation with the Danish Agr. Advisory Center was released in the spring 1991. Such systems, through a frequent up-dating, will secure a rapid exploitation of novel research findings.

The political expectation is of a transition to integrated cultivation systems, combining preventive measures in the form of crop rotation, tillage methods, choice of varieties, time and density of sowing and fertilizing strategies. That is, control thresholds, reduced pesticide dosages, split applications and mechanical control will make heavy demands on the research and advisory service in the weed domain.

In future it is not sufficient to consider weed problems apart. With a prospect of European prices on crop products approaching world market prices it becomes necessary to evaluate economically the husbandry systems as a whole. This for instance might mean, that to facilitate the prevention of fungal diseases a more open crop canopy is sought for, making greater demands on the weed control.

Future research in the weed domain must aim at being applicable in integrated cultivation systems, meaning the exploitation of interactions between a wealth of factors. But demands on the knowledge of the farmer, who must be able to comprehend the integrated system, seem unrealistic unless computorized advisory systems are developed. These, on the basis of a description of the actual conditions, then must be able to indicate an optimized strategy of cultivation and capable of adjusting the strategy throughtout the growing season according to changing growth conditions.

Within a time limit of only 3-5 years this is an unrealistic prospect. Still, however, it is important that research efforts in the weed domain in the years to come aim at being applicable also in those advisory models necessary for future integrated husbandry systems.

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OPTIMISATION OF HERBICIDE USE IN FRANCE

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ABSTRACT

Association de Coordination des Techniques Agricoles initiated a project in 1987 named "optmisation of herbicide use", in which several extension and research institutes and universities, as well as the Rhône Poulenc company, took part. In this context, optimisation means lowering the ratio between the applied quantity of a pesticide and the quantity which reaches its biochemical target. The primary aim of the project was to assess the weight of the factors affecting herbicide efficacy in French field conditions, so as to disseminate among farmers reliable information about the feasability of modifying herbicide dosage. The paper describes the assessment of the so-called "Gentet method" as well as the current trends in which the project is now engaged : dose variation as a function of weed species and stage (Institut Technique des Céréales et des Fourrages) and seed oils as additives.

INTRODUCTION

As in other European countries, attempts are being made in France to optimise herbicide use. This is a relatively recent trend since it commenced at the beginning of the 80's. Although its environmental implications are now fully appreciated, it actually originated from economical considerations. At this time, due to the shift of European Community agricultural price policy, margins started to decline and some farmers together with their advisers judged that crop protection was a budget item more amenable to reduction than fertilisers or seeds. It must be stressed that although individuals from official services did give the impetus to optimisation, their institutions did not support them at the beginning, although research and extension institutes later played a decisive part in rationalising practices and erecting safeguards. The unusual way the movement developed explains some of its present features, and it is worthwhile taking a look at its history.

To this end it is appropriate to present the different actors in this evolution. ITCF (Institut Technique des Céréales et des Fourrages) is an extension institute devoted to cereals and fodder. Basically, it is funded by levies on cereals sales by farmers. ITB (Institut Technique de la Betterave) is the extension institute for sugar beet, also financed through levies. ACTA (Action de Coordination des Techniques Agricoles) coordinates the work of crop-based institutes. Chambres d'Agricultures are found at the "département" and regional levels. They stem from the Ministry of Agriculture to give technical and economic advice to farmers. CETA (Centre d'Expérimentation des Techniques Agricoles) are groups of farmers financed by a subscription on a hectare basis. Their aim is the dissemination and exchange of information among their members, as well as local adaptation of new techniques. To that end they are often supported by the Chambres d'Agriculture to carry out field assays and training. The technical level of these farmers is generally very high and they are very innovation-minded. INRA (Institut National de la Recherche Agronomique) is a research institute devoted to basic science related to agriculture.

THE GENTET METHOD

At the begining of the 80's French farmers were not familiar with low application volumes and there was a widespread belief that weeds had to be extensively wetted (300-500 l ha^{-1}) for optimum herbicide efficacy. To decrease costs and increase spraying opportunities, experiments had already been carried out to reduce application volumes (Gentet, 1977 ; Bouchet *et al.*, 1981). A decisive part was played by C. Gentet, in charge of the spraying department of ACTA, who studied to which limit application volume could be reduced and what constraints it implied in the design and the operation of the sprayer. He also promoted information and training campaigns for farmers, mainly among CETAs.

The first results showed that, provided that some care was exercised in the preparation of the spray mixture and a few flow problems in the sprayer were resolved, it was possible to go down to 75 l ha^{-1} with flat fan nozzles. Secondly, it was realised that the herbicides tested did not lose efficiency at low volumes (Gentet, 1977 ; Bouchet *et al.*, 1981). Thirdly, when low volumes were assayed in sugar beet weed control, a tremendous increase in phenmedipham ("Betanal") efficiency was sometimes observed. We now know that the main reason lies in phenmedipham crystallisation (Galoux *et al.*, 1986) due to partial solubility of isophorone (phenmedipham solvent in the product) in water. As the water / isophorone ratio diminishes, more solvent is available to dissolve the herbicide.

Opportunities for dose reductions were explored and in further trials at low application volumes the herbicide dose was halved or divided by 4. But phenmedipham then showed poor efficacy since more of it crystallised due to the increase in the water / isophorone ratio. Given these conflicting results C. Gentet, joined by B. Demaine (Ile de France Chambre d'Agriculture), tried tank mixes of isophorone with low doses of phenmedipham in field experiments, and observed that it often gave good and inexpensive weed control. The method rapidly became popular among the farmers who had made their fields available for the trials; especially the members of the CETA in Magny en Vexin, near Paris. C. Gentet and B. Demaine further improved phenmedipham action thanks to early treatment, at the cotyledon or first-leaf stage of the weeds, even though it often implied several successive treatments. This was new in sugar beet weed control because the previous herbicides were fully selective only when the crop had developed 4-6 leaves, whereas because of phenmedipham's good selectivity, it was then possible to pay exclusive attention to the weed stage.

The success of isophorone addition to phenmedipham led to the idea that the biological efficacy of commercial preparations could be improved, the more so as it was realised that the main constraint in herbicide formulation was physico-chemical stability ; biological efficacy was secondary. C. Doux, chemistry teacher at the School of Agriculture in Toulouse, suggested further additions to phenmedipham and a rather complex mixture was then proposed to farmers. It was popularised under the names "mélange (mixture) Gentet", "cocktail Gentet", "sauce Gentet" ... Its composition was indicated on a ha basis : 0.5 l isophorone, 0.5 l mineral oil, 0.1 l wetting agent and 5 l liquid nitrogenous fertiliser (39 % mixture of urea and ammonium nitrate in water). Recommended application volume was 75 l ha^{-1}. The rationale behind these additions was that isophorone would dissolve the active ingredient, oil would further increase efficacy, the wetting agent would increase spray retention and liquid nitrogenous fertiliser would, in spite of its low dosage, add some phytotoxic action.

The cocktail's fame spread, moving quickly from CETA to CETA, but C. Gentet was adamant that it should not be recommended like a cooking recipe but integrated in what was advertised as "Méthode Gentet". It consisted in particular attention being paid to sprayer performance, low (< 100 l ha^{-1}) application volumes, the addition of the Gentet cocktail and treatment at the earliest possible stage of the weeds. The "Méthode" was taught only after C. Gentet had tested and improved the sprayers, trained the farmers in their proper use and given basic knowledge on herbicide and adjuvants mode of action.

At that time no research had been done in France on these aspects of herbicide action and the promoters of the Gentet method were to a large extent unaware of the results already obtained abroad on related subjects. Betanal's odd behaviour obscured the issue and the strange belief grew that what mattered in weed control was not herbicide dosage per hectare but its concentration in the spray mixture. Moreover, the lack of scientific background favoured hasty conclusions and generalisations, for instance the naive belief that the same mixture of additives could be used with all herbicides in every crop!

Indeed, the Gentet method was also used in cereal weed control. Diclofop-methyl doses were said to be halved and C. Doux advised bringing the spray mixture pH to 10, hoping in this way to "destabilise the cuticle". Because of confusion with foliar fertilisation, this was in some places misinterpreted as acidification so that we had either "acidic" or "alcaline" CETAs. Still on an anecdotal note, alcalinisation did marvels when a few people brought it back to sugar beet weed control since in such conditions phenmedipham half life is measured in minutes! Dose reduction of isoproturon and bifenox cereal herbicides were not only advised but also recommended because of selectivity problems. When used with the latter herbicide the effects of the Gentet cocktail were spectacular : the wheat leaves which were developed at the time of the treatment became chlorotic and dessicated. Under good growing conditions the crop generally recovered. Promoters of the Gentet method ascertained that no yield loss was to be feared but many farmers did not share this optimism, in particular those who had to sow again. However, it seems that the groups of farmers who applied the method under close supervision by C. Gentet and B. Demaine met with success.

THE INITIAL REACTION OF OFFICIAL INSTITUTIONS

Although C. Gentet and B. Demaine worked in official services (ACTA and Ile de France Chambre d'Agriculture respectively), they were far from being fully supported by their institutions. Of course, these had to take a stance since they were questioned by the ablest farmers about the validity of the Gentet method. They saw positive aspects in it but were embarassed by others.

The positive aspects of the Gentet method

First of all it fought against systematic treatments (half of them were probably unnecessary) and it supported the trend towards postemergence treatments. Secondly, in field trials it had of course long been noticed that the recommended dose could sometimes be disappointing whereas in other instances a reduced dose was satisfactory. This is amplified in France by the need for a registration dose to be the same all over the country, which means in places meteorogically similar to England in the North and to Spain in the South. But until the 80's everybody was satisfied with the use of full recommended doses and the Gentet method upset this peaceful state of affairs and led people in France to start thinking about herbicide efficacy.

In addition, farmers who tried out the method had a closer look at their sprayer and thought more deeply about its operation. This might seem trivial but was indeed a major contribution of the Gentet method. Finally, farmers were led to visit the fields more regularly to watch weed emergence and spray as early as possible.

<u>The pitfalls of the Gentet method</u>

The major pitfall was that the promoters of the method gave only scarce experimental evidence of its validity. Moreover, when the extension institutes (above all ACTA and ITCF) assayed low volume applications and the Gentet cocktail, it did not work so well with a root-acting herbicide like isoproturon, and it had no significant effect with broadleaf herbicides (mixtures of auxin-like and contact herbicides). Only with graminicides such as flamprop-isopropyl and diclofop-methyl was a better efficacy observed - insufficient, however, to allow a halving of the dose (Dumont, 1983 ; Dumont and Bouchet, 1983). In sugar beet weed control results were also disappointing (Deterre, 1983 ; Muchembled, 1983). The explanantion might be that the Gentet method consisted in the simultaneous improvement of several spraying parameters, possibly with some synergy, whereas in their trials the extension institutes tested only one or two aspects of the method. Indeed, the proper control should have been the treatment of well developed weeds, at 500 l ha^{-1}, at the wrong time of the day, by means of a poorly adjusted sprayer (state of the nozzles, height of the boom, pressure, etc). Of course, the sprayers of ACTA, ITCF and ITB operated in optimal conditions. In addition, their treatments might have taken place at a later stage of the weeds than required by the Gentet method. As pointed out by Bouchet (ACTA) in a discerning article (1984), the predominent parameter among all those listed above was the sprayer setting, followed by the growth stage of weeds.

Two further points embarassed the extension institutes. The Gentet method recommended mixtures of pesticides, which poses a legal problem in France if the compounds are marketed by different companies - not to mention the traps of physico-chemical compatibility! Moreover, the extension institutes are bound to give the same advice to everyone, irrespective of their technical competence which may vary considerably from one farmer to another. The dangers of the Gentet method and the technical ability required to implement it (starting with putting the mixture in the tank properly!) forbade its broad dissemination.

A limited number of farmers have seriously tried the Gentet method. Its implementation is still very patchy, whole regions having no notion of its existence. No survey was published and probably none was carried out but some people estimate the number to be much less than 10,000. This represents 1 % of French farmers, but about 5 % of those who grow cereals and sugar beet efficiently. However, the influence of the method went far beyond them and lasted longer than expected because its very existence convinced many farmers that reductions in pesticides dosage were often possible but that they were not given the proper advice to implement them. There was even loose talk of a conspiracy between official services and companies to maintain unnecessarily high pesticides doses! The belief spread that adding various compounds to herbicide preparations could improve their efficacy and since the mid 80's many additives have been tried (unfortunately not based on experimentation) from salt and tank cleaners to carbon dioxide and even milk. Interviews of farmers putting forward substantial dose reductions through low application volumes, and the use of additives flourished in agricultural newspapers. Extension institutes kept being asked to assay more or less exotic additives which appeared in every part of France, sometimes only to vanish a few months afterwards, too often retailed by unscrupulous practitioners. ACTA, which had rather unwillingly given birth to the Gentet method, decided that some more work had to be done on the subject, in order to disseminate reliable information among farmers on the factors affecting herbicide efficacy.

OPTIMISING HERBICIDE USE

This was the designation of a project initiated in 1987 by ACTA and led by F. Severin, who defines optimisation as lowering the ratio between the applied quantity of a pesticide and the quantity which reaches its biochemical target (Severin, 1988). In fact, ACTA and ITCF had been experimenting on various aspects of herbicide efficacy since 1983 and the new project was intended for information exchange, coordination of new experiments and involvement of more basic studies. At the outset, it associated several extension institutes, universities and research organisations, as well as the Rhône Poulenc company, but only ACTA, ITCF and INRA took an active part in the studies, together with Rhône Poulenc whose help in formulation was decisive. They examined, in French conditions, the influence of additives and climate on herbicide efficacy and selectivity.

Additives

Because of its origins the project was biased towards additives. A first step was to assess what occurred as regards herbicide efficacy and selectivity when a farmer used the Gentet cocktail. To that end wheat was chosen as the crop, ryegrass as the weed whenever possible, together with isoproturon (a root-acting herbicide sprayed in a non-dissolved state) and diclofop-methyl (a foliage-acting herbicide sprayed in a dissolved state). Only a few studies were carried out with broadleaf herbicides (mixtures of auxin-type and contact compounds) because they had shown limited increase in efficacy and severe injury to wheat (Fabre and Jouy, 1986).

Isoproturon

Since isoproturon is a cheap herbicide, ACTA wanted to see whether the trouble of preparing the Gentet cocktail was worth the crop injury risks. In a three-year study Duvernet found, in 1985, a 20 % increase in isoproturon efficacy against *Alopecurus myosuroides* with either the cocktail or petroleum oil as additives, but this was observed neither in 1986 nor in 1987 on *Poa annua* and *Lolium multiflorum* (Duvernet, 1988). In 1985 selectivity was not impaired, unlike in 1986 and 1987. Gain in efficacy and loss in selectivity seemed in some way to be related to meteorological conditions, but no clear-cut conclusions could be drawn. As for ITCF, in a three-year study (1983 to 1985), no effect of the Gentet cocktail was detected on isoproturon efficacy against *Alopecurus myosuroides* (Fabre and Jouy, 1986). Another series of ACTA outdoor studies on *Lolium multiflorum* (1985-1989) led to the same conclusion (Beaufreton *et al.*, 1989).

Although isoproturon is a post emergence herbicide, it is a root-acting compound (Blair, 1978), whose location in the soil relative to the roots (of the crop and the weeds) plays a great part in selectivity (Blair and Martin, 1987). This might explain why the action of adjuvants promoting foliar activity is so erratic. In a controlled environment, we showed that the Gentet cocktail increases spray retention by wheat but not ryegrass (Gauvrit and Dufour, 1990a), and that herbicide penetration is promoted to a greater extent in wheat than in ryegrass (Fig. 1). This explains the observed decrease in selectivity. However, since injury to wheat occurs at an early stage in its development (3-leaf to 1-tiller), no influence on yield is generally detected .... provided that no water stress occurs in late spring or in summer (Chadeuf *et al.*, 1991). Indeed, yield losses do not seem to be uncommon when isoproturon is added with the Gentet cockail, especially in the southern half of France. Hence, the message to farmers was that using oil or the Gentet cocktail with isoproturon is questionable.

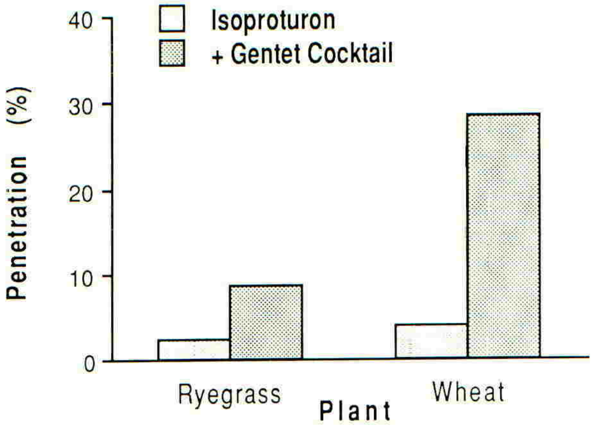

Figure 1 : The effect of the Gentet cocktail on the foliar penetration of isoproturon (formulated as a flowable concentrate) in wheat and ryegrass. SE = 2.7 (8 d.f.). Adapted from Gauvrit and Dufour (1990a).

Diclofop-methyl

Outdoor experiments at ACTA (Bouchet and Beaufreton, 1988 ; Beaufreton *et al.*, 1990) found that the Gentet cocktail increased diclofop-methyl efficacy on *Alopecurus myosuroides, Avena fatua* and *Lolium multiflorum*, often allowing halving of the dose. The same results were found with quizalofop-ethyl. Interestingly, petroleum oil alone was as active as the whole Gentet cocktail in promoting herbicide efficacy and we paralleled this result in foliar penetration studies (Fig. 2).

ITCF workers found similar results on *Alopecurus myosuroides*, and stressed the occasional occurrence of injury to wheat (Fabre and Jouy, 1986). CETAs and Chambres d'Agriculture have carried out such field experiments but they have published them only on a very local scale.

Mineral oil was singled out as the most promising additive for graminicides and the efforts focussed on it. In 1989 ITCF found that injury caused by diclofop-methyl or tralkoxydim + petroleum oil did not impair yield. But the most interesting results came from the newly-marketed fenoxaprop-ethyl ("Puma"). Half the recommended dose + oil was as effective as the full dose (Orlando and Jouy, 1990). As no injury was observed on wheat it allowed ITCF to recommend the technique to farmers. The following year, the same experiments were conducted with the new fenoxaprop-ethyl preparation ("Puma S"), but petroleum oil allowed only a 25 to 33 % dose reduction (Decoin, 1991), which reduced the saving from 14 to 7 ECU ha^{-1}. This indicates that the companies may also have a herbicide optimisation program.

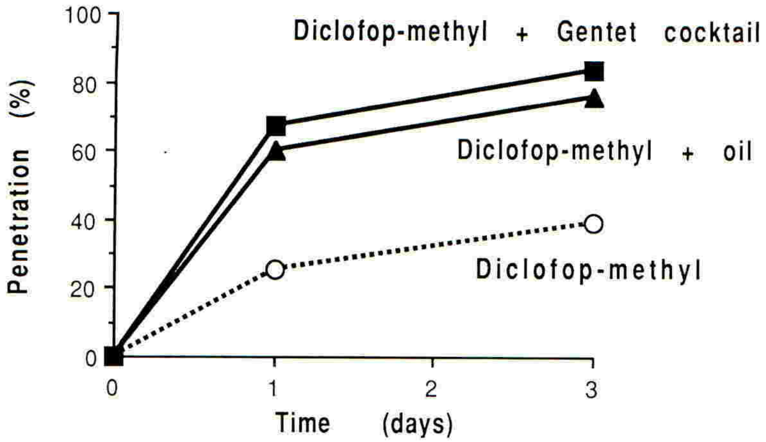

Figure 2. Penetration of diclofop-methyl ("Illoxan") in ryegrass leaf as influenced by additives. SE = 3.1 (12 d.f.). Adapted from Gauvrit and Dufour (1990b).

Meteorological conditions

ACTA tried to determine in field studies the influence of meteorological conditions on herbicide efficacy (Bouchet and Beaufreton, 1988). Apart from the well-known effects of temperature and humidity, an interesting observation was that different combinations of short (1-3 days) but contrasted successive meteorological sequences might affect herbicide efficacy to a large extent. However, interpretation of the results was difficult because of the number of factors, the link between weed stage and climate and the heterogeneity of weed infestation. The same difficulties were encountered by ITCF when Jouy *et al.* (1988) performed analogous studies with broadleaf herbicides. In addition, for a given herbicide, the effect of temperature seemed to depend on weed species. For example, the sensitivity of *Stellaria media* to mecoprop + ioxynil esters depended far more on temperature than on stage, whereas the reverse was true for *Papaver rhoeas*. The field experiments were not pursued for it became obvious that controlled environments would be more appropriate.

Time of treatment

ITCF closely examined its numerous volume / additives experiments performed from 1983 to 1985 in 7 different locations and noticed that 3/4, 1/2 and 1/4 of the recommended dose gave satisfactory results in 68 %, 48% and 25 % of the cases respectively (total number of observations : 256). Analysis showed that application volume (75, 150 or 300 l ha^{-1}) was not an efficacy factor, either for root-acting isoproturon or for foliar-acting mecoprop + bifenox and diclofop-methyl. As already discussed, the effects of the Gentet cocktail were limited except for the latter herbicide. Finally, the predominant efficacy factor was the stage of the weeds (Fabre and Jouy, 1986). This prompted further studies (Réal *et al.*, 1990 ; Réal, 1991) and led to the broadly-publicised ITCF slogan "Désherbez plus tôt" (treat earlier) - which is all the more advisable as in the 80's French farmers sowed wheat earlier and earlier (Réal, 1990).

CURRENT TRENDS

Again, the primary aim of the project is not to identify factors affecting herbicide efficacy (they are to be found in the literature) but to assess their weight in French field conditions and to send out messages that are both safe enough for the farmers of limited technical competence and innovative enough for those who are more proficient.

Weeds species

Doses for graminicides have long been modified according to the target species, perhaps because of the low number of graminaceous weeds. By contrast, broadleaf herbicides are recommended at a unique dose, perhaps because of the range of dicotyledonous weeds. Another reason is that they are often associations of two or more compounds, most of the time differing in their mode of action, efficacy and sensitivity to environmental factors (Bouchet, 1986). ITCF has launched studies on a large scale to indicate how to modify the doses necessary to control major broadleaf weeds in each region.

Evaluation of new additives

Every year farmers enquire about new compounds advertised to increase pesticide efficacy. As it is impossible to assay all of them in the field, we are trying to implement a rapid indoor test using as little greenhouse surface as possible. To this end test plants such as oats or quick-growing maize are evaluated, together with a fluorescence method to detect increases of foliar penetration brought about by additives.

Rapeseed oil

As rapeseed oil was registered in 1989 as an additive in France, and as it was successfully incorporated into a phenmedipham formulation (Darchy *et al.*, 1990), it was decided to include it in the project. Studies are under way not only with rapeseed oil but also with its ester derivatives (Schott *et al.*, 1990, 1991 ; Urvoy and Gauvrit, 1991), whose action is often more consistant than the parent oil (Jouy and Orlando, 1990).

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COST-EFFECTIVENESS OF WEED CONTROL IN CEREALS - SYSTEMS BASED ON THRESHOLDS AND REDUCED RATES

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ABSTRACT

A series of trials was established in farm cereal crops on 10 sites throughout the United Kingdom in the 1987/88 season. The experiment was designed to test in practice systems of weed control which placed differing degrees of reliance on weed threshold models developed at Long Ashton Research Station. It also studied the effectiveness of systems which reduced herbicide input by halving the product application rates. Weed populations were monitored, both to determine the need for treatment in threshold-managed systems and, by comparison with untreated areas, to assess herbicide efficacy. Over a wide range of soil types and locations, on typical arable farms, the risk-aversive thresholds were exceeded on about 80% of occasions. The reduction in efficacy when herbicide rate was reduced by 50% from that recommended on the product label was, over a wide range of situations, small. Grain yield was generally unaffected by frequency of herbicide use or by herbicide rate. As a direct consequence, the most cost-effective strategies were those which involved the least expenditure on herbicides.

INTRODUCTION

Expenditure on weed control can form a significant proportion of the variable costs of production of winter cereals grown throughout the United Kingdom (Nix and Hill, 1990). Precise figures are not readily available, but estimates of between 10 and 35% of variable costs (about £20 to £80 at 1991 prices) are quite reasonable. Given the size of this component, and the actual and forecast reduction in the real value of cereal crops,it is not surprising that considerable attention has been focused on maximising the cost-effectiveness of these agrochemicals. It is a fortuitous coincidence that the current pressure to investigate strategies to minimise pesticide use on environmental grounds, can be met by experiments which also yield useful results on the economics of achieving varying degrees of weed control.

In simple terms, the cost of herbicide treatment in cereals typically requires a grain yield increase of between 0.3 and 1.0t/ha to break-even in any one year. The situation is complicated in reality by the potential influence of treatments applied in 'year one' on yields and weed populations in subsequent years. Thus it is unlikely that single year experiments designed to investigate herbicide efficacy can reliably identify the best long term strategies.

Systems of managing herbicide inputs, based on assessment of weed populations and estimation of their likely effect on grain yield have been proposed (Cousens, 1985; Cousens et al, 1985). However, these threshold techniques have not been tested on a large scale, or on long-term sites in the United Kingdom. A practical alternative, and one which is used quite widely by farmers in the UK is to adopt a prophylactic, insurance, approach but to reduce application rates below those recommended on the product labels (J Orson, D H K Davies, pers. comms.).

The experiments described here were designed to test in practice weed management systems based on weed threshold models developed at IACR, Long Ashton Research Station (Cousens et al, 1985; Wilson, 1986). They assessed potential savings in herbicide usage, the short and long term costs of changes in weed control practice and the relative performance of alternative approaches to cost reduction.

MATERIALS AND METHODS

Sites

The experiment was established in autumn 1987 on commercial cereal crops throughout the UK and Northern Ireland. There were five sites in England, four in Scotland and one in Northern Ireland, on soils ranging from loamy sand to calcareous Lias clay.

Experimental design

The sites all employed a randomised complete block design with three replicates. Plot size was 10-18m x 30-50m, allowing herbicide treatments to be applied by tractor-mounted farm sprayers.

Treatments

Four core treatments were tested at all sites:

1. Insurance - Broad-leaved weeds (BLW) and grasses controlled in the autumn, BLW (and, if required, grasses) controlled in the spring.

2. Half-rate insurance - As treatment 1., but all herbicides used at half the rate recommended on the product label.

3. Threshold managed - BLW and grass control in autumn and spring determined by assessing the crop equivalence (CE) of the weed population and comparing this with a predetermined spray threshold.

4. Half-rate threshold managed - As treatment 2., but all herbicides used at half the rate recommended on the product label.

The English and Northern Irish sites tested four further treatments which provided a gradation in reliance on prophylaxis between the insurance and threshold-managed systems described above.

5.Autumn insurance - BLW and grasses controlled in the autumn, BLW controlled in the spring if thresholds exceeded.

6. Half-rate autumn insurance - As treatment 5., but all herbicides used at half the rate recommended on the product label.

7. Autumn grass insurance - Grasses controlled in the autumn, BLW controlled in the spring if thresholds exceeded.

8. Half-rate autumn grass insurance - As treatment 6., but all herbicides used at half the rate recommended on the product label.

Sites in Scotland and Northern Ireland tested an untreated control (the English sites used untreated quadrats located within each plot to assess herbicide efficacy). The Scottish sites employed a split plot design and superimposed a comparison of the effects of pre-harvest glyphosate ('Roundup'), against an untreated control, on their five main plot treatments. This comparison was designed to evaluate the effectiveness of a late season desiccant for improving harvestability in a crop with relatively high residual weed populations following earlier threshold or reduced rate treatments.

The choice of herbicides used to implement the main treatment strategies was not prescribed but rather was made by local site managers. However, there were similarities across the country with products containing isoproturon and diflufenican, or isoproturon ± ioxynil + bromoxynil being used in the autumn. In the spring, combinations of metsulfuron-methyl, metsulfuron-methyl + thifensulfuron, mecoprop and fluroxypyr accounted for most of the products used.

Assessments

Weed populations

Weeds were counted in the autumn after crop emergence, in the spring at about GS30 and in late July to determine the need for treatment on the threshold-managed plots. For the two earlier timings, forty eight (96 in the first year) 0.1m^2 quadrats were counted in each plot. The July assessment for grass weed panicles used nine 1.0m^2 floating quadrats per plot. On each occasion, mean weed numbers/m^2 were computed and these were then converted to crop equivalent (CE)/m^2 using standard CE values for each species. Crop equivalent values were determined in earlier work (Wilson, 1986 ; pers. comm.) as the ratio of dry matter accumulation in individual weed plants compared to that of individual wheat plants. Threshold spray treatments were triggered at 5.0 total CE/m^2 except where *Galium aparine* or *Alopecurus myosuroides* were present when a figure of 1.0 CE/m^2 was used.

Weeds were also counted in May or June to assess herbicide efficacy. Nine quadrats of about 0.5m^2 were counted in each plot and total CE/m^2 computed as described above.

Weed seedbanks

Representative soil samples were taken to cultivation depth from each plot at every site in autumn 1987. Weed seeds were extracted from these samples and identified by researchers at the Scottish Crop Research Institute. This procedure was repeated in autumn 1989, by which time the sampled areas had been subjected to experimental treatment for two full seasons.

Grain yield

Grain yield (t/ha at 85% DM) was measured by combine harvester cut. Grain dry matter (%) and specific weight (kg/hl at 85% DM) were determined.

RESULTS

Grain yield

Average grain yields from harvests in 1988-1990 are shown, for the core treatments, in Table 1. Most of the information is from crops of winter wheat, but two of the Scottish sites grew winter or spring barley and the Irish site grew spring wheat in year three.

TABLE 1 Mean grain yield, all sites, 1988-1990 (t/ha at 85% DM)

Strategy	Herbicide rate Full	Half
a) Winter wheat		
Insurance	8.09	8.07
Threshold	8.00	8.07
b) Winter barley		
Insurance	7.92	7.52
Threshold	7.76	7.12
c) Spring barley		
Insurance	7.35	7.38
Threshold	7.44	7.26

Thresholds

Throughout the course of the experiment, and at most sites, treatment thresholds were exceeded more often than not. Overall, thresholds were exceeded on 80, 56 and 79% of occasions in the 1988, 1989 and 1990 harvest seasons respectively. The pattern of threshold success over these three years is illustrated by data from the ADAS sites in Figure 1.

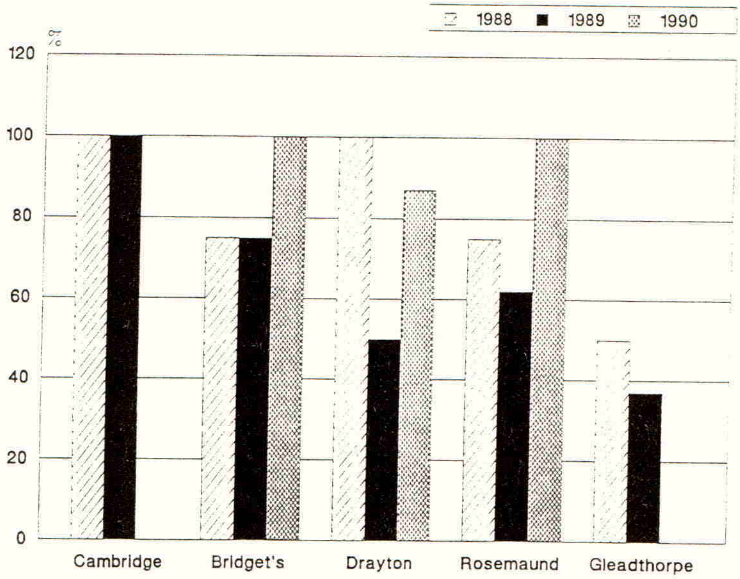

Figure 1 Percentage of assessment occasions on which spray decision thresholds were exceeded. ADAS sites, 1988, 1989 and 1990 (not Cambridge or Gleadthorpe).

Herbicide efficacy and weed populations

Overall, the differences in levels of weed control between full and half rate treatments were small. However, differences which did exist tended to favour the full rate treatments. Overall, there was little evidence that the differences became larger as the trial progressed, although pre-treatment weed counts from some of the Scottish sites showed that weed populations were rising under the threshold managed regimes. (Table 2, Figure 2).

TABLE 2 Mean weed populations at three ADAS sites (Bridget's, Drayton and Rosemaund) in 1989 and 1990, assessed after all treatments had been applied and had taken effect (CE/m^2)

	Treatment			
	1	2	3	4
1989	3.5	2.0	4.0	6.5
1990	1.3	5.8	2.9	4.7

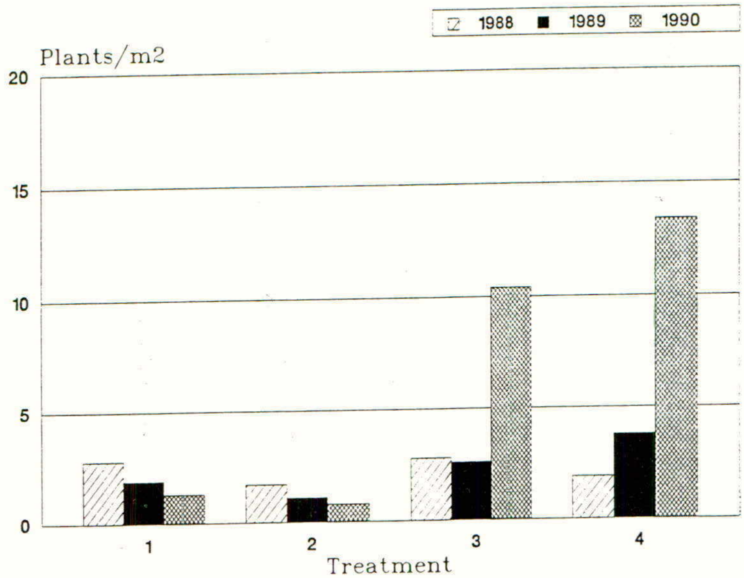

Figure 2 Pre-treatment population of *Stellaria media* at the SAC site 'Remote' in 1988, 1989 and 1990 (plants/m^2).

Cost effectiveness

TABLE 3 Mean cumulative margin over herbicide costs (MOHC) relative to MOHC for full rate insurance treatment (3 years; £/ha)

Strategy	Herbicide rate Full	Half
a) ADAS (12 trials)		
Insurance	0	+ 82
Threshold	+ 41	+ 100
b) QUB (2 trials)		
Insurance	0	+ 69
Threshold	- 24	+ 61
c) SAC (5 trials)		
Insurance	0	+ 99
Threshold	+ 153	+ 200

Weed seedbank

When the baseline assessments were made, the number of species recorded ranged from 17 (Cambridge) to 31 (Rosemaund) at the ADAS sites, from 14 (Remote) to 29 (Niddrie Mains) at the SAC sites and included 27 species at the Northern Irish site. At most of the English and Irish sites, weed populations fluctuated between 1987 and 1989 but few of the differences could be ascribed to treatment effects. At Drayton, for example, seed populations fell by between 53% (full rate insurance) and 41% (half rate threshold) over the period. At on Scottish site, however, a build up of *Stellaria media* plants in winter barley was mirrored by the recovery of seeds. The insurance treatments, at either rate, prevented this but with either threshold system levels rose from 0 to 700 - 1000 seeds/m^2 between 1987 and 1989.

DISCUSSION

Most of the information in this series of trials was from crops of winter wheat and it is clear from the figures shown in Table 1 that the intensity of herbicide use had no effect on grain yield. The averages do not hide any developing trends, and early indications from the 1991 harvest at the ADAS sites confirm that any effects the different weed control strategies may have had on weed populations are not reflected in harvested yield. The data in Table 1 also conceals few important differences at individual sites. At the English and Irish sites, few treatment differences have been significant and half rate treatments have yielded at least as well as full rate ones. However at the Scottish site whose *Stellaria media* explosion is depicted in Figure 2, there was a clear and significant benefit to weed control with full rate herbicides.

Given that yield was quite insensitive to herbicide use, it is not surprising that in terms of cost-effectiveness, the cheapest strategies were the best. Measured as MOHC, the position was generally optimised by reducing the frequency of herbicide use (using thresholds) and halving the herbicide rate. The figures in Table 3 take no account of either the costs of threshold assessment or of herbicide application. The former works against any threshold system, and while the technique used in these trials was far too laborious to be seen as a farmers' or advisers' tool it still yielded population estimates which were quite variable. It must be admitted that in practice an assessment method need not accurately quantify the weed population. An assurance that the population is either above or below the threshold is all that is required. However the inherent variability of weed populations means that even this simple question may not be easily answered.

The value of thresholds is also challenged by the observation, depicted in Figure 1, that at 5.0 or 1.0 CE/m^2 they are exceeded more often than not. The sites for this study were selected to represent a wide range of soil types and to be not particularly weedy. The expectation must be that in commercial crops, these thresholds would be exceeded even more frequently and their usefulness would be further diminished.

The conclusions from this section of what was a larger project are simple and straightforward, but at the same time are incomplete and beg further questions.

At one level, there is compelling evidence that lower input alternatives to the use of herbicides in an insurance fashion and at recommended rates are likely to be more cost effective. If the reduction in input is achieved by reducing rates while maintaining a prophylactic stance, the approach will also be sustainable. This discovery is not altogether surprising. Recommended rates include increments for reliable performance in adverse environmental conditions, for adequate performance against less susceptible weeds and to provide effective control even if the product is used alone rather than as part of a programme. Further, the use of reduced doses has become a fairly widespread practice amongst growers and consultants throughout the United Kingdom (J. Orson, D.H.K. Davies, pers. comms.).

Formal thresholds are used much less widely, although the work here shows that there are benefits to be gained by further refining a 'full rate vs. half rate' decision. This seems to be the area in which the most useful developments will take place. Thus if a threshold, or range of thresholds, is to be used a rapid and reliable assessment technique will be needed. Similarly, if full rate is often, but not always, too much and half rate frequently gives good performance, there seems to be a great need for better dose-response information on a wide range of herbicides under realistic field conditions.

ACKNOWLEDGEMENTS

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THE FIELD USE OF REDUCED DOSES OF BROAD-LEAVED WEED HERBICIDES IN CEREALS

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ABSTRACT

The prophylactic use of targeted doses of broad-leaved weed herbicides in cereals offers a more realistic way of reducing chemical use than spray/no spray thresholds. A field-walking procedure is being developed based on a simple trials system to allow the correct choice of herbicide and selection of dose such that the risk of poor control is minimised by recognising key factors which influence herbicide efficacy.

INTRODUCTION

Reduction in agrochemical use is both environmentally and economically desirable. Spray/no spray thresholds have been put forward as a means of reducing herbicide inputs. However, there are problems with thresholds: (i) high assessment costs; (ii) can produce large fluctuations in weed seed bank; (iii) high research costs with too much weight on mathematical theory. The apparent success of threshold systems in some countries is perhaps predictable given that so long as the threshold weed level is conservative then thresholds will always be better than insurance spraying because the threshold simply selects trials in which the probability of a yield response is small.

Dissatisfaction with thresholds has led to more emphasis on research into the prophylactic use of targeted doses. This approach reduces, although does not minimise, herbicide use, reduces risk in both the short and long term and above all is easily communicated to the farmer who is often willing to cut herbicide dose but not withhold control completely.

MATERIALS AND METHODS

Trials were conducted throughout the main arable areas of Scotland in 1989 and 1990 on winter and spring barley and winter wheat. Two types of trial were used:

a) Screening trials superimposed onto commercial crops consisting of a range of herbicide products tested at a minimum of three doses with two replicates. Plot size 2 x 8m.

b) Plots drilled with an Oyjord drill or superimposed onto farm crops and taken to yield. Treatments, tested at several doses with a minimum of three replicates, were those which had shown most promise in screening trials. Plot size was 2 x 20-24m

All herbicides were applied with a Van der Weij propane knapsack sprayer at 210 kPa in a water volume of 200 l/ha.

Weed control data from both trial series were used to construct dose response curves using a method modified from that described by Streibig (1988) and to determine ED_{90} (dose required to give 90% control) values. These data were used to give preliminary recommendations for the use of targeted doses and to provide the basis for development of future research work.

RESULTS

a) Product choice. Weed control data were characterised by ED_{90} values for product x weed species. Such data allow the strengths and weaknesses of products at reduced doses to be determined.

In winter cereals diflufenican/isoproturon (DFF/IPU, 'Panther', Rhone-Poulenc) and pendimethalin ('Stomp 330', Cyanamid) gave the most consistent control of *Stellaria media*, the dominant weed in most fields in Scotland. DFF/IPU had a weakness on *Fumaria officinalis* and pendimethalin on oilseed rape (Table 1)

TABLE 1 ED_{90} values for DFF/IPU and pendimethalin, autumn 1989

	ED_{90} (% full recommended dose)$	
Weed species	DFF/IPU	Pendimethalin
S. media (13)	29.9	63.3
F. officinalis (2)	> 100	25.1
Oilseed rape (2)	47.5	> 100

( ) No. of trials $ Full recommended dose:100 g/ha DFF + 1000 g/ha IPU. 1320 g/ha pendimethalin.

In spring cereals most products so far tested have given good control of a range of weeds at low doses. Table 2 shows metsulfuron-methyl ('Ally', Du Pont) and thifensulfuron /metsulfuron-methyl ('Harmony M', Du Pont) both with mecoprop ('Duplosan', BASF) as an example where using ED_{90} values a site with significant levels of *Polygonum aviculare* would favour the use of thifensulfuron /metsulfuron-methyl + mecoprop.

TABLE 2 ED_{90} for two spring barley herbicide mixtures, 6 trials 1990

Weed species	ED_{90} (% full recommended dose)$ Metsulfuron-methyl + mecoprop	Thifensulfuron-methyl/ metsulfuron-methyl + mecoprop
Stellaria media	15.0	20.3
Galeopsis tetrahit	24.7	14.8
Polygonum aviculare	> 100	69.0
Fumaria officinalis	67.8	> 100
Chenopodium album	23.9	< 12.5

$ Full recommended dose 6g/ha metsulfuron and 4.2 g/ha metsulfuron + 40.8g/ha thifensulfuron methyl both + 1200 g/ha mecoprop-P.

b) Choice of dose. As herbicide dose was reduced the consistency of weed control decreased; in thirteen trials in 1990 the control of *S. media* with DFF/IPU had 95% confidence interval of 80.2% +/- 19.3 at the 25% dose compared to 99.1% +/- 2.0 at the full dose. It would be desirable to eliminate some of this variability and reduce the risk of poor control by defining situations when control would be at the higher end of the confidence interval:

(i) Effect of environmental conditions. One of the major limitations to weed control with soil acting herbicides is soil moisture. A comparison of three times of application of DFF/IPU in a winter barley screen trial in Aberdeenshire in 1990 showed differences in control of *S. media* and oilseed rape (Table 3). Pre-emergence (T1) applications to dry soils gave poorer control than application to small weeds and soils which were getting wetter in mid-October (T2) (Figs. 1a/b). The mid-October timing may also have given better control because the chemical could also work by foliar uptake rather than relying solely on root absorption. The mid-November timing (T3) gave the poorest control. Soil moisture was probably no longer a limiting factor at T3, but larger weeds and falling temperatures would have restricted efficacy.

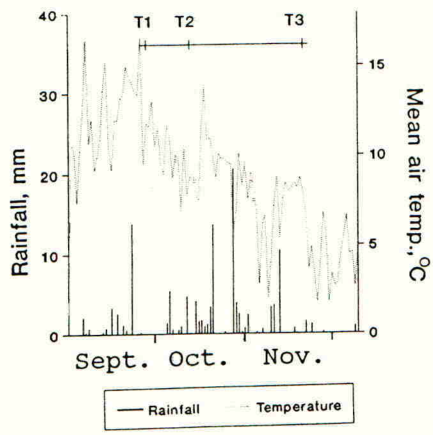
TABLE 3 Comparison of ED_{90} for three timings of DFF/IPU, Aberdeenshire 1990

Time of application	Weed species	Weed size at spraying	ED_{90} % full dose$
T1 Pre-emergence 27.9.89	*S. media*	-	44.9
	Oilseed rape	-	61.2
T2 Post-emergence 12.10.89	*S. media*	Cots - 2 lf	< 25.0
	Oilseed rape	Cotyledons	< 25.0
T3 Post-emergence 20.11.89	*S. media*	4 - 6 cm	50.2
	Oilseed rape	2 - 4 lf	> 100

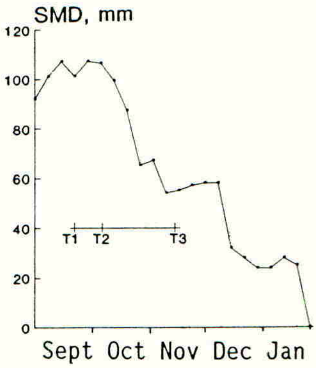
$ Full recommended dose : 100 g/ha DFF + 1000 g/ha IPU

Fig. 1 a) Rainfall and Temperature and b) Soil moisture deficit under grass Dyce airport autumn 1989

a)



b)



In contrast it was not possible to show such simple determinants of efficacy as soil moisture for spring herbicides. However, other factors were shown to affect levels of control achieved :

(ii) Weed size. In trials there was some evidence that weed size influenced efficacy. Control by spring herbicides was improved in some cases by applications to small weeds e.g. control of *Viola arvensis* in spring barley with metsulfuron-methyl + mecoprop decreased as weed size increased (Table 4). However, in general it has proved difficult to study the effect of weed size *per se* on spring herbicide activity under field conditions, because of the complex interaction with temperature etc.

TABLE 4 % Control of *Viola arvensis* with metsulfuron-methyl + mecoprop, spring barley Bush 1990

Spray Date		Crop GS	Weed GS	% full herbicide dose 12.5	25	50
T1	11.5.90	22	2 lf	67	92	100
T2	25.5.90	30	4 lf	0	72	64

(iii) Crop vigour. Herbicide efficacy was greater in vigourous crops which competed well with weeds. Table 5 shows a trial comparing five wheat varieties of differing competitive ability unsprayed and sprayed with metsulfuron-methyl + mecoprop at 50% and 12.5% of the full dose in the spring. Varieties which achieved ground cover earlier required a lower dose to reduce weed ground cover to 5%.

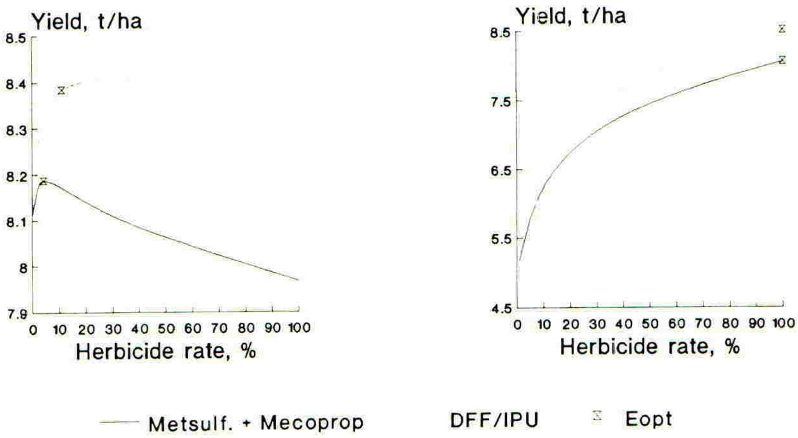
TABLE 5 Winter wheat variety x herbicide dose, Ploughlands 1990

Variety	Earliness of crop ground cover (1-9) 9 = early	% Full herbicide dose required to reduce weed ground cover to 5% crop GS85
Parade	5.0	> 50
Slejpner	7.0	42
Fortress	7.0	47
Mercia	8.0	36
Apollo	8.7	18

(iv) Yield. In winter cereals the yield response to herbicide dose was often proportional to the level of weed control achieved and in general the higher the weed level, and the more competitive the weed, the higher the dose required to give the economically optimum (Eopt, point at which the marginal cost = marginal revenue) return. Figs. 2a/b show the response curves for a) Mean of five winter wheat trials in 1989 in which the mean density of *S. media* was 7.6/m^2 compared to b) winter wheat trial in 1990 at Treaton where there were greater numbers of a more varied weed flora - *S. media* 10.3 /m^2, *V. arvensis* 146.6 /m^2 and *F. officinalis* 4.5 /m^2. The low weed levels in 1989 gave a much lower Eopt than at Treaton where the full dose of the herbicides tested was required to control the high weed density and the different weed species. In some trials in both 1989 and 1990 yield declined as herbicide dose was increased above the optimum eg. metsulfuron-methyl + mecoprop in fig 1a. This effect of the herbicide on the crop in winter cereals was often linked with the use of mecoprop in the spring.

Fig. 2 Yield response curves for:

a) Winter wheat five trials 1989 b) Treaton winter wheat 1990



Curves fitted to yield data all used the general formula

$$Y = a + b_1.\log_e(\text{herbicide dose} + 1) + b_2[\log_e(\text{herb. dose} + 1)]^2$$

In spring cereals the relationship between level of weed control and yield was very poor in all trials.

DISCUSSION

There has been much emphasis placed on the use of cost/benefit analysis to produce more objective decisions for agrochemical use. However, defining costs and benefits in all situations is not straightforward. For weed control, benefits derived from weed density/yield loss data are unreliable because so little of the variation is accounted for by fitted curves (Streibig, 1990) and long-term effects of weed seed return from not controlling weeds are equally impossible to determine with any certainty. The relevance of such an approach is doubtful given that no reliable data exists and is unlikely to be produced because of the difficulty of modelling a complex situation. The prophylactic use of targeted doses for broad-leaved weed control therefore offers a practical solution.

Research so far has concentrated on producing simple guide-lines for selecting a herbicide to suit the weed flora and to then modify dose according to weed density/competiveness, weed size, timing, crop vigour and environmental conditions:

a) What weed species are present and at what density? This assessment can be made relatively quickly by a simple field-walking procedure. Herbicide choice can then be made by referring to ED_{90} values and deciding which is the best product based on the relative importance, both in terms of density and competitive ability, of each weed species present.

b) Control in the autumn or spring? In winter cereals the advantages of control in the autumn are: early removal of weeds before they have a chance to compete, minimising crop damage from the herbicide and allowing a second chance to control weeds. This last point is important when using low doses as the risk of poor control increases as dose is reduced. The decision when to apply the herbicide will depend upon the weed species present eg. *Viola arvensis* is easier to kill with autumn residuals, and weed density - the more weeds the greater the advantage of using an autumn herbicide. Trials in general have shown that an autumn or autumn/spring sequence offers greatest scope for reduction of total chemical use. This is because most weeds, except *Galium aparine*, are easier to control in the autumn when they are smaller and reliance upon a single spring application to fields with significant levels of weeds limits dose reduction because of the more variable control achieved by spring herbicides as dose is reduced.

c) What dose? The determination of absolute doses for individual fields based upon objective data such as relative humidity is perhaps unrealistic and suffers from the same problems as thresholds i.e. difficulty in modelling a complex situation. Results to date have highlighted factors which minimise risk of using reduced doses :

(i) Trial data suggests the probability of reducing herbicide dose diminishes as density or competitive ability of the weed increases. This is the result of increased risk of poor weed control as dose is reduced and the requirement to reduce the population below yield damaging levels. Simply 90% control of a lot still leaves a lot. Other factors which can determine level of weed control are effects of weeds on harvesting and weed seed return:

Effects on harvesting in cereals can be linked to particular weed species and crops eg. *Polygonum aviculare* in spring barley (Davies & Whiting, 1990) and may require an increase in herbicide dose to limit this effect. Increase in grain moisture, grain contamination and lowering of grain quality are **NOT** important in deciding level of weed control. This is because these effects are proportionately much smaller and cannot occur independent of the effect of weeds on yield and/or harvesting.

If there are broad-leaved crops in the rotation which are poor competitors and for which herbicide choice is expensive and limited and control unreliable then control within the cereal crop must be of a high standard to limit weed populations in these following crops.

(ii) Key environmental factors such as soil moisture for autumn residuals can provide good indicators to optimise herbicide efficacy and so minimise herbicide dose. For spring herbicides based on hormonal or contact action the complex interaction under field conditions between weed size, relative humidity, air temperature, rainfall and light intensity limit the scope for defining optimum conditions and increase the risk of using reduced doses. However, the study of consistency of control of some weeds by particular products can give information useful for product choice e.g. fluroxypyr has been shown to give more consistent control of *G. aparine* than mecoprop at low temperatures (Tottman, Steer, Orson & Green, 1989).

(iii) A vigourous crop both aids herbicide efficacy and limits re-growth of any weeds that are left if low doses are used.

(iv) Damage to the crop from herbicides can influence both herbicide choice and dose. Yield reductions from herbicides are unpredictable, but in both winter cereals and spring barley some herbicides have consistently produced poorer yields. Such results strengthen the argument to reduce doses and perhaps leave some weeds uncontrolled as total weed control does not necessarily maximise yield, particularly for spring barley.

Future work should continue to investigate the efficacy of a range of herbicides against a range of weed species using a simple trials system. At present field trial evidence suggests that sophisticated computer models to determine herbicide dose are of doubtful value because of the difficulty of investigating and describing the complex interaction between environmental and crop factors. A visual assessment of weed species and density should be developed to: a) allow the correct choice of herbicide b) choose a dose which will minimise the risk of poor weed control by recognising simple key factors such as crop vigour, weed density x competiveness, weed size etc. c) ensure effective communication and uptake of results by farmers and their advisers.

ACKNOWLEDGEMENTS

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THE ROLE OF COMPETITION IN DEVELOPING AN APPROPRIATE RATE STRATEGY FOR WEED CONTROL IN SPRING BARLEY.

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ABSTRACT

Crop competition in spring barley is confirmed as complementing the efficacy of the herbicide metsulfuron-methyl. Although good control of susceptible species can be maintained with reduced rates even at very low crop densities there is an increased likelihood of more tolerant species surviving. The simulation of weed competition using oilseed rape indicates that there may be a decline in weed control at high weed levels. The data confirm that, as competition increases, crop recovery from weed removal is diminished, also that optimum yields may not coincide with maximum weed control.

INTRODUCTION

The experiments reported are part of a series funded in part by DANI and in part by The Home-Grown Cereals Authority. The aim being the development of a cost effective strategy for weed control in cereals.

The aim of this study has been to understand the principles of crop and weed competition which govern the effective use of herbicides in cereals rather than to evaluate the efficacy of individual chemicals. An approach previously very well illustrated by the data of Hakansson (1986).

Crop competition is undoubtedly the single most important factor influencing weed control and complementing herbicide efficacy. Salonen (1990) concluded that, in spring cereals, 50% rate reductions in herbicide were feasible at normal crop densities in spring barley. A 100 plants/m^2 sowing reduced weed control by about 10% compared to the recommended density of 500 m^2.

Although the basic relationships between weed density have been amply demonstrated in recent years (Cousens 1985, Auld *et al* 1990), little attention has been given to the effect of weed density on herbicide efficacy, or the interaction of weed removal and crop tolerance.

METHODS AND MATERIALS

Effect of Crop Density on Herbicide Efficacy.

This experiment was carried out at the Agricultural Research Institute, Northern Ireland. The spring barley (cv Prisma) was sown 21st March 1990 at a range of seeding densities (0, 50, 100, 200, 400 m^2). The herbicide metsulfuron-methyl ('Ally' DuPont UK Ltd.) was applied 17th May at 0, 0.25, 0.5, 1.0 normal rates of application (30 g/ha). The individual weed species biomass was assessed on the basis of two 0.5 m^2 quadrats taken in July. The plots 2 m x 20 m were combined for grain yield.

Effect of Weed Density on Herbicide Efficacy.

A series of trials was started in 1989 with oilseed rape sown in spring barley to simulate a range of weed infestation levels.

Experiment 1. In 1989, at a farm site in County Down, oilseed rape was broadcast into a spring barley crop at three rates - zero, medium and high giving 0, 97, and 351 plants m^2. There was a very low background weed population (24 m^2), mainly *lamium purpureum*. Three herbicides, metsulfuron-methyl ('Ally'; DuPont UK Ltd.), MCPA/dichloroprop ('Hemoxone'; ICI Plant Protection Ltd;) and fluroxypyr/ioxynil/bromoxynil ('Advance'; ICI Plant Protection Ltd) were applied each on 7th June at 0.25, 0.5, 1.0 and 2.0 the normal recommended rates. Biomass samples from 0.5m^2 of each plot were taken on 24 June 1991, and plots were harvested by combine.

This experiment to examine the effect of weed density on herbicide responses has been repeated at Greenmount Agricultural College, County Antrim during 1991. Oilseed rape was broadcast onto the spring barley (cv Frolic) seedbed to give established seedling densities at the time of spraying of approximately 0, 200, 400, 800, 1600 m^2 and a crop stand of 260 m^2 (Table 1). The individual plot size being 2.5 x 5 m.

TABLE 1. Oilseed Rape Density Experiment 2 1991.
Crop/Oilseed Rape Details at Spraying.

Density Treatment	Barley Leaf No.	Barley Tiller No.	Barley Nodes	Plants m^2 barley	Plants m^2 OSR
D0	5.8	4.8	0	272	
D1	5.9	3.5	0	292	204
D2	6.1	3.4	0	276	368
D3	5.6	1.6	0	232	912
D4	5.2	0.8	0	268	1652

The crop was sprayed on 7th June at the developmental stages presented in Table 1. The herbicides, metsulfuron-methyl and MCPA/dichloroprop, were applied each at 0, 0.5, 1.0 and 2.0 the normal recommended rates. Biomass of crop and weed was assessed in 0.5 m^2 samples taken in early July.

RESULTS

The Role of Crop Density.

The data (Fig. 1) suggest that, although the reduction of crop stand and competition does reduce herbicide efficacy of both broadleaved and total weed biomass reduction, it was only in the absence of the crop that the full rate of herbicide was necessary to maintain control of broadleaved weeds. This experiment indicates that in spring barley, crop competition is sufficiently effective even at 50 plants per m^2 to allow the use of reduced herbicide inputs. It is apparent, however, that the competition from the crop does complement the activity of the herbicide to maintain

Fig 1 INTERACTION OF CROP DENSITY WITH WEED CONTROL AND SPECIES BALANCE IN SPRING BARLEY
(a) DICOTYLEDON v GRASSES

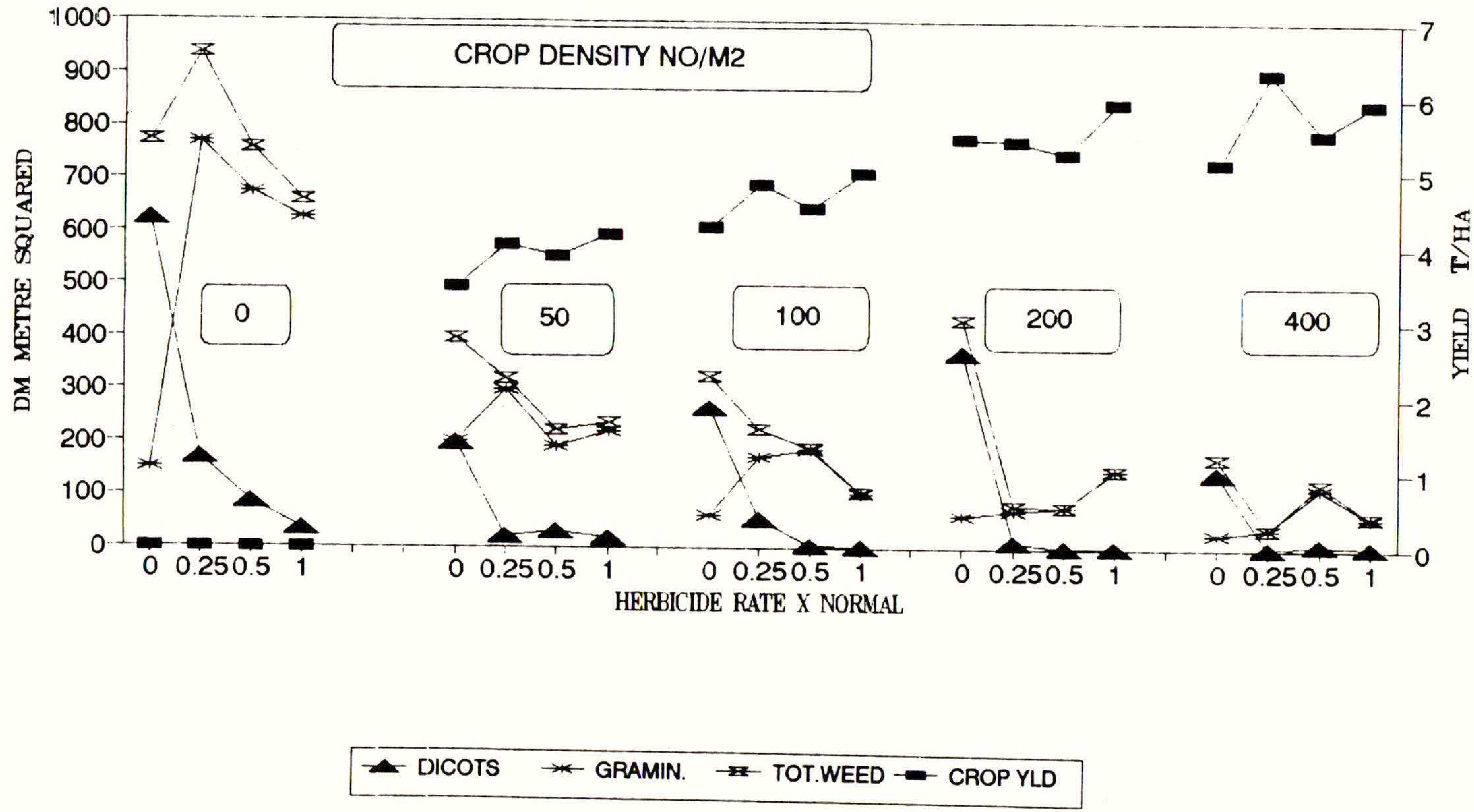
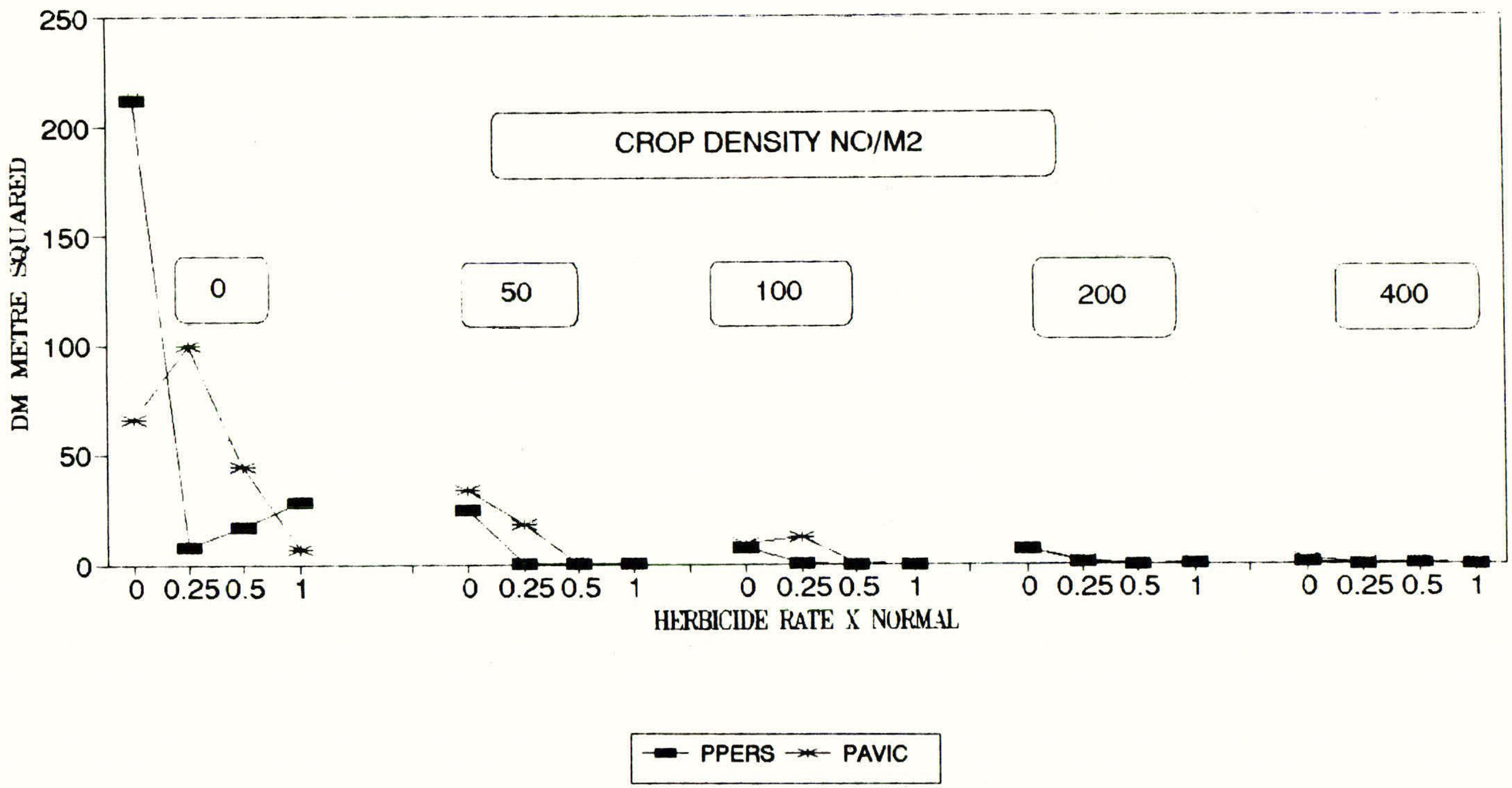


Fig 2 INTERACTION OF CROP DENSITY WITH WEED CONTROL AND SPECIES BALANCE IN SPRING BARLEY
(b) P. PERSICARIA v P. AVICULARE



control of more tolerant species which might otherwise replace the more susceptible species if a reduced rate is used. In the absence of the crop, grass weeds mainly *poa annua*, quickly became dominant even with a full rate of herbicide. This replacement of broadleaved species by *P. annua* is clearly illustrated at the 0.25N rate at the 0, 50 and 100 crop densities. The use of a higher rate and/or an increase in crop density tends to suppress this replacement process.

A similar although less dramatic change occurred between *Polygonum persicaria* and the more tolerant *Polygonum aviculare*. This is most clearly demonstrated in the absence of crop, but also at the lowest crop densities where some *P. aviculare* still persisted at the lower herbicide rates.

The crop yields reflect and increase with crop density and, although not significant, do tend to increase with rate of herbicide up to the recommended rate.

These data show that 0.25N treatment rates gave total broadleaved weed control over a wide range of crop densities but that crop competition was important in preventing the replacement of susceptible by more tolerant species.

<u>The Role of Weed Density on Herbicide Efficacy.</u>

The weed biomass of the oilseed rape in July, some four weeks after spraying, and the grain yield data from the initial experiment are shown in Fig. 3.

Fig 3 EXPT 1. OSR SIMULATED COMPETITION - EFFECT OF DENSITY ON HERBICIDE RESPONSE

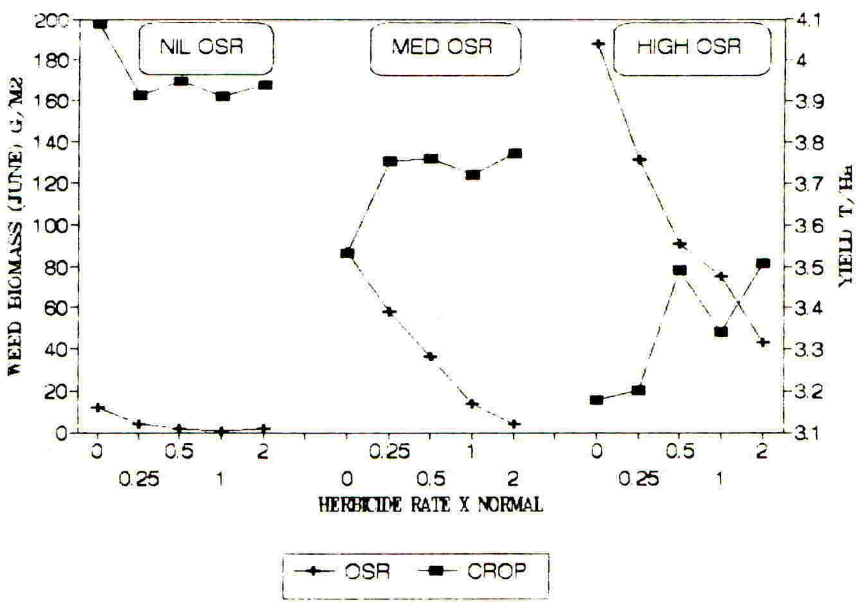


Fig 4 EXPT 2. EFFECT OF OSR DENSITY ON HERBICIDE RESPONSE (METSULFURON-METHYL)

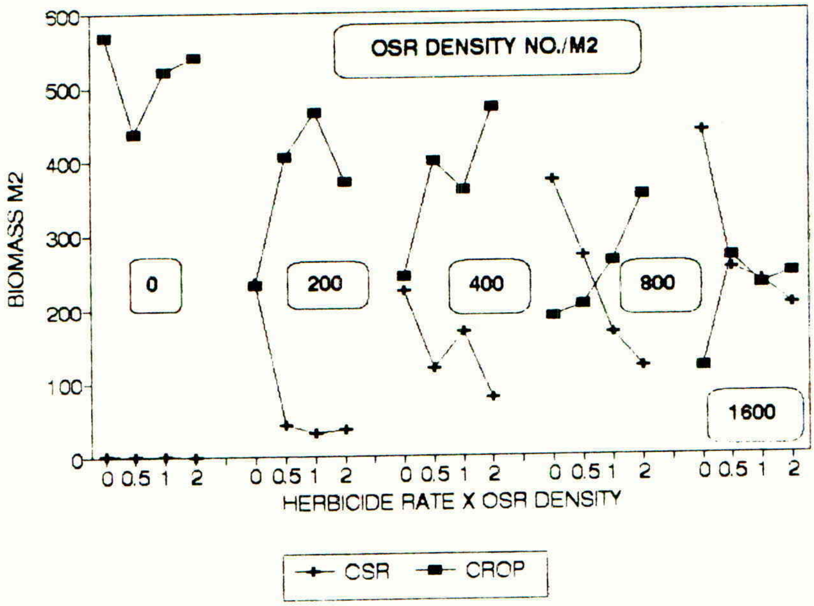
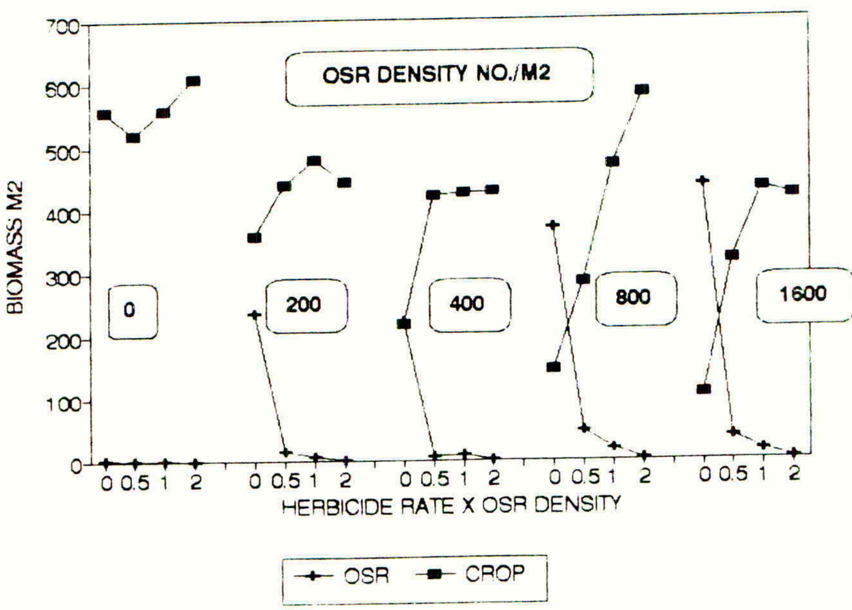


Fig 5 EXPT 2. EFFECT OF OSR DENSITY ON HERBICIDE RESPONSE (MCPA/DICHLORPROP)



This is the mean data for the three herbicides in the absence of significant weed competition (no oilseed rape). There is an indication of a reduction in yield from all the herbicide rates. As competition was increased, weed control increased progressively through to the highest rate of herbicide. Yield, however, although it was increased by 0.25N rate of herbicide, showed little further response to herbicide. The yields did not recover to the levels evident in the nil OSR treatment. At the highest simulated weed density, weed control again increased with rate, but was less effective compared to the medium and nil OSR treatments. In this instance the yield increased up to the 0.5N rate and little above that. The residual effects of the competition, which even at the time of spraying had severely reduced tiller and leaf numbers (Table 1) constrained the potential for response to the removal of the weeds. At the medium weed level, maximum yield response preceded the maximum weed control.

The 1991 data, although based on weed and crop biomass in July rather than grain yields, confirm the main effects observed in the first experiment.

The metsulfuron-methyl data (Fig 4) show a reduction in herbicide efficacy as OSR numbers increased, and, again, that the crop biomass fails to recover to the weed free crop situation. In this experiment the rate response relationship is not consistent with crop increases occurring through to the 2.0N rates. The MCPA/dichlorprop treatment gave more effective weed control with only a slight indication of reduced weed control at the higher OSR densities. The crop showed a more pronounced response to the herbicide through to the 1.0N rates.

DISCUSSION

The prime importance of crop competition in complementing herbicide activity in cereals has long been recognised (Pfieffer and Holmes, 1961) from the work on control of *Avena fatua* with barban and more recently the studies by Ervio (1983), Hakansson (1986) and Salonen (1990). The experiment at Agricultural Research Institute (Hillsborough), although confined to single herbicide, confirmed that effective broadleaved weed control could be maintained even at low crop densities. It does, however, demonstrate that crop competition becomes of crucial importance for the control of more tolerant weeds, and their potential increase as herbicide rates are reduced.

The simulation studies with oilseed rape are important in exploring the basic competition and herbicide response relationships. They do indicate that weed density does influence both the efficacy of the herbicide and the recovery potential of the crop. Although the simulated OSR densities were designed to cover the extreme situations, they do suggest that density may very well combine with environmental constraints on herbicide activity to diminish weed control and crop yield. The indication that in a number of instances the optimum yield response occurs in advance of total weed control raises the issue of how much weed control is required to optimise the balance between the benefits of weed removal and potential increased crop phytotoxicity as herbicide rates are increased.

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THE EFFECT OF OILSEED RAPE POPULATIONS ON WEEDS, HERBICIDE PERFORMANCE AND CROP YIELDS

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ABSTRACT

The results of thirteen trials conducted in the harvest years 1988-1990 are presented. Various populations of oilseed rape were established and subjected to six herbicide treatments. Naturally occurring weed populations ranged from 10.8 - 194.3/m^2. Weed incidence was reduced with increasing rape population. There was no correlation between weed control and yield increase; 43% of the observations showing a nil or negative response to herbicide. Yield response to herbicide treatment averaged 4.3% at low rape plant population and - 1.5% at the highest populations. Financial margins from herbicide treatment were predominantly negative, low cost herbicides giving the best financial margin.

INTRODUCTION

The use of herbicides for broad-leaved weed control in winter oilseed rape has seldom given significant yield benefits, oilseed rape being tolerant of high numbers of many broad-leaved weed species (Lutman, 1984; Davies, 1987). Where yield increases have been observed these were often due to high weed numbers in a late sown and slow establishing crop (Bowerman, 1989). A recent analysis of 40 herbicide experiments has indicated that approximately 45% of broad-leaved weed herbicide treatments have given no yield increase over untreated yields (Lutman, 1991). The effects of oilseed rape seedrate on weed incidence and herbicide performance have been reported in a preliminary paper (Sansome, 1989). This paper aims to present further weed control data, yield and economic data from the same trial series. The implications of the economics of weed control in oilseed rape under proposed EEC legislation are also discussed.

MATERIALS AND METHODS

Trials were conducted in commercially grown winter oilseed rape crops with naturally occurring weed infestations. Volunteer cereals were controlled with fluazifop-P-butyl where present. Broad-leaved weeds present were common chickweed (*Stellaria media*) sites 2, 4, 6, 8, 9-13; common field speedwell (*Veronica persica*)sites 1, 4, 5, 7, 8, 10, 11; field pansy (*Viola arvensis*) sites 4, 7, 10, 11; mayweeds (*Tripleurospermum* sp.) sites 3, 10, 11, 13; shepherds-purse (*Capsella bursa-pastoris*) sites 4, 6, 12; parsley piert (*Aphanes arvensis*) sites 2, 11; common fumitory (*Fumaria officinalis*) site 7; knotgrass (*Polygonum aviculare*) site 5; and the grass weed annual meadow-grass (*Poa annua*)sites 2, 3, 6, 13. All subsequent mention of weeds includes annual meadow-grass.

Site details are presented on Table 1. Trials were designed as a 3 x 4 or 3 x 5 factorial with plots replicated 4 times. Minimum plot size 20.4 m^2.

Oilseed rape was drilled through Oyjord or Nordsten plot drills. Herbicides were applied by pressurised knapsack sprayer through the fan nozzles Tee Jet-8002, Tee Jet 11002 or Lurmark F02-80 at a total volume equivalent to 200 - 255 l/ha.

TABLE 1 Site Data

Site No	Harvest year	Location	Soil	Variety	Drilling date	Rape plants/m^2 established 1	2	3	Total broad leaved weeds/m^2 (nil herbicide low seedrate)
1	1988	Norfolk	ZL	Ariana	4 Sept	39	75	100	36.2
2	1988	Hereford	ZCL	Ariana	4 Sept	24	37	44	96.6
3	1988	Cheshire	SZL	Ariana	2 Sept	18	41	79	99.5
4	1988	Oxon	ZL	Ariana	27 Aug	31	59	79	176.4
5	1989	Norfolk	ZL	Libravo	26 Aug	51	83	108	72.0
6	1989	Hereford	ZL	Libravo	5 Sept	28	38	48	60.0
7	1989	Salop	SZL	Ariana	25 Aug	30	65	89	194.3
8	1989	Notts	C	Ariana	23 Aug	43	80	116	10.8
9	1989	N'land	SL	Cobra	25 Aug	35	64	91	12.0
10	1990	Salop	SL	Libravo	31 Aug	67	94	120	67.1
11	1990	Leics	SL	Libravo	28 Aug	32	49	63	71.0
12	1990	Oxon	ZL	Libravo	25 Aug	32	59	66	41.0
13	1990	N.Yorks	SL	Tapidor	22 Aug	16	52	79	147.0

TABLE 2 Herbicide and Seedrate Treatment Data

Herbicide	Abbreviation	kg/ha AI	Timing	Cost £/ha
1) nil	Nil	-	-	0
2) metazachlor	met/met	0.75/0.50	a & b	45.00
3) (metazachlor	met + ben	0.75	c	47.60
(tank mix				
(benazolin + clopyralid		0.225 + 0.037		
4) cyanazine	cyan	0.2	d	9.20
5) (metazachlor	met/cyan	0.75	a	33.90
(followed by				
(cyanazine		0.15	d	
6) (trifluralin	trif/cyan	1.1	e	14.26
(followed by				
(cyanazine		0.15	d	

Timing details

a = pre-em of crop
b = majority of crop cotyledon stage
c = post-em of weeds
d = rape plants 5 leaves and winter hardy
e = pre-drilling incorporated by drill

Seedrates

	Seeds/m^2 1	2	3
Sites 1 - 9	50	100	150
Sites 10 - 13	30	100	170

Weed control was assessed prior to oilseed rape stem extension in the spring using a minimum of six 0.25 m^2 quadrats per plot. Herbicide and seedrate treatment and timing details are presented in Table 2. Seed yields were recorded using a combine harvester.

RESULTS

Actual oilseed rape populations established are presented in Table 1. Absolute site yields are presented in Table 3. Further yield data in Table 6 and Fig. 2 are expressed as a % of nil herbicide treatments, thus eliminating variation due to differences in absolute yields of individual sites.

Analysis of weed numbers in the nil herbicide plots (Fig. 1) shows that weed numbers were reduced by 0.65/m^2 for every increase of one rape plant/m^2. The data are variable and, although significant ($P = 0.04$) the fit of data to the line is poor ($R^2 = 10.6\%$).

If weed control is calculated as % control related to the lowest seedrate (at individual sites), and nil herbicide, there is an apparent trend for herbicide performance to improve with increasing seedrate (Table 4). Averaged across all treatments this represents an increase from 48% to 78% weed control from the lowest to the highest seedrate, the effect varying for individual herbicides. However, as is shown by Fig. 1 and Table 4, much of this increased control is due to the reduction in weed numbers caused by rape competition alone. In Table 5 weed control is expressed as a % of the nil herbicide at each seedrate thus removing seedrate effect. There is little variation in herbicide performance across seedrates, the only noticeable effect being a decrease in weed control achieved from the cyanazine and trifluralin/cyanazine treatments. This may be due to a dense crop canopy shading target weeds and affecting the foliar efficacy of cyanazine.

There was no correlation of % weed control and % yield increase due to herbicide treatment. Many of the data points appear below the 100% yield line indicating yield decrease due to herbicide treatment (Fig. 2). Of the 129 data points representing herbicide treated yields, 43% record a nil or negative yield response to herbicide treatment. There was a strong trend for % yield increase due to herbicide treatment to decline with increasing rape seedrate (Table 6). Yield responses were greatest at the lowest seedrate averaging 4.3% across all herbicide treatments. At the highest seedrate responses averaged - 1.5%. The metazachlor sequence gave the highest mean response across all seedrates of 3.79% and cyanazine the lowest at - 0.55%. Using herbicide costs given in Table 2 margins over chemical costs (MOCC) are presented in Table 7. This is the yield increase of herbicide treatments compared with untreated at two stated market prices for rape, less the herbicide product cost. With rape at £280/t the only positive MOCC generally occurred at the lowest seedrates, being related to yield responses presented in Table 6. With rape at £130/t, no herbicide treatment gave a positive MOCC. Meaned across all seedrates all herbicides gave a negative MOCC. The lowest negative MOCC was given by the trifluralin/cyanazine sequence or cyanazine alone, with oilseed rape prices calculated at £260/t and £130/t respectively. In the absence of herbicide treatment yield increased with increasing seedrate (Table 8 (1)). Similarly, meaned across all herbicide treatments (Table 8 (2)), yield increases related to seedrate were observed, although herbicide treated yields were less than nil herbicide yields at the higher seedrates as discussed above regarding Table 6.

TABLE 3 Site Yields (t/ha @ 91% d.m)

Herbicide	Seed rate	SITE 1	2	3	4	5	6	7	8	9	10	11	12	13
Nil	1	1.80	2.29	2.99	2.64	2.77	2.60	2.35	3.69	4.41	3.08	3.12	2.69	1.91
	2	2.40	2.83	3.34	3.19	2.91	2.61	2.33	3.71	4.48	2.92	3.35	3.30	2.61
	3	2.62	2.90	3.50	3.09	2.77	2.56	2.34	3.78	4.80	3.01	3.31	3.33	2.95
met/met	1	2.13	2.43	3.32	3.13	2.89	2.69	2.49	2.96	4.78	3.25	3.19	3.05	2.16
	2	2.68	2.99	3.67	3.22	2.86	2.46	2.43	3.80	5.03	3.29	3.49	3.17	2.91
	3	2.94	2.83	3.50	3.23	2.81	2.16	2.40	3.71	4.76	3.08	3.40	3.24	2.86
met + ben	1	2.18	1.96	3.43	2.82	2.54	2.36	2.19	3.82	4.61	-	-	-	-
	2	2.77	2.62	3.59	3.15	2.77	2.58	2.31	3.75	4.95	-	-	-	-
	3	2.69	2.62	3.30	3.25	2.61	2.30	2.31	3.85	4.60	-	-	-	-
cyan	1	2.12	2.21	3.10	3.01	2.82	2.56	2.35	2.67	4.39	3.09	2.82	3.02	1.96
	2	2.58	2.70	3.59	3.24	2.72	2.60	2.32	3.88	4.70	3.09	3.49	3.48	2.56
	3	2.80	2.68	3.45	3.17	2.72	2.25	2.34	3.80	4.42	3.03	3.15	3.36	2.50
met/cyan	1	-	-	-	-	-	-	-	-	-	3.29	3.31	2.80	2.00
	2	-	-	-	-	-	-	-	-	-	3.15	3.60	3.09	2.57
	3	-	-	-	-	-	-	-	-	-	3.07	3.48	3.12	3.04
trif/cyan	1	-	-	-	-	-	-	-	-	-	3.27	2.94	2.78	2.00
	2	-	-	-	-	-	-	-	-	-	3.36	3.26	3.27	2.54
	3	-	-	-	-	-	-	-	-	-	3.10	3.26	3.32	2.66
SED Herbicide		.129	.112	.097	.075	.139	.126	.064	.131	.118	.091	.104	.090	.130
SED Seedrate		.111	.097	.084	.087	.069	.073	.032	.065	.102	.071	.081	.070	.100

TABLE 4 % weed control (as a % of nil herbicide lowest seedrate)

Seeds/m^2	nil	met/met	met+ben	cyan	met/cyan	trif/cyan	Mean
30	0	80.5	-	30.8	78.6	47.0	47.8
50	0	80.5	56.6	31.8	-	-	42.2
100	19.3	85.4	61.9	49.1	89.7	69.5	57.0
150	26.6	85.9	60.4	50.8	-	-	55.9
170	57.5	93.6	-	68.7	94.3	76.6	78.1
Mean	18.5	84.7	59.6	45.6	87.6	65.0	55.0

TABLE 5 % weed control (as a % of nil herbicide at each seedrate)

Seeds/m^2	nil	met/met	met+ben	cyan	met/cyan	trif/cyan	Mean
30	0	80.5	-	30.8	78.6	49.0	47.8
50	0	80.5	56.5	31.8	-	-	42.2
100	0	79.0	52.1	35.1	84.0	49.6	44.4
150	0	79.8	48.1	28.1	-	-	39.0
170	0	81.2	-	7.6	87.5	24.5	40.1
Mean	0	79.9	52.3	29.5	83.3	41.0	

TABLE 6 % yield increase due to herbicide treatment (as a % of nil herbicide at each seedrates)

Seeds/m^2	met/met	met+ben	cyan	met/cyan	trif/cyan	Mean
30	8.5	-	1.25	5.5	2.00	4.31
50	5.78	1.56	0.56	-	-	2.63
100	4.85	2.00	2.15	1.75	2.00	2.55
150	0.00	-3.00	-2.22	-	-	-1.74
170	-0.25	0.19	-4.50	1.00	-2.25	-1.50
Mean	3.79	0.19	-0.55	2.75	0.58	

TABLE 7 Margin over Chemical Cost £ ha
Rape @ £260t (130t)

Seeds/m^2	met/met	met+ben	cyan	met/cyan	trif/cyan	Mean
30	9.9(-17.5)	- -	- 4.8(- 7.0)	5.5(-14.2)	- 3.0 (-8.6)	1.9(-18.5)
50	11.9(-28.4)	-34.9(-41.3)	-17.4(-13.3)	- -	- -	-21.4(-27.7)
100	-5.3(-25.2)	-64.8(-36.4)	10.3(- 0.6)	-27.6(-30.8)	- 7.5(-10.9)	-19.0(20.7)
150	44.3(-45.3)	-71.5(-59.6)	-29.4(-19.3)	- -	- -	-48.4(-41.4)
170	46.9(-45.9)	- -	-44.6(-26.9)	-26.5(-30.2)	-31.9(-23.1)	-37.4(31.5)
Mean	-19.7(-32.5)	-57.1(-45.7)	-17.2(-13.4)	-16.2(-25.0)	-14.1(-14.2)	

TABLE 8 Effect of Seedrate on Yield

Seeds/m^2	30	50	100	150	170
% yield (1)	100.0	100.0	112.1	113.0	120.5
% yield (2)	103.5	102.0	114.8	111.7	118.5

(1) Mean of nil herbicide treatment as a % of nil herbicide, at the lowest seedrate at the individual sites.

(2) Mean of all herbicide treatments as a % of nil herbicide, at the lowest seedrate at the individual sites.

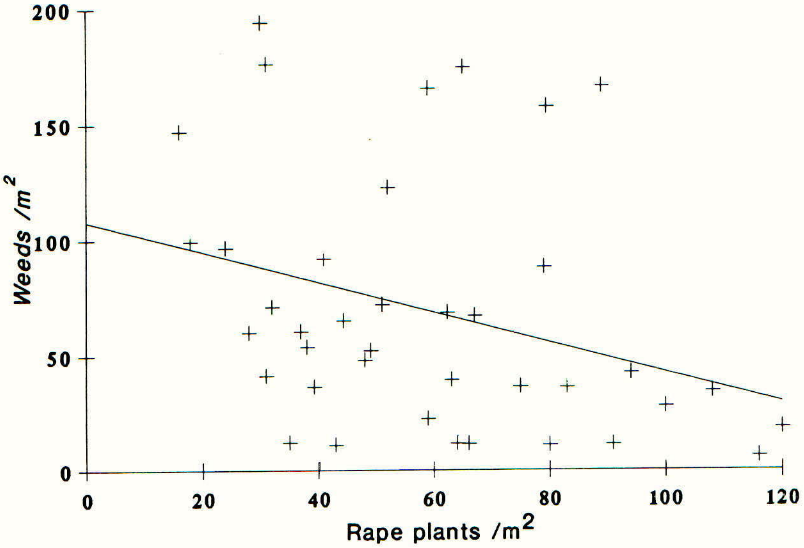

FIGURE 1. The effect of Oilseed Rape plant population on broad-leaved weed numbers.

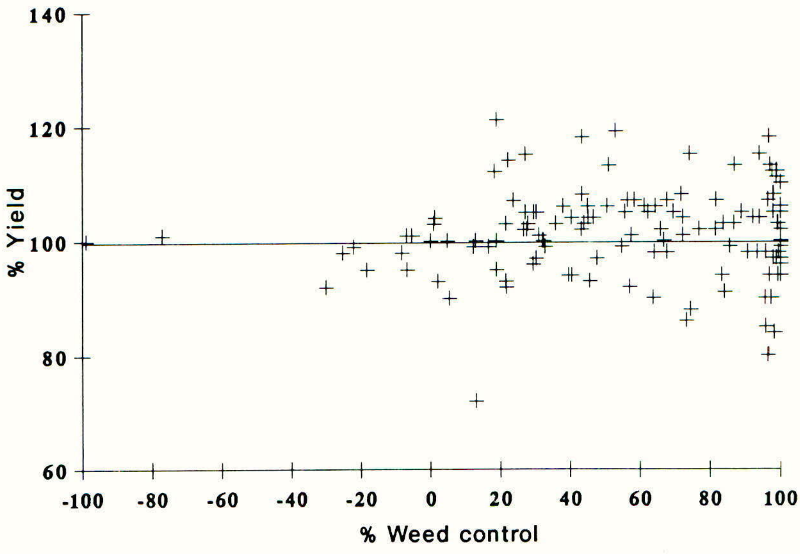

FIGURE 2. The effect of weed control on yields of Oilseed Rape (both expressed as a % of nil herbicide at each seed rate)

DISCUSSION

Weed numbers were reduced by higher oilseed rape populations arising from higher seedrates. The effects have been shown to vary according to individual weed species (Sansome, 1989).

The lack of correlation between weed control and yield is consistent with earlier work (Lutman, 1984; Davies, 1987; Davies, 1989; Walker et al., 1990.) Although giving high levels of weed control many herbicides gave a yield decrease particularly at the higher seedrates. This is presumably a phytotoxicity effect. This would have been masked at the lower seedrates due to the benefits obtained from weed control, whereas in instances of less weed competition it is more apparent.

Due to the low yield responses to weed control the MOCC are small or negative. Although not giving the highest levels of weed control, low cost herbicides such as cyanazine or trifluralin/cyanazine resulted in the least financial loss. This agrees with earlier work in Scotland (Walker et al., 1990) where products giving the poorest weed control gave a slightly better margin over herbicide cost compared to products giving the best weed control. It has been suggested that inexpensive herbicides or reduced rates of expensive herbicides may give a sufficient level of weed control for rape to fulfil yield potential (Davies, 1989). The financial data presented here would support that view in terms of financial return to the grower.

The results show that competitive populations of oilseed rape are unlikely to benefit from herbicide treatment for many broad-leaved weeds. Not only will there be the financial cost of the herbicide treatment, there is likely to be an associated yield decrease. The extent of the financial loss to the grower is dependent on the herbicide cost and market price received for oilseed rape.

Current EEC proposals are that oilseed rape in the UK will trade at a projected world price of £130/t at harvest 1992 with an area aid payment being made. Margins from herbicide use will be affected as shown in Table 7. It is possible that such crop prices may lead to a re-evaluation of crop-husbandry. Factors such as a reduction in autumn or total nitrogen use or alterations in seedrates could have an impact on crop competitiveness and hence weed incidence. Herbicide inputs will be scrutinised . Broad-leaved weed control in oilseed rape appears not to be justified in many instances, because it leads to financial loss. Broad-leaved weed herbicide use, in many situations, can only therefore be justified in the light of weed control in the rotation, which unlike the situation with grass weeds, is not easily quantifiable, or where sample contamination and harvesting difficulties are likely to be encountered.

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POTENTIAL FOR REDUCING HERBICIDE INPUTS/RATES WITH MORE COMPETITIVE CEREAL CULTIVARS

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ABSTRACT

Data are presented on 'early ground cover' and 'canopy density' of winter wheat and spring barley cultivars. These data have been recorded on cultivar trials in Scotland. Evidence is given of a relationship between these data and the growth and control of weeds.

INTRODUCTION

There is evidence that cereal cultivars may vary in their ability to compete with weeds and workers have noted that a number of morphological characters can affect the way a crop competes (Donald, 1981; Amos, 1988; Richards, 1989).

Studies of differences between cereal cultivars in SAC trials was initiated in 1987 (Richards, 1989). This work has continued in order to accumulate data on differences in growth habit between cereal cultivars. It was decided that the major visual differences between cereal cultivars could be represented by two characters: 'early ground cover' and 'canopy density'. These are similar to characters presented in the Dutch Rassenlijst of cereal cultivars (Anon, 1991). Scotland has an organised system of cultivar testing that provides information for National List purposes and for the SAC Cereals Recommended Lists, for example the 1991 list (SAC 1990). Since 1990 the two additional characters 'early ground cover' and canopy density' have been recorded on the Scottish cultivar trials and some of these data are presented here.

The Home-Grown Cereals Authority has funded research in Scotland into reduced rates of herbicide for weed control in cereals. As part of this program of research trials have been carried out to investigate the relationship between early ground cover of cereal cultivars and the growth of weeds and their control with reduced rates of herbicide. In addition to these trials a number of organic cultivar trials have been carried out which provide additional evidence of the relationship between early crop ground cover and weed growth.

METHODS

Cereal cultivar trials

Until 1990 when changes were made to the system, there were seven winter wheat trials and twelve spring barley trials per year at various locations in Scotland. The trials are managed according to a set protocol for cultivar trials. Recordings were made on replicates of the trials that received optimum fertiliser, herbicide and fungicide, and in wheat growth regulator, to allow cultivars to perform to their full potential. 'Early ground cover' was recorded by visual assessment on a 1-9 scale at mid to late tillering, 9 = early ground cover, 1 = late. Canopy density was also recorded on a 1-9 scale, 9 = dense, 1 = thin; this character was recorded at the flag leaf to ear emergence stage. In addition to these two characters straw length is routinely recorded on cultivar trials.

These data were recorded on 1990 and 1991 trials, data summarised across 1991 trials is used to produce a mean value for each cultivar given in this paper. This summary was done using the Fitcon technique to take account of variation between sites (Patterson & Silvey, 1980).

Cultivar x weed control trials

There was one winter wheat trial in season 1989/1990, and one spring barley trial in season 1990/1991. These two trials were on conventional farms. Additionally there were, on organic farms, four spring barley trials and one winter wheat trial grown with no chemical weed control. Site details for these trials are given in tables 1&2.

TABLE 1. Site details for conventional cultivar x weed control trials

Trial	6	7
Site	St Boswells	Glenrothes
Year	1989/90	1990/91
Crop	winter wheat	spring barley
Date sown	6 October	31 March
Seed rate	220 kg/ha	190 kg/ha
Fertiliser nitrogen	200 kg/ha	130 kg/ha
Herbicide application:		
date	18 April	14 May
crop GS	30	21
weed size	> 20 cms	2-4 leaf
Main weeds present	Fumaria officinalis	Galeopsis tetrahit Polygonum aviculare Polygonum persicaria Stellaria media Viola arvensis

The conventional, cultivar x weed control trials were of split plot design with herbicide either at zero rate, eighth manufacturers recommended rate or half that rate. At St Boswells the herbicide used was metsulfuron-methyl (Ally, DuPont) + mecoprop-P (Duplosan New System CMPP, BASF); eighth rate was 0.75g + 172g A.I./ha; half rate was 3g + 690g A.I./ha respectively. At Glenrothes the herbicide was metsulfuron-methyl + thifensulfuron-methyl (Harmony M, DuPont) + mecoprop-P; eighth rate was 5.2g + 172g A.I./ha; half rate was 20.6g + 690 g A.I./ha respectively. These herbicide rates were chosen in order to achieve less than 100% weed control so that the effect of crop competition on weed control could be seen. Assessments of crop 'early ground cover' and 'canopy density' and of weed percent ground cover were made by visual assessment over the whole plot. A comprehensive fungicide program was applied to trials 6&7, but in trial 7 the variety Blenheim suffered early mildew infection that reduced its early ground cover and ability to compete with weeds. Trials were harvested by Claas Compact or Deutz Fahr M660 combine harvester, samples for correction of yield to 85% dry matter were taken from each plot.

TABLE 2. Site details for organic cultivar x weed control trials.

Trial	1	2	3	4	5
Site	Edinburgh	Edinburgh	Edinburgh	Fife	Inverness
Year	1988	1988	1989	1990	1990
Crop	w wheat	s barley	s barley	s barley	s barley
Date sown	18 Nov	24 April	1 April	4 April	30 March
Seed rate	240 kg/ha	188 kg/ha	188 kg/ha	220 kg/ha	220 kg/ha
Main weed spp.	S. media G. tetrahit Capsella bursa-pastoris	S. media Poa annua P. persicaria	G. tetrahit P. aviculare P. persicaria	S. media	G. tetrahit P. persicaria Spergula arvensis

Table 2 gives details of organically-grown variety x weed control trials undertaken in 1988-1990. Cultivars grown in these trials were as follows; site 1: Apollo, Rendezvous, Mercia, Galahad, Parade, Riband; Site 2: Blenheim, Tyne, Prisma, Malibu; Site 3: Blenheim, Tyne, Nomad, Camargue; Sites 4&5: Blenheim, Heritage, Sherpa, Shirley, Tyne.

RESULTS AND DISCUSSION

Competitiveness data from cultivar trials

Winter wheat

TABLE 3. Mean early ground cover, canopy density and straw length of winter wheat.

	Earliness of ground cover 1-9 (9 = early)	Canopy density 1-9 (9 = dense)	Straw length cms
Apollo	6.3	5.8	88
Avalon	5.7	8.1	85
Beaver	* 5.2	5.7	78
Galahad	5.7	8.0	82
Haven	5.2	5.7	79
Hereward	5.3	6.4	80
Hornet	5.9	6.2	86
Mercia	6.1	7.5	85
Norman	6.2	7.1	84
Riband	5.6	6.1	84
Slejpner	4.4	6.6	78
Talon	* 5.8	7.2	87

* 1991 data indicate that these cultivars have better early ground cover than is indicated here.

Table 3 shows that many cultivars have average early ground cover and canopy density, but these data are of particular value to identify those cultivars that are substantially poorer or better than average. For example Slejpner winter wheat is poor and 1991 data indicates that Hereward is poorer than average. Apollo is better than average. Canopy density is largely related to the size of the flag leaf, cultivars such as Avalon with a large flag leaf have better canopy density.

Spring barley

Spring barley cultivars are of distinct juvenile growth habits. These are associated with dwarfing genes; those posessing the erectoides dwarfing gene derived from Golden Promise have an erect juvenile growth habit whereas those posessing the denso dwarfing gene derived from Diamant through Triumph have a semi-prostrate juvenile growth habit. Cultivars lacking a dwarfing gene are classed as intermediate.

Many cultivars with intermediate juvenile growth habit tend to achieve early ground cover with good potential to supress weed growth. Varieties with the erectoid juvenile growth habit tend to have poor early ground cover. Varieties with the semi-prostrate juvenile growth habit vary in their early ground cover, Forester for example has very good early ground cover with good potential to supress weed growth while Digger has poor early ground cover and is a less competitive variety.

TABLE 4. Mean early ground cover, canopy density and straw length of spring barley.

	Juvenile growth habit	Early ground cover 1-9 (9 = early)	Canopy density 1-9 (9 = dense)	Straw length cms
Alexis	Semi-Prostrate	5.2	5.8	77
Atem	Intermediate	-	-	87
Blenheim	Semi-Prostrate	5.2	5.6	76
Camargue	Semi-Prostrate	4.9	4.9	75
Cask	Erectoid	4.0	4.6	75
Chad	Erectoid	4.9	3.9	82
Corniche	Semi-Prostrate	-	-	78
Decor	Semi-Prostrate	5.6	6.3	78
Digger	Semi-Prostrate	4.3	5.6	68
Doublet	Semi-Prostrate	-	-	69
Forester	Semi-Prostrate	6.2	6.9	75
Golf	Intermediate	5.9	5.3	75
Hart	Intermediate	-	-	83
Klaxon	Intermediate	6.6	6.1	83
Natasha	Semi-Prostrate	-	-	77
Nomad	Semi-Prostrate	5.3	5.8	76
Nugget	Intermediate	-	-	79
Prisma	Semi-Prostrate	5.8	5.5	79
Sherpa	Semi-Prostrate	5.6	6.4	77
Shirley	Intermediate	-	-	82
Triumph	Semi-Prostrate	5.4	5.4	79
Tyne	Erectoid	5.1	4.6	73
Volga	Intermediate	5.9	5.6	86

- denotes cultivar on NIAB Recommended List 1991 for which there is no data.

Correlation with cultivar trial data (in Tables 3&4)

There tended to be a poor correlation in the organic trials 1-3. In trial 1 this was because, in order to comply with rules for organic production, no seed dressing was used. Fusarium nivale infection affected seedling growth particularly in Apollo and cultivars did not achieve ground cover as would normally be expected (Richards 1989). In the other organic trials mildew infection influenced establishment of some cultivars, which meant that early ground cover data was not comparable with that in tables 3&4 from the conventional cultivar trials. There was a tendency for the better growing organic trials to have a better correlation (trials 4&5), and it is likely that the data from conventional cultivar trials will be of value for organic crops that are grown well using disease resistant cultivars.

In trials 6&7 that were conventionally-grown, there was a better correlation; although no cultivar trial data were availably for Parade which affected the quality of the correlation in trial 6. There was some early mildew infection on Blenheim that affected its early growth and thus the correlation in trial 7.

Effect of cultivar competitiveness on weed growth

Table 5 shows replicated trials carried out by SAC (trial details in Tables 1&2) where a range of cultivars were grown and there were plots untreated with herbicide. Early ground cover data are given for each trial, and a correlation coefficient to indicate how well data from these trials match that recorded in the cultivar trials (given in Tables 3&4). For each trial in Table 5 a regression value is given to indicate how good is the relationship between early ground cover of the crop and total weed percent ground cover in that trial.

TABLE 5 Effect of early ground cover of the crop on subsequent % weed ground cover in the cultivar x weed control trials; correlation of early ground cover data in these trials with that from cultivar trials.

Trial 1 (winter wheat) R^2 = 97.9 (weeds% = 74.2-6.62early ground cover)
*Correlation = -0.676

	Apollo	Mercia	Galahad	Riband	Parade
Early ground cover	2	8	8	7	6
Total weed %	62	20	25	27	32

Trial 2 (spring barley) R^2 = 27.3 (weeds% = 22.0-0.667early ground cover)
*Correlation = -0.317

	Blenheim	Tyne	Prisma	Malibu
Early ground cover	5	8	6	8
Canopy density	7	7	7	8
Total weed %	20	18	16	16

Trial 3 (spring barley) R^2 = 24.8 (weeds% = 42.1 + 1.2early ground cover)
*Correlation = 0.0

	Blenheim	Tyne	Nomad	Camargue
Early ground cover	5	6	3	4
Canopy density	7	6	6	8
Total weed %	49	50	48	43

Trial 4 (spring barley) R^2 = 12.9 (weeds% = 10.9 + 2.21early ground cover)
*Correlation = 0.883

	Blenheim	Heritage	Sherpa	Shirley	Tyne
Early ground cover	7	8	7	8	6
Canopy density	6	7	8	8	7
Total weed %	27	30	18	31	28

Trial 5 (spring barley) R^2 = 41.2 (weeds% = 34.3-3.83early ground cover)
*Correlation = 0.812

	Blenheim	Heritage	Sherpa	Shirley	Tyne
Early ground cover	6	7	6	7	6
Canopy density	5	6	5	8	4
Total weed %	11	10	9	5	14

Trial 6 (winter wheat) R^2 = 90.0 (weeds% = 119-11.71early ground cover)
*Correlation = 0.405

	Parade	Slejpner	Fortress	Mercia	Apollo
Early ground cover	5	7	7	8	9
Canopy density	6	7	8	8	7
Total weed %	62	37	37	20	22

Trial 7 (spring barley) R^2 = 83.1 (weeds% = 61.0-6.38early ground cover)
*Correlation = 0.958

	Shirley	Forester	Nomad	Blenheim	Cask
Early ground cover	8	8	7	6	5
Canopy density	8	7	9	7	5
Total weed %	8	15	13	20	32

* Correlation between early ground cover recorded in these trials and that given in tables 2&3 that is derived from conventional cultivar trials.

Effect of early ground cover on weed growth

This was influenced more by crop growth than trial type. In trial 1 where there were very large differences in crop growth there was a large influence on subsequent weed development and a good correlation. As a generalisation in the best trials where cultivars were able to achieve optimum growth, there was good supression of weeds by the strongest growing cultivars. In poorer trials even the very vigorous cultivars were comparatively slow to achieve ground cover.

There was also a good correlation between early crop ground cover and weed growth in trial 6 (Fig. 2) and trial 7 (Fig. 1). In both cases those cultivars that achieved ground cover earlier suffered lower subsequent weed infestation.

FIGURE 1. Effect of earliness of crop ground cover on growth of weeds in spring barley (trial 7).

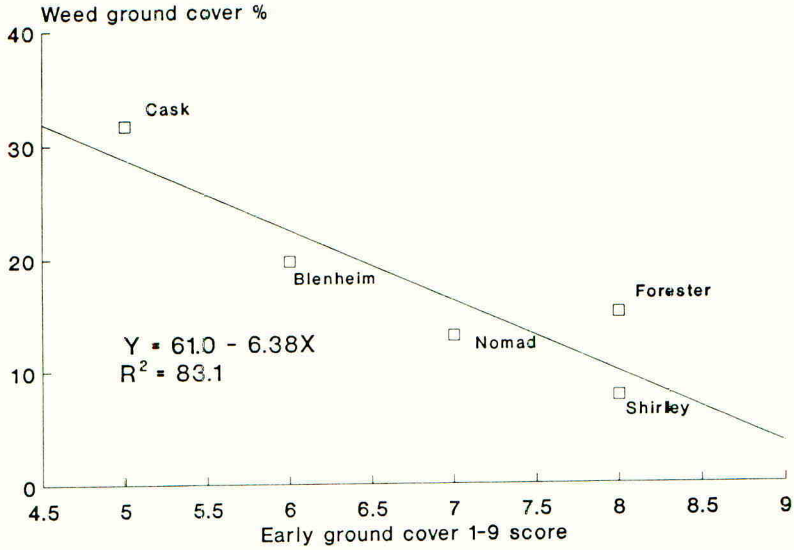
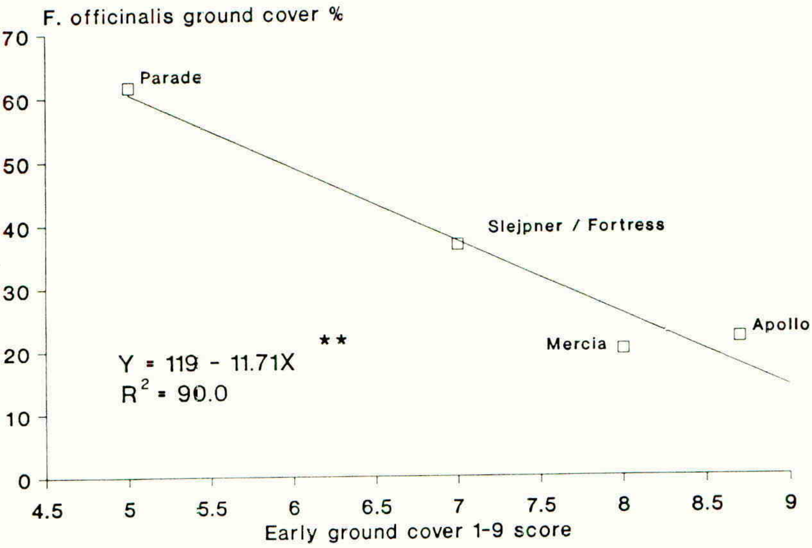
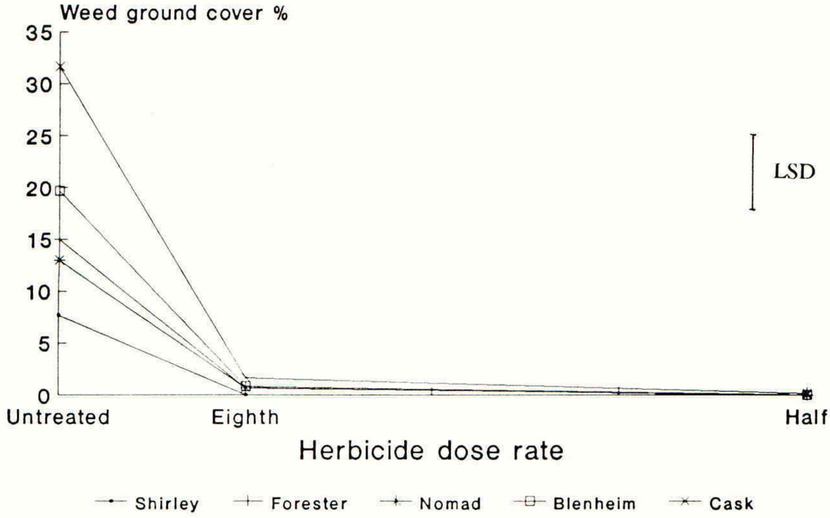


FIGURE 2. Effect of earliness of crop ground cover on growth of weeds in winter wheat (trial 6).



Effect of cultivar competitiveness on herbicide dose requirement

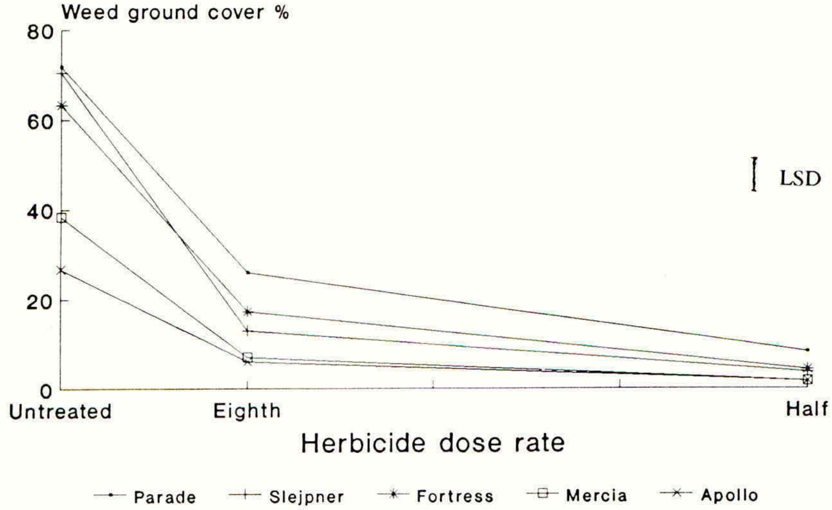
FIGURE 3. Response of weed levels to herbicide dose in different cultivars in spring barley (trial 7).



In trial 6 there was significantly more F. officinalis with Parade than with other cultivars after treatment with both reduced rates of herbicide; with Apollo and Mercia there was significantly less F. officinalis. There was an additional factor of spray interference caused by the denser crop canopy with the more competitive cultivars that reduced the percentage weed control achieved, but this effect was smaller than the differential effect of the cultivars (Whiting & Richards 1991).

In trial 7 differences in weed levels between cultivars following herbicide treatment were not significant. Almost complete control was achieved with half and eighth rate of herbicide.

FIGURE 4. Response of weed levels to herbicide dose in different cultivars in winter wheat (trial 6).



CONCLUSIONS

Good correlations have been achieved between early ground cover of selected cultivars and weed growth. Future trials will concentrate on identifying the effect on herbicide response. In general, even the eighth herbicide rates used in these trials have been too high to quantify differences in response between cultivars because the herbicide has been unexpectedly active at these sites.

This experimental approach of recording crop growth on weed free cultivar trials, then testing this information with selected cultivars in the presence of weeds, is seen as an inexpensive way of providing information on differences between cultivars. The obvious alternative would be to have whole cultivar trials with replicates untreated with herbicide, actual competition could then be assessed with every cultivar. Another alternative would be to grow cultivars in competition experiments with selected species. Both these options are more costly but may be justified in the future years.

When sufficient evidence is gathered it may be possible to select cultivars, given equal benefits in other areas of importance, particularly yield, quality and disease resistance, on the basis of giving best likelihood of competing with weeds on both the organic farm and the farm practicing integrated approaches to weed control including reducing herbicide inputs. This could lead to competitive ability with weeds being used as a breeding objective by plant breeders.

ACKNOWLEDGEMENTS

We are indebted to farmers who provided trial sites, colleagues within SAC who have managed trials and recorded these data, to the H-GCA for funding part of this work and to Dr Bill Thomas, SCRI for his insight into the genetic basis of differences between cultivars and to SASS, Edinburgh.

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POTENTIAL FOR REDUCING HERBICIDE INPUTS IN SUGAR BEET BY SELECTING EARLY CLOSING CULTIVARS

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ABSTRACT

Three sugar beet cultivars were studied in three field experiments to evaluate how their competitive ability may assist in reducing herbicide inputs. The selected cultivars varied in growth form ranging between an erect leaf rosette (cv. Carla) and an architecture with more horizontally arranged leaves (cv. Lucy). Survival of late emerging weeds (*Chenopodium album, Polygonum persicaria* and *Stellaria media*) was significantly lower in cv. Lucy than in cv. Carla. Analyses with a mechanistic simulation model for crop-weed competition showed that early establishment of complete ground cover (associated with horizontally arranged leaves) may increase the competitiveness of the sugar beet to late emerging weeds. It is suggested that by selecting early closing cultivars, the total number of herbicide applications can be reduced in low-dosage weed control systems for sugar beet.

INTRODUCTION

Relatively high attention is paid to weed control in sugar beet compared to other arable crops. Sugar beet yields can be considerably reduced by competition from certain weeds (see references cited by Zimdahl, 1980). Generally, weeds need to be controlled until the sugar beet plants have 10 to 12 true leaves or a leaf area index of 0.5 (Scott & Wilcockson, 1976; Kropff, 1988). The relatively late closing of the canopy and the small crop height compared to tall weeds as *Chenopodium album* are probably the key factors to explain these strong competition effects.

A research project was initiated in 1989 to assess the possibilities for reducing herbicide inputs in sugar beet by selecting certain competitive cultivars. The main aim of this project is to quantify the relationship between plant architecture characteristics that fix the limits of the time of canopy closing and the relative competitiveness of the crop. To indicate to what extent observed differences in competitiveness between cultivars are indeed associated with architecture of sugar beet plants, a mechanistic model for crop-weed competition is used. In this paper some preliminary results are reported and discussed with respect to the potential for reducing the number of weed control practices in sugar beet crops.

MATERIALS AND METHODS

Field experiments

Plant architecture and relative competitiveness of sugar beet cultivars were studied in three experiments. Three cultivars were selected: Lucy, characterized by more horizontally arranged leaves; Carla, characterized by an erect leaf rosette; and Univers with an intermediate plant architecture. These cultivars have been described as reaching early, relatively late and moderately late full ground cover, respectively (Anonymous, 1989). The experiments were conducted at two sites: Droevendaal (5° 40' E, 52° 00' N; loamy fine sand) in 1989 and 1990, and De Eest (5° 45' E, 52° 40' N; silty loam) in 1990. They were of a randomized block design with four replicates. Plot size was 12 m x 12 m. Sowing date (between 6 and 24 April) and fertilization of the soil were according to standard practices. Distance between rows was 0.5 m and between plants 0.18 m. For 15 to 80 days after emergence, plant height and circumference (line around the leaf rosette) of four individual sugar beet plants per plot were determined with intervals of c. 10 days. Spatial distribution of the leaves was characterized by the ratio plant circumference / height. This ratio approximates the reciprocal of the tangent (times 2 π) of the angle between leaves and the soil surface. A high value thus indicates horizontal leaf arrangement. The degree of ground cover was estimated by the index:

$$\frac{\text{Circumference} / 2\pi}{0.5\sqrt{d_{between}^2 + d_{within}^2}}$$

where $d_{between}$ is the distance between rows and d_{within} the distance between sugar beet plants within a row. The latter index equals 1 when leaves of diagonally opposed plants meet. Times of canopy closing were expressed in degree days based on local daily weather data (base temperature 2 °C).

Pre-germinated seeds of *Chenopodium album* L., *Polygonum persicaria* L. and *Stellaria media* L. were sown at 30 and 45 days after crop emergence. The seeds were positioned right between two sugar beet plants within a row. After about one week, the emergence of seedlings was determined. Non-emerged seedlings were excluded from further analysis to be able to restrict the observations to competition between the crop and established seedlings. At harvest (on 26 September - 9 October, 154 - 163 days after crop emergence), survival of individual weed plants was determined (n=48-133 per plot).

Simulation analysis

The growth of the sugar beet crop and weed was simulated with a mechanistic model of competition for light. This model calculates the daily growth rates of the species in the canopy from the distribution of light over the species. Availability of water and nutrients is considered as being not growth limiting. The dry matter produced is distributed over the plant organs as a function of the developmental stage of crop and weed. Leaf area development of both sugar beet and

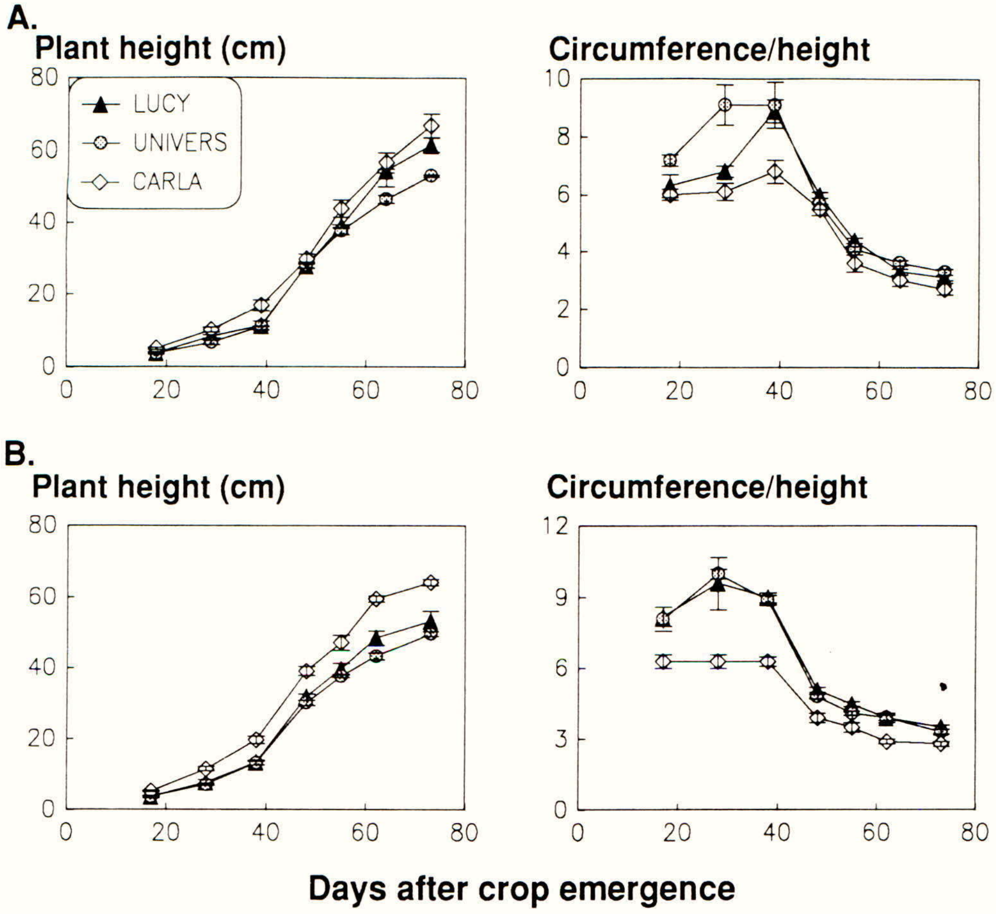

FIGURE 1. Plant architecture of three cultivars of sugar beet at Droevendaal (A) and De Eest (B). Bars indicate SE (over four blocks).

weed is simulated early in the growing season on the basis of an experimentally determined temperature-dependent relative growth rate of leaf area. After the sugar beet has reached a leaf area index of 0.75, crop leaf area development is calculated from the dry matter increment of the leaves and an experimentally determined specific leaf area, which is a function of the developmental stage. During this stage of crop development leaf area development of the weed is still simulated on the basis of the experimentally determined temperature-dependent relative growth rate of leaf area. When the canopy has closed, the leaf area of the weed is also calculated from the dry matter increment of the leaves and the specific leaf area. Spitters & Aerts (1983), Kropff (1988) and Spitters (1989) have supplied a detailed presentation of the model' s structure and its validation for sugar beet and maize.

The following model inputs were used: long term daily weather data from Wageningen, The Netherlands (maximum and minimum temperature, total global radiation); date of emergence of the crop (1 May), density of the crop (11.1 plants m^{-2}) and the weed (100 plants m^{-2}); for both sugar beet and the weed (i.e. *Chenopodium album*) height development, specific leaf area and pattern of biomass partitioning were derived from Kropff *et al.* (in prep.)

RESULTS

In both experiments in 1990, sugar beet plants of cv. Carla appeared to grow higher than plants of cv. Univers (Fig. 1). Plants of cv. Lucy showed an intermediate position. After 40 days after crop emergence leaves of cv. Carla were considerably more vertically arranged than leaves of the two other cultivars (Fig. 1). At the Droevendaal site the Lucy plants started with relatively erect leaves compared to Univers plants (first two observations). However, no difference in arrangement of leaves between these cultivars was found at the De Eest site. Even in the second half of the observation period leaf rosettes of cv. Carla tended to be slightly more erect than those of the other cultivars (Fig. 1).

At both study sites Lucy plants tended to reach full ground coverage earlier than plants of the other cultivars (Fig. 2). Only on day 64 after emergence were these differences significant between degree of ground cover of cultivars at Droevendaal (F= 7.7; d.f.= 2,6; P<0.05). At De Eest these differences were more pronounced during the second half of the observation period (from day 48 to day 73, F ranging from 9.1 to 5.5; d.f.= 2.6; in each case P< 0.05). The time of canopy closing was graphically determined by interpolating at the ground cover value 1 (Fig. 2): at Droevendaal, cvs. Lucy, Univers and Carla attained this value at 567, 704, and 719 degree days after crop emergence, respectively; at De Eest this was achieved at 532, 704, and 653 degree days after crop emergence.

Survival of weeds until the end of the cropping season was significantly lower in cv. Lucy than in cv. Carla (Table 1). In each trial weed survival in cv. Univers was intermediate to those in Lucy and Carla. These tendencies were also observed for each sowing date and weed species, separately (data not presented).

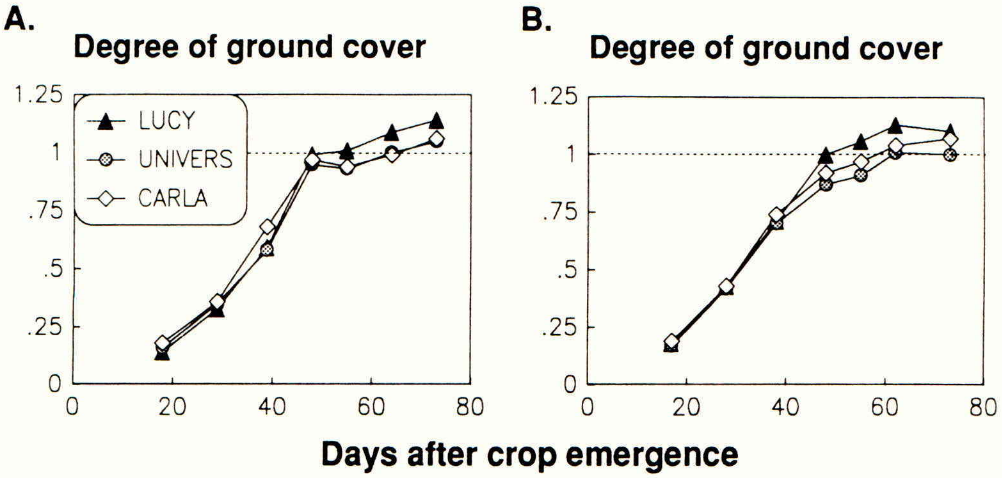

FIGURE 2. Development in ground cover by three cultivars of sugar beet at Droevendaal (A) and De Eest (B). At value 1 leaves of diagonally opposed plants meet (see text).

TABLE 1. Survival of weeds in three cultivars of sugar beet. Data are total percentages survival of the species *Chenopodium album*, *Polygonum persicaria* and *Stellaria media*, sown at day 30 and day 45 after crop emergence. Levels of significance of differences between cultivars are indicated (χ^2-test, *** P< 0.001)

Sugar beet cultivar	Site: Droevendaal 1989	Droevendaal 1990	De Eest 1990
Lucy	40	58	57
Univers	54	70	66
Carla	64	72	77
	***	***	***

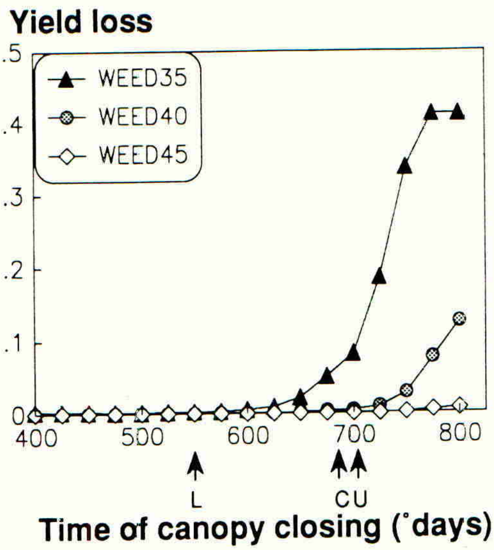

FIGURE 3. Simulated yield loss of sugar beet at different times of canopy closing. The weed (*Chenopodium album*, 100 plants m^{-2}) emerged on day 35, 40, and 45 after crop emergence (weed35, weed40, and weed45, respectively). Arrows indicate the corresponding time of crop closing of the cvs. Lucy (L), Univers (U) and Carla (C).

Simulated yield loss (defined as yield reduction due to weeds relative to the yield of the crop in absence of weeds) appeared to depend, at the chosen density of the weed *C. album*, only on time of canopy closing when weeds emerged at day 45 after crop emergence or earlier (Fig. 3). Given the mean experimentally determined times of canopy closing in 1990, the simulation results show no yield loss in cv. Lucy, irrespective of time of weed emergence (Fig. 3). However, weeds that emerge at day 35 after crop emergence cause c. 10 % yield loss in the other cultivars. In this simulation analysis no yield loss was found for weeds that emerged on day 45 after crop emergence (or later) in any studied cultivar.

DISCUSSION

The present study shows differences in survival of weeds in three cultivars of sugar beet. These differences were demonstrated in field experiments for three weed species that are considered to be troublesome in sugar beet crops. Therefore, these results suggest that the farmer may increase, to some extent, the relative competitiveness of the sugar beet by selecting certain cultivars.

We tried to relate observed differences in plant architecture to increases in competitiveness of the sugar beet by combining the experimental data with results of a simulation model for crop-weed competition. In the field trials the growth form of the cv. Carla was more erect, and the development of ground cover in time slower, than those of cv. Lucy. Compared to these two cultivars, the relative performance of cv. Univers varied between trials and was generally intermediate to the others. Simulations showed that, given the used inputs, we might indeed expect some effect of differences in development of ground cover on the competitiveness of the sugar beet to relatively late emerging weeds. At a high density of a weed species that is considered as being harmful in sugar beet (*C. album*, 100 plants m^{-2}), no yield loss was simulated if the crop canopy closed at the time corresponding with the observed canopy closing of cv. Lucy. For weeds emerged on day 35 after crop emergence these simulated yield losses were c. 10 % in cvs. Univers and Carla. Weeds emerging on day 40 after crop emergence (or later) caused no yield reduction in any cultivar in these simulations. Therefore, it is concluded that on the basis of the available information we may expect that the relative competitiveness of sugar beet is only increased by selecting certain cultivars,with horizontally arranged leaves, with respect to weeds that emerge on c. 35 days after crop emergence. As stated earlier, this emergence time corresponds with the last part of the period considered to be generally critical with respect to weed competition in sugar beet (Scott & Wilcockson, 1976; Kropff, 1988).

The results suggest that selection of sugar beet cultivars with more horizontally arranged leaves may imply a potential reduction of herbicides input in this crop. This reduction will be of a limited extent and is restricted to only the last part of the critical period. Omission of a herbicide application at that time may lead to not more than c. 10% of yield reduction in cultivars with erect growth forms (less competitive cultivars) due to competition by late emerging weeds (e.g. *C. album*). Moreover, less competitive weed species will probably cause even less yield reduction. Due to seed production of surviving weeds, effects on weed population dynamics might be, however, more pronounced.

Practical application of selecting early closing cultivars to reduce herbicide inputs may be promising in low dosage systems for controlling broad leaf weeds in sugar beet (Wevers, in press). In these systems cocktails (mostly of contact and soil acting herbicides) are applied at intervals of 7-10 days in reduced rates to control weeds that have just emerged or where weeds are germinating. When after the latest application, a further flush of weeds emerges, and these weeds are expected to still cause yield reduction or increased weed densities in subsequent crops, repetition of the herbicide application has to be considered. In these systems reduction of herbicide use may be realised by growing sugar beet cultivars with more horizontally arranged leaves. In these more competitive cultivars the total number of herbicide applications can probably be reduced.

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HERBICIDE APPLICATION TO TARGETED PATCHES

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ABSTRACT

A concept is described for targeting herbicide application to weed patches in arable crops so that sprays can be applied only to the detected patches. Alternatively a low dose rate can be applied over most of the field with a higher dose rate or a different mix of herbicides used to treat the identified weed patches. Detection of weeds at the time of spraying has been shown not to be feasible with existing technologies and therefore sprayer control is based initially on a treatment map. Methods of detecting and mapping weed patches are reviewed in the paper and the options for sprayer control are evaluated. The patch application system requires rapid response times and minimal variation of response times along the boom. It is shown that responses can be improved by using small bore supply pipes to give a variation along the boom of less than 1 second on an 18 m boom.

INTRODUCTION

There is considerable evidence to show that some of the more aggressive grass weed species in cereal crops occur in well defined patches. Wilson and Brain (1990) reported that, over a ten-year period, black grass *(Alopecurus myosuroides)* grew in well defined patches on a commercially operated farm. The patches were stable and there was little evidence of new patches forming. Marshall (1988) found that three grass weed species - barren brome *(Bromus sterilis)*, common couch *(Elymus repens)* and meadow brome *(Bromus commutatus)* - grew in definite patches in a field of winter wheat. The stability of weed patches and seed movements associated with harvesting and cultivation operations are the subject of study at Rothamsted Experimental Station. Results from this work have shown that most seeds are displaced only a few metres by such operations and therefore weed patches are likely to remain relatively stable. Substantial savings in herbicide use could be achieved by only treating weed patches rather than applying overall sprays.

There is much less evidence of patchiness of broad-leaved weeds in cereal crops and it is likely that many of the common annual weed species would have to be controlled by an overall application of a broad spectrum herbicide.

The density of weeds has a direct effect on crop yield although the magnitude of the yield reduction varies with weed species. Wilson (1989) indicated that highly competitive weeds such as cleavers *(Galium aparine)*, wild oats *(Avena fatua)* and mayweed *(Matricaria spp.)* cause a 2% yield loss in cereals at weed densities as low as 1 to 2 plants m^{-2} in a crop with densities of some 200 crop plants m^{-2}. Other weeds such as red dead nettle *(Lamium purpureum)* and field pansy *(Viola arvensis)* only cause substantial loss at densities of 20 to 30 plants m^{-2}.

One possible approach to the patch spraying of herbicides is to aim to detect weeds at the time of spraying. In this case, the weed sensing system would probably be mounted on the spraying vehicle and the signals from the weed detector would need to be processed and the sprayer controlled in a time period of approximately one second or less. For the system to operate effectively it would require sensors that could detect close to 100% of the weeds present even at stages of growth when they were occluded by the crop canopy. Work at Silsoe (Thompson et al, 1991; Thompson et al, 1990) has reviewed possible methods of distinguishing weed from crop in arable situations. Two basic approaches were identified, namely:

(i) to detect geometric differences between the crop and weeds such as leaf shape, plant structure or the position of plants with respect to the crop row; and

(ii) to detect differences in spectral reflectance.

Thompson et al (1990) showed that a resolution of the order of 1 mm^2 per image-pixel was required to distinguish between weed and crop on the basis of shape. At this resolution, a 512 x 512 pixel conventional video camera could view less than 1 m^2, and therefore the system becomes prohibitively expensive in terms of capital equipment costs, processing requirements and response times. The problem of weed and crop plants being obscured by neighbouring plants was also found to be a major limitation to the accurate and reliable detection of weeds even at relatively early stages of crop growth. Spectral reflectance techniques were found to be useful at distinguishing weeds from bare soil, stones and mature crop (straw) but it was not possible to establish robust thresholds to distinguish weeds from crop. Thompson et al (1990) therefore concluded that initially a practical patch sprayer controller would not be based on a system for the real time detection of individual weeds, but would instead use a field mapping approach.

An effective patch spraying system based on the mapping approach will require:

(a) a method of generating and storing field maps within the sprayer control system;

(b) a system for detecting and locating weed patches in the field;

(c) a navigation system to locate the sprayer with reference to the map; and

(d) a means of controlling sprayer output to match the requirements of the patches to be treated.

The development of field maps and navigation for agricultural vehicle systems is the subject of research that is common to other spatially selective field operations such as the application of fertiliser according to existing levels of plant nutrients in the soil (Stafford and Ambler 1991). This paper therefore makes only brief reference to the map generation and field navigation systems required for a patch spraying system. Here, the likely spatial resolution for patch herbicide application is considered together with methods by which the sprayer output can be controlled. The possible approaches to the detection of weed patches and the production of spray treatment maps are also reviewed.

PATCH SPRAYER CONTROL

On/off control

The simplest form of control is to turn on the output from the complete boom or from individual boom sections such that spray is applied to the weed patch. This strategy is already implemented manually by some operators although such manual operation is tiring and it is difficult to maintain accuracy during an extended spraying period. On/off control of conventional boom sprayers has other potential disadvantages when used for patch spraying, namely:

(i) the choice of patch treatment is limited to either applying the herbicide mix at a pre-determined rate depending on tank concentrations, nozzle size, pressure and forward speed or applying no treatment at all;

(ii) it will be difficult to predict accurately the total area of patches that will be treated. It is therefore likely that there will be excess dilute herbicide remaining after the completion of the spraying operation leading to problems of safe disposal; and

(iii) the spatial resolution of the patch treatment is limited to the size of individual boom sections on the sprayer.

On/off control does mean that the sprayer need not travel into areas of the field where there are no weed patches. However this control strategy requires a good performance from the weed detection and mapping systems. The discussion in the introduction to this paper indicated that the presence of 1-2 plants m^{-2} of an aggressive weed species would result in a 2% yield loss and justify herbicide treatment. This means that weed detection systems need to operate at this level and with some safety margin if on/off control is to be the only available strategy.

The response time of an on/off control strategy with a conventional single pipe spraying system is dependant only on the response time characteristics of the solenoid control valve. A photographic study (Miller and Watt, 1980) showed that this response time was typically 20-40 milliseconds.

The use of injection metering systems (Landers, 1990), which keep the active pesticide formulations separate from the diluting water until the time of application, can eliminate problems relating to the disposal of unused diluted herbicide. Such systems, previously designed to maintain a constant dose rate independently of forward speed by changing spray concentrations, may be used in a patch spraying situation.

More complex control strategies

An alternative approach to on/off control is to apply some base level treatment to the whole of the field and increase the dose or change the herbicide mix when treating patches. Such treatments cannot be applied with a conventional sprayer without some modification. If a spatial resolution equal to the full width of the boom is acceptable, then injection metering systems may be used to control the output from a conventional sprayer in response to the requirements of the weed treatment map. Since the location of the weed patches to be treated are available to the controller from the map, the mean response time due to the fluid flow in the pipe arrangement can be allowed for in the control of the injection metering system. However with conventional pipe arrangements, the response time will vary along the boom because of the different path lengths that the concentration front has to travel (Fig 1).

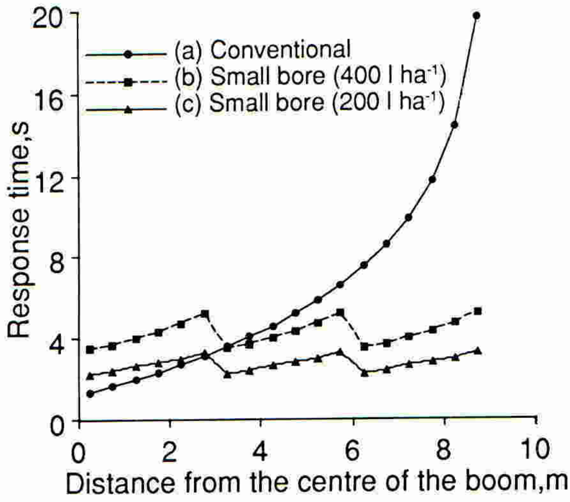

Fig.1 Response times along an 18 m boom operating at 200 l ha^{-1}
Conventional boom in two sections, small bore pipes in six sections

Frost (1990) pointed out that the use of small bore pipe arrangements could minimise response times (and the residual volume of herbicide in the pipes) and improve the uniformity of response times along the boom. The performance of a small bore system capable of operating at volume rates up to 400 l ha^{-1} on an 18 m boom is also shown in Fig. 1. The computer program used to produce the results in Fig. 1 accounts for the delays due to the fluid flow in the feed pipes but does not include the solenoid valve response time. The use of small bore pipe work does incur pressure drops which must be taken into account when designing the system. For example, the small bore pipe system designed for 200 l ha^{-1} in Fig.1 requires a pressure of 6.2 bar at the pump to give nozzle pressures of between 2.75 and 3.25 bar. The major parameter relevant to the design of a patch spraying system is the difference in response time along the boom. For the 18 m conventional boom arrangement plotted in Fig.1, the range in response times along the boom is 18.38 s whereas for the two small bore pipe systems the equivalent values are 1.73 and 0.98 s. The conventional and small bore pipe arrangements shown in Fig.1 are both arranged in feed sections which can be isolated to control the effective width of the sprays. Reducing the number of nozzles in each section and increasing the number of sections will reduce the variation in response times along the boom providing the pipes feeding each section are matched for length and use the minimum diameter consistent with the allowable pressure drop. If pipe sizes are not reduced, which is the case on many commercial machines, then response times and the variations in response times along the boom will be increased by dividing into a larger number of sections.

In designing a small bore pipe system, the pipe sizes that can be used are a function of the highest volume application rate to be applied with the sprayer. The results in Fig. 2. show the improvement in response time that can be achieved by reducing the maximum application volume rate that system can deliver. Although mean response times can be taken into account using the mapped weed patch information, reducing them will minimise the errors due to any speed variation during the lead time between a controlling action being initiated and the concentration front reaching the spray nozzles.

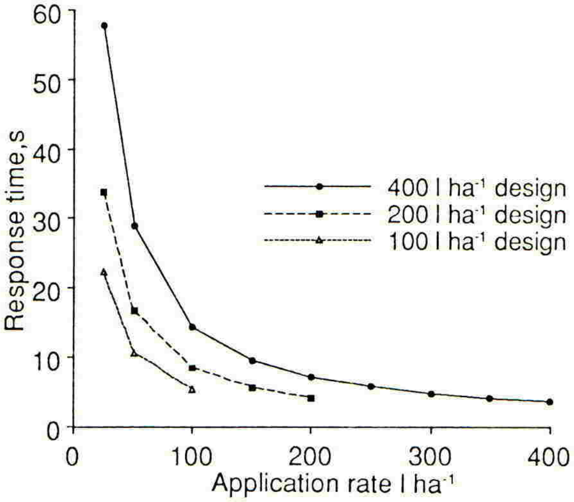

Fig.2. The effect of volume application rate on response times for small bore pipe systems designed to work at different maximum volume rates.

The use of small bore pipe arrangements using a relatively large number of boom sections can also be used to give a patch spraying system with a spatial resolution of less than the full width of the boom. Feeds to individual nozzle sections can be turned on and off to give a spatial resolution equal to the length of one boom section. In order to apply multiple level treatments, more than one spray line must now be used. This is the approach being taken with an experimental patch spraying system currently under construction at Silsoe Research Institute. This will be used in full scale field experiments in conjunction with Rothamsted Experimental Station, to study the performance and required specification of a patch herbicide treatment system.

WEED PATCH DETECTION

Approaches to weed detection

Three approaches are being investigated to collect data on weed patch position for input to the field map; field walking, vehicle-based video cameras and aerial imaging.

Currently, most farmers walk their fields regularly and have a good knowledge of the past and present conditions of the fields. This knowledge may be added into the weed map even though it is only a small sample of the distribution of weeds in the field. Information on weeds obtained during field walking and other field operations has been entered into a data logger and subsequently down-loaded to the computer holding the database. Location will initially be determined by reference to the tramlines. In due course, a GPS (Global Positioning System) hand-held receiver could be integrated into the data logger to automatically tag the weed information with location. A Global Positioning System determines position from signals received from at least two orbiting satellites. The availability and resolution of these systems is currently limited but can be improved by using a ground based reference receiver at an accurately known location. One satellite receiver is mounted on the field vehicle and a radio link established between the vehicle and the ground-based reference receiver.

The second method of data collection is via a TV-standard video camera mounted on a field machine. The weed information can be gathered during any field operation in the crop season. This approach essentially gathers information on individual weed plants, and can only be used for sampling part of the field as complete coverage would be impractical with current imaging systems. The sampling of particular parts of the crop canopy such as between crop rows at early stages of growth or the region above the top of the crop canopy may make such approaches much more effective.

The third approach to weed patch detection is via aerial imaging. In this case, the outline of weed patches rather than individual weeds is detected in the context of the complete field. Light aircraft, model aeroplanes and gas filled balloons have all been used as platforms for taking photographs of crops for the purposes of predicting final yield, or determining crop stress. We are working with model aircraft equipped with a 35 mm photographic camera to capture images of weed patches in crops at times chosen such that there is maximum discrimination between weed and crop, e.g. when weeds are flowering, or when the weeds are still green but the crop has senesced (Thurling, Harvey and Butler, 1985). In due course, the photographic camera may be replaced with a video camera for direct data transfer. Photographic material does have the advantage over conventional video cameras of much higher resolution (20 million pixels as compared to 0.25 million pixels per image).

Images captured from an airborne platform have been digitised into an image analysis system where thresholding techniques have been used to highlight weed patches. Successful weed patch identification will be very dependent on choice of time within the crop season for capturing the images. Even then, it is difficult with grey level images to discriminate between some weed patches and variations in crop colour. The use of selective filtering of images and colour images to enhance discrimination is currently under investigation.

Location systems

The weed patch data must be spatially located within the field. With aerial imaging, the weed information can be related to field boundary features, but a location system is required for vehicle based and manual data collection. A location system is also very important for the spray vehicle when it is interpreting the weed map. The system needs to have sufficient resolution to match the definition of the weed map and the controllability of the sprayer. The range must be sufficient to operate across whole fields. Thus the resolution initially chosen is 2m x 2m with a range of at least 500m.

Three systems are being evaluated in our present research. The simplest is dead reckoning using accurately placed tramlines and a distance transducer to indicate distance travelled along a given tramline. The second system is laser-based (McLeod 1990) with a rotating laser beacon radiating a vertically fanned beam, mounted on the field vehicle. A series of retro-reflectors positioned at known locations around the field boundary reflect the laser beam back to a receiver on the rotating beacon. The third system is the global positioning system (GPS) as discussed above.

FIELD MAP GENERATION

The field map of weed patches includes data from a number of detection methods that will be used as input data for the controlled sprayer. We have based our field map generation procedure on a geographic information system (IDRISI from Clark University, Massachusetts, USA) linked to an image analysis system. Both systems are Personal Computer based. The base field map, containing field boundaries and identifiers, has been input from an Ordnance Survey 1:2500 scale map. The UK National Grid system was used as the co-ordinate system for the field map so that field details were easily located, both locally and globally. Data on weed density and species obtained by various techniques may then be input to the mapped system either directly or via the image analysis system.

Where dead reckoning is used, the positions of tramlines are determined either by measuring on the ground or from aerial photographs and their end point coordinates are input to the map such that the tramline system can be overlaid on the base field map.

As data is collected on weed location, so this is added to the map enabling sensed weed information, gathered at various times, can be overlaid one on each other. Changes in weed type and distribution can then be monitored and used in deriving a treatment map for the herbicide sprayer.

Combining the data of weed patch position together with information relating to factors such as crop and weed species, densities and soil type will then enable the farmer, with the help of the system, to produce a treatment map for the sprayer controller.

CONCLUSIONS

The use of patch spraying treatments offers the potential for making substantial reductions in pesticide use. Injection metering of chemical formulations with an appropriate design of control and sprayer pipe arrangement will enable relatively small weed patches to be treated with targeted dose levels and appropriate herbicide mixtures.

Further work is required to:

(i) improve the methods of weed patch detection in terms of reliability, cost and ease of use.

(ii) conduct field experiments to determine the required spatial resolution, levels of weed detection and treatment regimes to be applied to the patches, and

(iii) to assess the performance of areas subjected to patch treatments over a number of crop production cycles and growing seasons.

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