SESSION 3A

WEED CONTROL IN SMALL-GRAIN CEREALS IN A LOW PROFIT SITUATION

CHAIRMAN	DR F. B. ELLIS	
SESSION ORGANISER	MR F. B. COOPER	
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ARABLE CROPS: CURRENT POLICY ISSUES

C J A BARNES
Under Secretary, Arable Crops and Alcoholic Drinks Group,
Ministry of Agriculture, Fisheries and Food

ABSTRACT

Cereals are one of the key commodities in the CAP. The EC's attitude to cereal surpluses, and the measures adopted to deal with these have an impact on all arable producers. Changes to the regime, including an increase in the co-responsibility levy and the introduction of one year set-aside, were made at the 1991 price fixing. Adoption of the Commission's proposals for CAP reform would further alter the scene: and a successful outcome on agriculture at the GATT discussions would also act directly on prices and trade levels. The paper, prepared in early September, examines the state of play on these issues and outlines the Government's position.

INTRODUCTION

1. As ever, the organisers of the Conference have chosen their timing well. The debate about the future of the CAP in the arable sector is now in full swing following the presentation of what has become known as MacSharry II. After an initial round before the summer break the Council of Agriculture Ministers is about to return to detailed discussion of the proposals. Meanwhile, the GATT Uruguay Round talks continue.

2. These are the major political and institutional influences which will bear on those who, to quote the session title, practise weed control in small grain cereals in a low profit situation. But they are not the only ones. We must not forget the very important role that R&D, whether Government or industry funded, has to play. You might expect me to touch on this, given my background in relation to "near market" R&D.

THE MACSHARRY PROPOSALS

3. Arable crops are of central importance in the current discussions about reform of the CAP. Although the title of the session refers to cereals, this paper covers set-aside and also, briefly, oilseeds. The Commission's proposals, and the thinking that lies behind them, can only be fully understood if the arable sector is considered together.

4. The main part of the paper therefore:

- outlines the pressures that have led to the reform proposals,

- sets out, for the sake of clarity, what the Commission has proposed, although some of this will be familiar to many,
- explains the Government's thinking,
- speculates a little, as to the next steps.

Pressures for reform

5. Why should the CAP be in such a state of flux; what are the pressures that have brought this about? There are many reasons, including the following:

- historically, over generous price support has made it profitable to produce regardless of market requirements. This has led to market distortions of many kinds,
- production is continuing to rise as productivity increases. New developments eg in biotechnology make it likely that this upward trend will continue,
- meanwhile, consumption of some products such as meat and fats, is falling. Changes in eating habits seem likely to continue and they will of course impact on production patterns and on surpluses,
- world prices are unstable, reflecting a mix of international developments, including the disarray of major importers like the USSR. Eastern European production seems likely to rise.

6. Perhaps even more important, however, are:

- strong international pressures for trade reform; the GATT has already been mentioned. And at the time of writing much concern is being expressed by the Australians at the grain export policies of both the US and the EC;
- budgetary difficulties over the cost of the CAP this year and next (a weak dollar, falling world prices, and problems in the beef market have placed heavy strains on agricultural budget guidelines for 1991 and 1992);
- much public concern here and in some other member states - the Netherlands, Germany - over the environment. The CAP ought not to be changed without acknowledging this and the UK has been to the fore in arguing this. The Commission have proposals in hand.

7. One might say, "this is all very well but cereals are not the main problem. Major changes were introduced in 1988 - set aside, stabilisers. There is a co-responsibility levy. Why should the arable sector have to bear the burden of difficulties faced elsewhere in the CAP?". Unhappily, while one would be right to draw attention to these changes it would be wrong to imply that they have worked fully as intended. It is true that the intervention stock position in the UK has been good (ie low) compared with some previous years; but Community intervention stocks are rising. The 1990 harvest was unusually low because of widespread drought in Southern Europe. Moreover, former East German production has to be taken into account,

although not for the stabiliser calculation. Set aside has been introduced and gradually extended. There are encouraging signs that some of the laggard member states are now taking it seriously. But the fact that the Community has had to introduce, at short notice a supplementary one year scheme is evidence that the five year scheme has not bitten into surplus production in the way envisaged.

8. To date there remains a large structural surplus of cereals. Community production is currently about 30m tonnes above the level of domestic consumption. All of this will either have to be exported onto the world market with the aid of export refunds, thus further fuelling international concern; or go into intervention for subsequent disposal, at substantial cost to EC taxpayers. It is against this background, therefore, that the Commission has made its reform proposals.

Detailed Proposals

9. Commissioner MacSharry's proposals for CAP reform, first outlined in his "Reflections" paper, envisaged a revised CAP which would aim to keep as many farmers as possible on the land. He proposed a combination of lower institutional prices and direct payments, the latter being "modulated" - to use the Commission's term - in favour of small producers. These payments would be available only to those who set a proportion of their land aside - effectively compulsory set aside.

10. The Reflections package provoked much criticism, both here in the UK and elsewhere in the Community. The paper itself was put on hold, pending the outcome of the annual price-fixing, and the revised version appeared in July.

11. The package amounts to a radical reform. Indeed, the Commission's aim is to produce a wholly new and considerably more coherent policy for the major crop sectors. For cereals, the burden of support shifts from the consumer to the taxpayer - in many respects a return to the deficiency payment principle which we abandoned for most crops when we joined the EC. The oilseeds proposals retain the direct payment concept but calculate the aid in a different way, to meet the requirements of the GATT "Soya" Panel which found the current regime inconsistent with GATT rules. Let us look for a moment at the detail.

12. A target price for cereals would be set at 100 ecu per tonne, some 35% below the current buying-in price. The Commission assumes, heroically, that the world market price would also reach 100 ecu in a "stabilised" (presumably post-GATT) market. The intervention price would be set 10% below, and the threshold price for imports 10% above, this figure. (The current threshold price for feed wheat is 53% above the buying-in price.) Thus, if the market price stabilised

around the intervention price, the overall price cut would be 42% though this would be offset to some extent by the abolition of the co-responsibility levy. The same structure, with slightly different price levels, would also apply to rice.

13. Existing cereal producers would be compensated for the reduction in prices through the introduction of direct area payments. These would be available to all, not "modulated" as in the "Reflections" proposals. Participation in the aid schemes would, for all except small producers, depend on fulfilment of a set-aide obligation. Though participation would, in theory, be voluntary the economics are such that most (if not all) producers would participate and the Commission envisages 100% uptake.

14. The aid per hectare would be based on a payment per tonne of 55 ecu (matching the price cut), converted to rates per hectare according to average regional yields. For the UK as a whole this would mean a payment of around 320 ecu/ha (£255 ha) against an EC average of 255 ecu/ha. However, there could be variations within the UK since the Commission may require the regions to be at a sub-national level and based on sound agronomic criteria. We shall thus have to prepare "regionalisation plans".

15. There would be a special aid for durum wheat of 300 ecu per hectare, paid only in those parts of the Community which currently receive durum production aid (not the UK). This is intended to compensate producers for the full alignment of durum and other cereal prices.

16. These aids would be paid during the first half of the marketing year.

17. For oilseeds the Commission met the deadline of making proposals for the future oilseeds regime by 31 July. The present system of tonnage payments to processors would, under the new arrangements, be replaced by one of direct payments per hectare to producers. The aid would equal the difference between the estimated world market price and the intended return to the producer. The latter would be calculated on the basis of a ratio between oilseed and cereal values to ensure that unwanted swings between cereal and oilseed plantings did not occur.

18. The aid, which would be the same for all oilseeds (rape, sunflower seed and soya), would also be regionalised on the basis of cereal yields in the region concerned.

19. When the full arable sector proposals are brought in, from 1993, oilseeds growers would become subject to the set-aside requirement and would, where relevant, be eligible for the small producer scheme.

20. However, because the Council's commitment is to change the oilseed regime by 1 July 1992 in order to comply with the outcome of the GATT Panel, the Commission has proposed transitional measures for this sector only, to apply from that date. In effect, these bring in the new method of calculating the aid and paying it direct to growers but without any requirement for linked set-aside. For the transitional period only, the current MGQ system would be replaced by an MGA - Maximum Guaranteed Area - system.

21. Under the set-aside requirement arable producers (defined as producers of cereals, oilseeds and protein crops) other than small producers (defined below) would be required to set aside a proportion of their arable area as a condition of participation in the direct aid schemes. The set-aside requirement would be determined anually - in effect it would become a market regulator - but set initially at 15%.

22. Land set-aside, up to an area capable of producing 230 tonnes of cereals in the region concerned, would receive a payment equal to the regionally determined cereals direct aid. No payments would be made on land set-aside above this limit.

23. Land-set aside under these provisions would have to be maintained in an environmentally acceptable condition, and would have to be rotated annually. In principle, non-food use crops could be grown on set-aside land, but only if effective control systems can be devised. If non-food crops are included it is expected this will apply in all member states (unlike the present system which is optional).

24. The existing 5 year set-aside scheme would be phased out and replaced by a long-term (20 year) scheme. The new arrangements for cereals and protein crops would be phased in over the three years from 1991.

25. To complete the picture, small arable producers (defined as those with an arable area capable of producing not more than 92 tonnes of cereals on the basis of regional average yields) would be eligible for simplified arrangements without any set-aside requirement. They would receive the direct aid for cereals on the total arable area, regardless of the mix of crops sown.

26. Finally, as the new regime came in, the existing stabilisers for cereals, oilseeds and proteins, together with the cereals co-responsibility levy, would be terminated.

The Government's reaction

27. The Minister has made abundantly clear that MacSharry II is discriminatory against UK producers. There are two prime reasons why

the arable proposals impact more severely on UK producers than on those in other member states: firstly, the provision for a proportion of uncompensated set-aside for holdings with a total arable area capable of producing in excess of 230 tonnes of cereals: secondly, the exemption of small producers from the set-aside requirement.

28. The uncompensated set-aside requirement would (taking the UK as a whole) affect holdings with over 40 ha of arable land in the UK compared to an EC average of 50 ha. Overall, around 60% of set-aside in the UK would be uncompensated' compared to one third of the set aside area in the EC11. The exemption for small producers capable of producing less than 92 tonnes would cover 5% of the UK area and 40% of UK holdings compared to 40% and 90% respectively in the EC11.

29. The Minister has made very clear that the Government remains fully committed to reform. But he cannot agree that what the Commission is proposing is the way forward for a viable and competitive industry. If, under a GATT agreement, we are going to find ourselves in a more open world trading system, the last thing we should be doing is penalising the efficient and the forward-looking.

30. The Government had hoped that the Commission's proposals would seriously address the problems of the escalating agriculture budget but they appear to do no such thing. Support prices would be cut, and cut fairly significantly, but to compensate for this, new and very costly measures are proposed. The taxpayer would certainly not benefit from reform along these lines.

31. The proposals would penalise larger and specialised farms. In the UK, less than the first six hectares set aside on a holding would receive compensation, the remainder would be uncompensated. This would have a dramatic effect on our producers' competitiveness: over 60 % of land set aside in the UK would be uncompensated compared to less than a third in the rest of the Community.

32. What the Government wants to see may be summarised as follows:

- a steady decrease in price support to producers;
- but a decrease that bears equally on all producers, whatever their size or location, and introduced at a pace which gives farmers time to adapt;
- conditions to ensure that farmers care for the countryside;
- a truly voluntary set-aside scheme;
- direct aids, but degressive and time limited, only where they are essential to bring about specific objectives; and
- an agricultural policy that contains the cost to the taxpayer.

What happens next?

33. The debate is in full swing. Discussions in the Council continue; the GATT round likewise. It is difficult to foresee at the moment just how the timing will go but it seems very unlikely that CAP reform will be settled before the next price-fixing. Certain elements though, and especially oilseeds, will need to move at a faster pace.

34. Where does this leave the individual farmer? As always individuals will react differently according to their personal and business circumstances. Some who have scope to do so may increase production to maintain output; others may feel that they are already at the maximum and may seek to reduce input costs or diversify or extensify. Some may choose to go further into set aside, perhaps under the scheme for the introduction of much longer term set-aside. New sources of funding may well become available as the Commission's proposals on Agriculture and the Environment come into operation. These would, amongst other things, allow for the introduction nationwide of the Countryside Premium Scheme, currently operated by the Countryside Commisson in seven Eastern Counties as a top up to set-aside for those who carry out environmental enhancement - positive improvement of the environment in addition to the protection which all are obliged to undertake.

35. Then there is the question of non-food uses. This part of the package would allow crops to be grown on set aside land for industrial or other non-food use. No details are yet available and the Government would want to look carefully at both the economics (there is little point in re-creating the problems of the CAP by subsidising uneconomic uses) and at the effectiveness of control systems. There are, of course, precedents under the CAP for industrial uses of agricultural crops (eg cereals for starch, high erucic rape for use in plastics).

36. Much is as yet uncertain. But the Minister is certainly well aware of the concerns of arable producers - both at the discriminatory nature of the proposals and at the extent of any foreseeable change, whatever its precise nature. It is for this reason that the Minister has stressed the need for change to come about at a pace which allows farmers to adapt.

RESEARCH AND DEVELOPMENT

37. Adaptation to the new system, whatever its final shape, will take many forms. One of the ways in which the Government can help the industry to meet the pressures of change is through its R&D programme, which is an essential and integral part of its general approach to policy on arable crop production.

38. MAFF remains committed to funding strategic R&D to underpin future developments. This is a very important part of the Rationale

for R&D funding. The levy raising bodies and others need a sound foundation on which to base their own, generally more applied, programmes. The Government provides this in the work it is funding at the various AFRC institutes, with ADAS, the Universities and other contractors.

39. Indeed, many of you will be aware that the Government has strengthened its arrangements for R&D commissioning in recognition both of the need to keep closely in touch with industry's timing; and to ensure that the planning of R&D goes hand in hand with the development of policy. This is what lies behind the reconstitution of the Priorities Board which, through its six Advisory Sectoral Groups, advises Government on the planning of its R&D in the light of industry's needs and views; and behind the change in MAFF's internal arrangements whereby people like myself, who advise Ministers on policy, also hold responsibility for commissioning R&D. My own Group funds a wide range of R&D relevant to arable crops and we are, for example, remembering the theme of the Conference, directly involved in funding weed control work at Rothamsted.

40. Finally, there is the new research initiative - the LINK programme, announced at this year's Royal Show - which aims to bring forward projects to develop profitable farming systems which are sensitive to the needs of the environment and demands of the consumer. This collaborative research effort under which Government matches industry pound for pound, will explore new husbandry methods including crop management practices; weed, pest and disease control, and waste recycling. The aim is to develop new production systems for mainstream agriculture which are practical, profitable, environmentally-friendly and attuned to consumer demands.

41. The programme is an excellent example of creative co-operation between Government and industry, and will help to ensure that the results of MAFF-funded strategic research are fully developed and effectively exploited by UK industry. In order to develop profitable farming methods which farmers can sustain into the future, we need to investigate new technologies which cater for the long-term health of the environment and the changing demands of the consumer. Industry has already pledged funds to launch the scheme and individual projects are being developed.

CONCLUSIONS

42. These are difficult times, but also challenging and exciting ones. We are on the threshold of changes to our system of farming support which are as far-reaching and fundamental as those which took place when we first joined the EC. The prize is of a radically reformed CAP which meets the needs of farmers, consumers and taxpayers alike. It seems to be one well worth striving for.

CROP PRODUCTION, INPUT USE AND PEST MANAGEMENT UNDER A REGIME OF DECLINING PRODUCT PRICES

G.C. FOX, D. BARBER

Department of Agricultural Economics and Business, University of Guelph, Guelph, Ontario, Canada, N1G 2W1

ABSTRACT

A major share of Canada's small grain production is sold on export markets. As a result, trade conflicts between the United States and the European Community have translated into dramatically lower prices and lower margins for Canadian grain producers. This paper presents an economic analysis of the consequences of declining prices for weed control in small grains. The concept of economic thresholds in pest control is examined. The analysis is conducted with a view toward the long run strategic planning implications for small grain producers in light of the possibility of increased liberalization of trading arrangements in international grain markets.

INTRODUCTION

Farmers' input use decisions are coming under increasing scrutiny. High real interest rates, declining real product prices and declining margins have all contributed to a reassessment of agronomic practices in small grain production in Canada during the 1980s. Trade disputes, particularly between the United States and the European Community, have had a significant impact on the farm gate prices for wheat and barley, two small grains which are exported by Canadian farmers in substantial volumes. Prospects of increased trade liberalization as well as the possibility of continued trade wars between the United States and the European Community have prompted farmers to examine various means to improve efficiency in grain production.

As data presented in Figure 1 indicate, Canadian wheat prices have been and continue to be below farm gate prices received for wheat in the United Kingdom over the past 2 decades. Even recent declines in real grain prices in Europe have left domestic prices within the Community substantially above prices received by Canadian farmers. Convergence of the two price series in 1988 reflects drought assistance paid to Canadian producers for production in that crop year. This paper seeks to examine the consequences of product price conditions for weed management strategies in small grains. Later, we will also examine the implications of current price conditions for other agronomic practices and other adjustments in the farm sector that can and have been made in the Canadian grain industry in the past decade.

In addition to financial considerations, farm input use decisions have also received increased attention for environmental reasons. Concern regarding the contamination of ground and surface water by agricultural chemicals, both pesticides and nutrients, as well as from eroded sediment has motivated several initiatives intended to change farmer's input use. A policy to reduce pesticide use by 50% by the year 2002 has been introduced in Ontario. Later in this paper we will argue that the intensity of input use is influenced to a significant degree by product prices. Policy reform which facilitates the establishment of price regimes more

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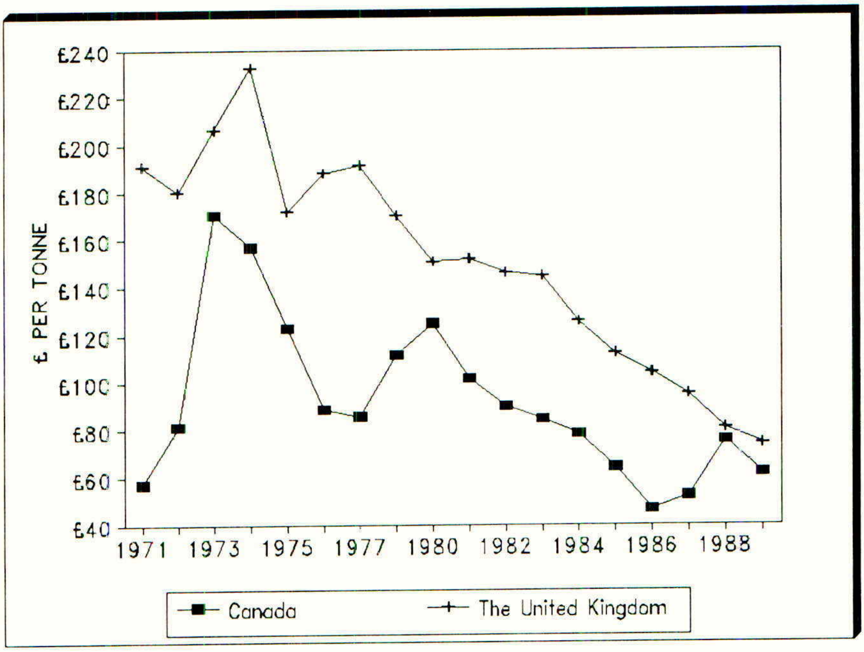
Figure 1

A Comparison of Wheat Prices in
the United Kingdom and Canada, 1971-1989
(Constant 1985 £)



Source:
Statistics Canada: Grain Trade of Canada, (selected years)
Bank of Canada: Bank of Canada Review, 1991 for exchange rate and
GDP Implicit Price Index
UK Annual Abstract of Statistics (1991)
UK Annual Review (selected years)

closely related to underlying conditions of supply and demand can not only improve the economic efficiency of grain production and distribution but also advance environmental objectives.

PROFITS, PRICES AND PEST CONTROL INPUTS

The logic of profit maximization requires that the contribution of the last unit of an input to gross revenue equal the contribution to total costs made by the use of that last unit of input. This principal of optimization, that the marginal sacrifice equals marginal gain at an optimum, is generic in that it applies to land, labour, capital and other inputs in the farm firm, including pest control inputs.

Figure 2 illustrates the application of this principle of optimization for the case of a pest control input. The analysis is somewhat more complex than, for example, the use of fertilizer, since the pest control input acts indirectly on pest population which subsequently influences yield. The lower left panel of Figure 2 portrays the relationship between application of a pest control input and pest density on a per hectare basis. Pest density in the absence of control efforts is represented as the intersection of the relationship in the lower left quadrant and the horizontal axis. Z_{H0} indicates a high pest density when pest control input is zero. Z_{L0} corresponds to a lower initial pest density. The respective levels of pest control input which would eradicate the pest are indicated by X_{HE} and X_{LE}. Grain yield per hectare depends on many factors, including weather, variety and fertility, as well as pest density. In the upper left quadrant of the diagram, yield is represented as a decreasing function of pest population. Yield per hectare in the absence of pests is indicated as Y_E. Yield without intervention depends on the pest density that would occur in the absence of control (eg. Z_{H0} or Z_{L0}). The upper right quadrant describes the relationship between pest control input and yield. Relationships in this quadrant have been the primary focus of economists studying pest control. Agronomists have emphasized relationships in the upper-left and lower-left quadrants. The higher line in the upper right quadrant corresponds to the lower uncontrolled pest density, Z_{L0}. Derivation of relationships in this quadrant begins with the bottom half of the vertical axis. For a low initial pest density (Z_{L0}) use of pest control input at the level X_1 gives a post-control pest density of Z_1. This translates, in the upper left quadrant, to a yield of Y_1. Using the 45° line in the lower-right quadrant translates the level of pest control input (X_1) onto the horizontal axis in the upper right quadrant. The combination of Y_1 and X_1 gives 1 point on the Yield/Pest Control Input relationship for a low initial pest density. Selection of other values for X can be used to trace out the rest of the relationship.

The straight line coming from the origin in the upper-right quadrant has a slope of (V/P) where V is the unit cost of applying a pest control input and P is the product price of the crop in question. The level of pest control input which maximizes net revenue occurs at the level of x which maximizes the vertical distance between the yield line and the straight line coming from the origin. The point where the slope of the yield/input function is equal to V/P is the level of pest control input which maximizes net income. Note that this point occurs at a lower level of X when the uncontrolled pest density is lower. The net revenue maximizing level of pest control input (X^*) is associated with an optimal yield, which is generally less than Y_E, and an optimal pest density, which is generally greater than zero. Actual optimal values for pest control input, yield and pest density depend on the nature of the underlying biological relationships in the two panels on the left side of the diagram, as well as on product prices and pest control costs.

Figure 2

A Model of Optimal Pest Control

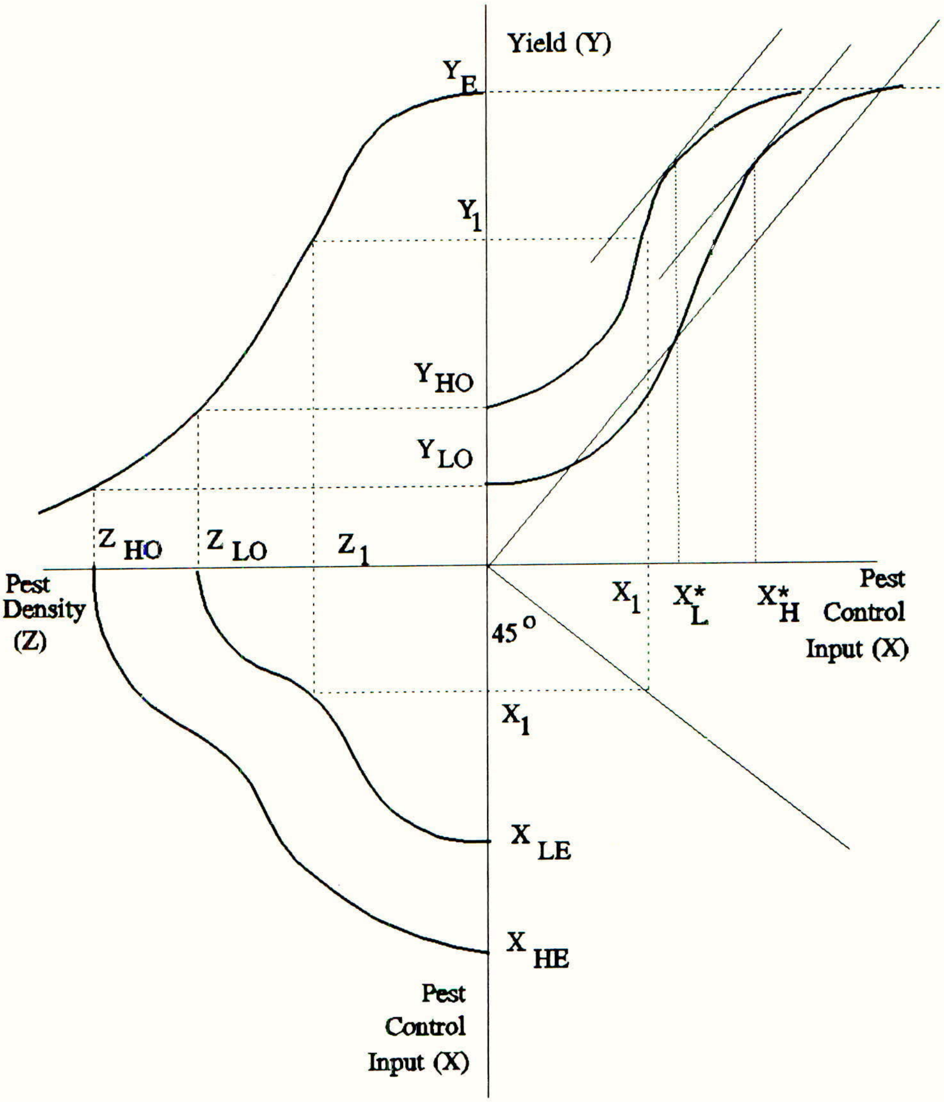
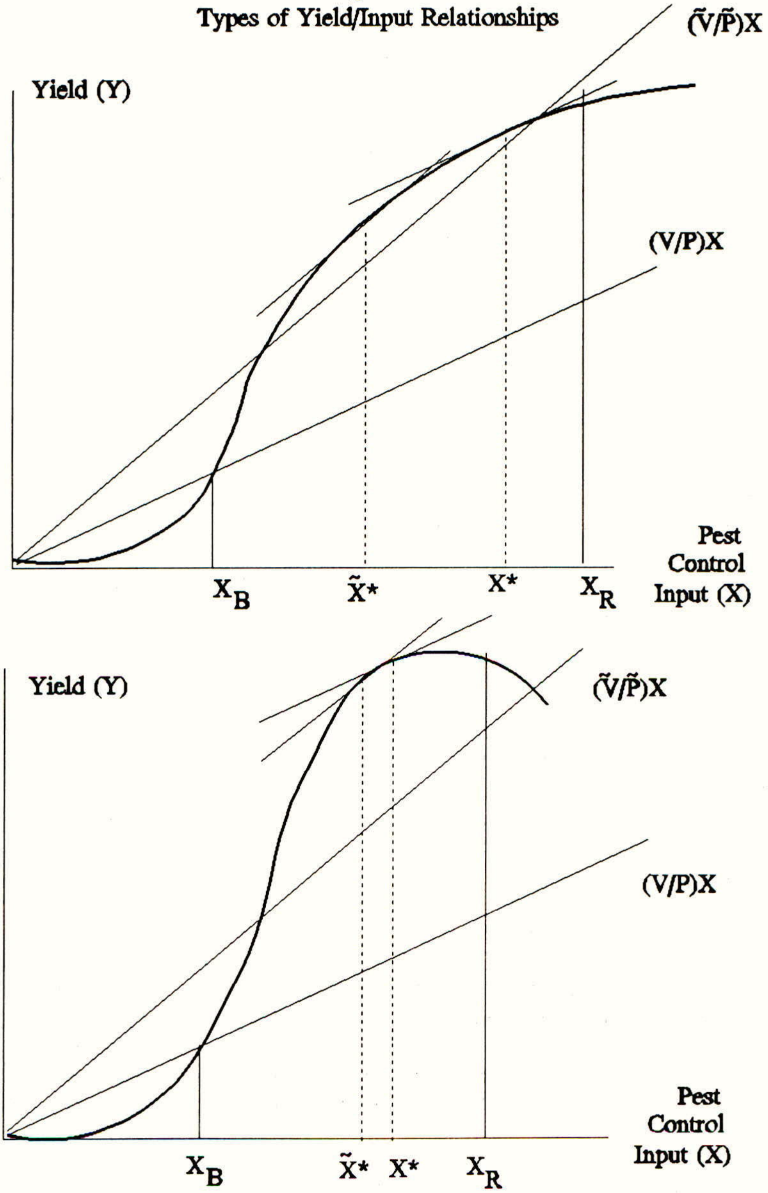


Figure 3
Types of Yield/Input Relationships



THRESHOLDS

This model enables us to address the impact of costs and prices on pest control strategy and also clarifies some discussion that has taken place in the literature regarding the concept of economic thresholds for pest control. In addition, as indicated by Figure 3, the curvature of the pest control-yield relationship, which is essentially a biological relationship arising from the nature of the dose-response relationship between pest control and pest density and then between pest density and yield, acts as an important constraint on the ability of farmers to adjust pest control practices to changes in product prices and costs. In the upper panel of Figure 3, a yield-pest control input relationship with relatively gentle curvature is represented. In the lower panel, the situation where either pesticide application must reach a critical level before appreciable decline in pest density is observed or pest density must achieve a critical level before appreciable yield losses are observed is represented. For purposes of illustration, profit maximizing pest control input is indicated as X^* in both diagrams, when prices for pest control inputs and grain are (V/P). If either pesticide costs increase or product prices decrease, the straight line coming out of the origin becomes more steeply sloped, for example $(\tilde{V}/\tilde{P})$, and the level of pest control which maximizes net revenues will fall. In the upper diagram, with the relatively gentle curvature in the relationship between yield and pest control, pest control input falls substantially more than is the case in the lower diagram.

The combination of Figures 2 and 3 clarify certain concepts which have been described as "economic thresholds" in the literature. Cousens (1987), Deen (1991) and Weersink et al. (1991) have discussed numerous concepts of economic thresholds regarding pest control. The three main candidates for the term economic thresholds can be represented using this diagrammatic analysis. The first concept, which has already been discussed, is the level of pest control which maximizes net revenues, indicated as X^*. At this point, the contribution to gross revenue of the last unit of pest control input applied is exactly equal to the marginal cost of the use of that last unit of input. From a farm managers perspective, this is the most important threshold concept. It has been discussed on occasion in the literature, but it has also frequently been confused with other concepts. A second economic threshold could be described as the break even pest control application rate. In Figure 3, this level of pest control is indicated as X_B. At this point, the total cost of applying pest control equals the total gain in gross revenue achieved from that level of pest control. The value of X_B depends on the initial or "absence of control" pest density. A third threshold concept arises as a consequence of the regulatory environment in which pesticides are developed and used in Canada. Typically, pesticides are approved for use at a specific application rate, described as the "label rate". It is in fact illegal for farmers, in many contexts, to vary the intensity of use of a pest control product in response to changing prices and conditions. It has been suggested, however, that compliance with this requirement is less than 100%. Nevertheless, a third threshold concept arises when farmers are constrained, at least in principle, to use a pest control product at a pre-defined rate. This could be termed the label rate threshold. In the upper panel of Figure 3, X_R indicates a hypothetical label rate set by regulation. In the example illustrated, the contribution to gross revenue from applying the pest control product at level X_R exceeds the total cost of applying the pest control input at that level when the price ratio is (V/P) but not when it is $(\tilde{V}/\tilde{P})$. Profits at X_R should be compared to those with no treatment to determine if pesticide use is warranted.

While this discussion of thresholds has taken place in output-input space, Figure 2 acknowledges the interdependence of input use, pest density, and yield. For each of the thresholds defined in terms of input use, the corresponding pest density associated with each of these thresholds can be derived in the upper left quadrant of the figure. This model could also be used to study other modes of pest management. The discussion above has presumed that X measured the pesticide application rate per hectare, but other types of pest control inputs, such as mechanical, biological or integrated controls, could be treated in essentially the same manner.

Unfortunately, as has been pointed out by Cousens and by Deen, the types of dose-response relationships illustrated in Figures 2 and 3 have not been the subject of sustained inquiry in pest control research by agronomists. Recent work at the University of Guelph, and elsewhere is attempting to fill in the gaps in our knowledge of these dose-response relationships which are critical to understanding the types of input use and pest control strategy adjustments farmers might make in response to changing price and cost conditions. In many instances, it appears that the situation described in the lower panel of Figure 3 is typical, which suggests that farmers have few options in the way of incremental adjustment of pest control application. As a result, the pest control strategy seems to be something of an all or nothing choice.

Comparing the importance of product prices and herbicide costs

As was indicated above, the ratio of herbicide cost to output price is a critical determinant of profitability. It is important to determine whether it is the numerator or the denominator of this ratio which has played a more important role. Producer complaints regarding differences in input prices across the U.S./Canada border are common (See Table 1 for a typical example). In addition, certain pest control products which are available in the United States have been banned in Canada (eg. Alachlor) and new products are frequently introduced later in Canada than in the U.S. However, as Figure 4 suggests, pesticide costs constitute a relatively small proportion of gross revenue for grains in Canada. As a result, downward movements in output prices have had a more significant impact on pest management strategies.

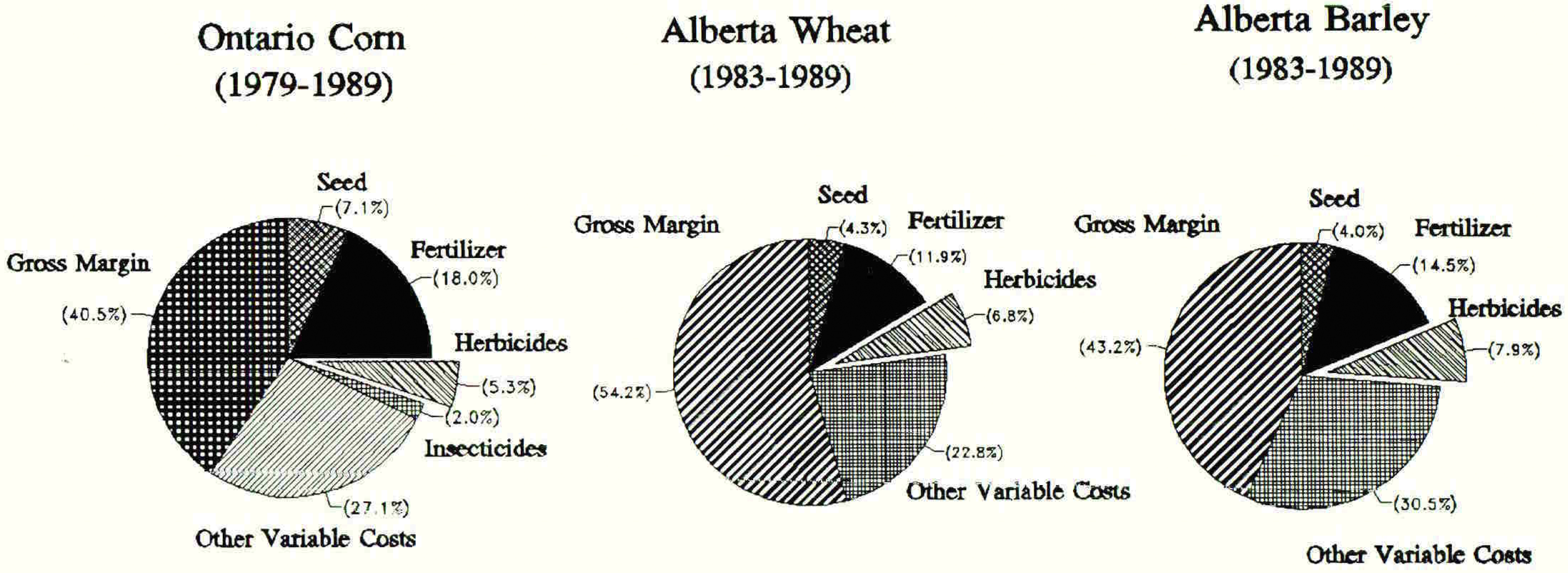
TABLE 1. Farm Input Price Comparison 1991

Fertilizer	Eastern Canada	United States	Difference
Potash (Tonne)	226.00	171.87	54.13
Urea	319.00	255.31	63.69
Map	352.00	276.68	75.32
06-27-27	288.75	230.37	58.38
12-36-12	339.93	238.75	101.18
Crop Protection			
Bladex	15.25 kg	12.07 kg	3.18
Fusilade	46.00 L	25.66 L	20.34
Dual 8E	20.70 L	16.90 L	3.80
Lorox DF	23.50 kg	20.18 kg	3.32
Banvel	24.75 L	18.55 L	6.20

Source: Farm and Country, August 20, 1991.

Figure 4

Comparison of Pesticide Costs as a Share of Gross Revenue in Canadian Grain Production



Source: Corn -- OMAF, Economic Information Report. (selected years)
Wheat and Barley -- Alberta Agriculture, Production Cost Tables (selected years)
GDP Implicit Price Index -- Bank of Canada Review, (February, 1991)

ECONOMIC ADJUSTMENTS TO LOWER PRODUCT PRICES

Expectations of lower product prices have led to a number of adjustments at the farm and sectoral level in the Canadian grain industry. Perhaps the most important of these adjustments has occurred in the land market. The English classical economist David Ricardo once said "the price of land is high because the price of corn is high and not the other way around". Significant downward adjustments in land prices have occurred in both Canada and the United States relative to prices observed in the 1970s. Land, particularly in grain growing regions of the Canadian Prairies, has few alternative modes of employment apart from grain production and its price is determined largely as a residual after other factors of production have been paid. Although current land holders absorb substantial capital losses when land prices are falling, these adjustments do not threaten the long term viability of grain production as an economic enterprise. Once land prices have adjusted to a new lower level based on expectations of lower grain prices, rates of return to investment are comparable to the situation of high land prices and expectations of high grain prices.

At the individual farm level, farmers may elect to use inputs less intensively on their crop land. Fertilizer application rates and even plant densities may be adjusted. Adjustments in pest control practices seem to be more limited. Anecdotal evidence of farmers employing less than so-called label rates of herbicides has been reported. Others have substituted mechanical methods of weed control for chemical methods. This includes the use of summer fallow on grain in western Canada and cultivation in corn in Ontario. In addition, farmers may apply pesticides on only a portion of their cultivated acreage or may rationally tolerate a higher weed density under lower product prices than they would under higher grain prices. Finally, adjustments in crop mix including increasing the production of crops like flax, canola, white beans, or soybeans can be undertaken if relative product prices for these commodities have been depressed less than prices for wheat, barley, oats, or corn. In some cases, such as fertilizer use, lower product prices can contribute to a reduction in water quality degradation from, say, less leaching of nitrates. However, substitution of mechanical weed control for herbicides can accelerate erosion and sediment deposition in streams and lakes.

IMPLICATIONS

Farming is a risky business. Weather, pest populations and management ability contribute to production risk and changes in market conditions contribute to price and cost risk. Economists have emphasized that farmers take these risks into account when making production decisions (see Robison and Barry, 1987). The analysis undertaken in this paper considered the impacts of pest control strategies on expected profitability. Work recently undertaken by Weersink et al. shows the potential of extending this type of approach to a stochastic model.

Whether one employs a stochastic model or an expected profitability model, however, the increasing attention being paid by farmers and non-farmers to pest control decisions mean that we will require better knowledge of dose-response relationships in pest control for grains in the future than we have had in the past. This may require an adjustment in experimental designs and statistical procedures used in the study of pest control systems. Simply put, we need to know more about the complete relationship between pest control input and pest density and between pest density and yield than we have in the past. We need to be able to characterize more of the surface of these functions and move beyond the determination of whether pest control at a particular level contributes more to revenues than it does to costs.

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WEED CONTROL IN SMALL GRAIN CEREALS IN A LOW PROFIT SITUATION. THE SHORT TERM VIEW

B. W. KEEN

Independent Crop Advisory Services, High Pound, Westhall Hill Lane,
Burford, Oxford. OX18 4BJ

SUMMARY

This paper is based on the author's experiences of pragmatic weed management on a variety of farms in North East Gloucestershire and the neighbouring areas of South Warwickshire and West Oxfordshire.

The Development of Cereal Herbicide Practice since U.K. entry to the European Economic Community.

The profitability of cereal growing changed overnight with our entry into the E.E.C. and this resulted in Cereal Production rapidly increasing in intensity, with an emphasis on autumn planted crops.

Intensive Cereal production is entirely dependent on herbicides for success. The Agrochemical industry has managed to keep abreast of changes in weed species by introducing a steady stream of new herbicides, which have allowed cereal crops to be grown in a virtually weed free environment. However, this was often achieved, at very high cost, by a 'blunderbuss' approach; which could easily result in 30% of the variable costs being expended on herbicides. During the halcyon first decade, after U.K. entry to the E.E.C., this level of cost was tolerable.

Currently farmers are facing a situation where real income from cereals is static whilst costs continue to rise. If arable farmers are to continue in business, every opportunity to reduce costs must now be explored. Although most arable farmers are likely to find greater scope for savings in fixed costs, variable costs should not be ignored.

Weed control costs are likely to show some scope for reduction in the short term; but care must always be exercised to ensure that short term savings do not result in higher costs in subsequent years.

CLASSIFICATION TABLES FOR CURRENT WEED PROBLEMS IN CEREALS

TABLE 1 Weeds only tolerable at very low levels due to loss of yield from competition.

	cost £/ha.		cost £/ha.
Lolium spp.	20-40	*Galium aparine*	9-18
A. myosuroides	27-48	*Brassica spp.*	9
Bromus spp.	45	*Vicia faba*	9
Avena sp.	18-48	*Galeopsis spp.*	9
Elymus repens	20	*Chenopodium album*	6
Agrostis spp.	20	*Atriplex patula*	6

TABLE 2 Weeds only tolerable at very low levels because they present major control problems in other crops in the rotation.

	cost £/ha.		cost £/ha.
Galium aparine	9	Chamomilla spp.	13
Papaver spp.	9	Polygonum sp.	13
Sonchus spp.	9	Geranium sp.	13
Cirsium spp.	9	Brassica sp.	9
M. perforata	13	Sinapis arvensis	6

TABLE 3 Weeds tolerable at moderate levels in competitve crops.

	cost £/ha.		cost £/ha.
Arrhenath. elatius	25-48	Stellaria media	9
Poa spp.	14	Myosotis arvensis	10

TABLE 4 Weeds tolerable at fairly high levels in competitive crops.

	cost £/ha.		cost £/ha.
Lamium spp.	10	Fumaria officinalis	9
Veronica spp.	10	Senecio fulgaris	10
Viola spp.	10	Thlaspi arvense	6
Aphanes arvensis	10	C. bursa-pastoris	6
Aethusa cynapium	14		

As can be seen from these tables it is the weeds which are most competitive which are usually costly to control.

NON-HERBICIDAL WEED MANAGEMENT PRACTICES

The role of break crops

I will refer only briefly to this aspect of weed management for reducing herbicide expenditure in subsequent cereal crops, because it is a topic which is more fully covered in another paper.

Experience has shown that Spring planted break crops can have a very useful role in reducing annual grass weed populations. However, as can be seen from the weed classification tables, introducing break crops into continuous cereal regimes has created new problems of volunteers as weeds, and requires that weeds in the cereal crop are more effectively controlled.

Cereal husbandry management

Weed control costs can be significantly reduced by some very simple management decisions. However most of these actions have deleterious effects on gross margins and increase the risk of poor crop performance.

1. Changing from winter cereal to spring barley could allow high populations of grass and broad leaved weeds to be effectively controlled for £36.00/Ha. (including a pre-planting non-selective herbicide).

2. Increasing winter barley at the expense of wheat reduces herbicide cost, because the competitive nature of winter barley usually allows a relatively low cost autumn spray to give season long weed control.

3. Delaying autumn planting until late October allows stale seedbed techniques to be used and reduces the requirements for selective herbicides to a spring application only. This technique has been successfully used for *Bromus spp.* (if the population is only moderate).

4. Planting autumn crops early, at high seed rates with narrow row spacing, will establish a competitive crop rapidly. Low rates of herbicides used early post-emergence, when environmental factors are optimum for herbicidal activity, can obviate the requirement for a follow-up spring application.

5. On some soils, where minimal cultivation is normally practised, rotational ploughing (every 3 years) can reduce weed pressure sufficiently to reduce herbicide expenditure. After the straw burning ban there will be an increased emphasis on ploughing, which is the most satisfactory method of straw incorporation. Experience has shown that straw incorporation by surface cultivation rapidly increases populations of *A. myosuroides*, *Bromus* and *Poa spp*., whereas ploughing-in straw reduces populations of these species, but increases populations of *Avena spp.* and 'Volunteers' from the previous crop.

ACTION PLAN TO MINIMISE HERBICIDE EXPENDITURE

Farmers should be prepared to treat every field, or even parts of a field, according to specific weed problems. To be able to achieve this:

1. Map and make notes of weed problems pre-harvest. This will enable correct decisions to be made regarding pre-emergence treatments and serve as a general 'aide-memoir' to patch treatments.

2. Walk fields thoroughly to identify weeds at the seedling stage and observe seedbed and weed germination conditions.

3. To minimise herbicide costs, it is essential to have in-depth knowledge of all relevant active ingredients. Important criteria are:

a. Weed spectra and degree of susceptibility to active ingredients.

b. Mode of activity and rate responses of weed species.

Generally speaking the activity of residual herbicides is determined by soil type, soil moisture and seedbed conditions. When used pre-emergence on soils with a high base exchange capacity, soil acting herbicides need the insurance built into their recommended rates. Contact and systemic herbicides generally allow more flexibility in application rate, because weed species and size, together with growing conditions, can be taken into consideration when determining the required rate. There is a dearth of detailed results from R. & D. to give guidance and field experience is of paramount importance when making decisions regarding rate reduction.

c. Weather and Soil Conditions.

Knowledge of the weather conditions which favourably or adversely affect herbicides is essential if the optimum choice and correct timing is to be achieved. Herbicidal activity is usually favoured by good growing conditions. (ie. warm and moist with adequate soil moisture). However there are exceptions. For example: diclofop-methyl works best under cool, moist conditions: surface applied trifluralin lacks persistence in high light intensity: soil acting herbicides lack persistence if soil temperatures are high.

d. Tank mix Options.

It is now a rare occurrence for a single active ingredient to be applied to a cereal crop. Tank mixes of two or three herbicides are common and fungicides and/or insecticides are frequently added. Farmers and sprayer operators prefer to use formulated products for simplicity, but these are often more expensive than the equivanlent tank mix, and because the ratio of active ingredients is fixed, they allow less flexibility with rates. However, the disadvantage of tank mixing is the increased loading of wetting and formulating agents which can enhance crop damage. This is especially worrying in autumn when growth is soft and the risk of frost is high.

e. Response to adjuvants.

Many of the claims made by manufacturers of adjuvants, for reduced doses of herbicides, are unsubstantiated by independent work. Often the herbicide saving is merely balanced by the expenditure on the adjuvant, and herbicide manufacturers will in no way support reduced rates of product plus adjuvant. Moreover, where multi-ingredient tank mixes are envisaged, adjuvants can greatly enhance the risk of crop damage. However, the benefits of some adjuvants are well proven (eg. Glyphosate with the addition of ethoxylated tallow-amine. Mecoprop and diclofop methyl with the addition of polyoxyalkylene glycol).

There is possibly scope for a reduction of some herbicide rates by the addition of adjuvants. Certainly, where rates of herbicide are reduced, there is a case for maintaining the concentration of wetting systems. However, there is currently little independent technical data available to potential users of these products, and there is a real need for H.G.C.A. funding of R. and D. to clarify the whole subject of adjuvants.

4. Having identified the target weeds, select the most appropriate (least cost) herbicide or tank mix and buy the chemicals at the best market prices. In this respect, the use of buying groups, brokers or crop consultants' services can save telephone time and ensure that agrochemicals are bought at least cost.

5. For most cereal producers, the conventional hydraulic sprayer with flat fan nozzles remains the most cost effective method of applying herbicides. When reduced herbicide rates are envisaged, it is invariably best to lower the total spray volume and maintain herbicide concentration. Apply at the optimum time under ideal weather conditions. For annual weeds this is usually when they have developed their 1st or 2nd true leaves, but where non-residual herbicides are used it is important to ensure that 90%+ of the weeds have germinated before spraying.

Choose the correct spray volume and quality to maximise retention on the target. It is worth noting that spraying conditions are often best very early in the morning or late in the evening and herbicidal activity is enhanced by the presence of dew.

To Summarize

By taking all factors into account, and provided crops are well established and competitive, dose rates of some herbicides can be successfully reduced, (sometimes to a fraction of recommended rates). However, removing all the insurance built into manufacturers recommended rates can result in failures and re-treatment at even higher cost.

WEED CONTROL IN PRACTICE

It is interesting to look at some examples of weed control costs where these techniques have been practised, because they point the way ahead for weed control in low profit cereal growing situations. These demonstrate the wide range of weed control cost that can exist and that, by judicious choice of herbicides the cost of weed control can be maintained at constant levels in real terms. The following examples are from three Cotswold Farms with differing weed situations.

*1985 Herbicide costs corrected by an inflation factor of 1.324

1. A. Mason, Hinton Farm, Ablington. Seed corn grower, meticulous attention to detail, wild oats and blackgrass hand rogued. Weeds not tolerated.

TABLE 5 - Winter cereals - *1985 Harvest

	Winter wheat		Winter barley	
	a.i./ha.	Cost/ha.	a.i./ha.	Cost/ha.
Mecoprop	2100g	5.56	120g	3.18
Cyanazine	375g	6.06	375g	6.05
Isoproturon (headlands 12%)	2000g	27.54	1000g	13.77
Pendimethalin (headlands 12%)			990g	17.87
Total average cost/Ha.		14.91		13.02

TABLE 6 - Spring barley - *1985 Harvest

	a.i./ha.	Cost/ha.
Dichlorprop	1500g	4.96
Cyanazine	165g	2.66
Total Average Cost/ha.		7.62

TABLE 7 - Winter cereals - 1991 Harvest

	Winter wheat		Winter barley	
	a.i./ha.	Cost/ha.	a.i./ha.	Cost/ha.
Mecoprop	1200g	3.00	1200g	3.00
Trifluralin	500g)		500g)	
Diflufenican	50g)	8.00	50g)	8.00
Fluroxypyr (headlands 12%)	100g	8.50	100g)	8.50
Isoproturon (headlands 12%)	2000g	21.60	2000g	21.60
Total Average Cost/ha.		14.60		14.60

No Spring Cereals grown in 1991

2. C. G. Phillips, Macaroni Farm, Eastleach. Meticulous attention to detail, farmed to crop competition winning standards, some problems with *A. myosuroides and Avena spp.* Weeds not tolerated.

TABLE 8 - Winter cereals - *1985 Harvest

	Winter wheat		Winter barley	
	a.i./ha.	Cost/ha.	a.i./ha.	Cost/ha.
Pendimethalin	990g	17.87	990g	17.87
Diclofop-methyl	532g	17.80		
Total Average Cost/ha.		35.67		17.87

TABLE 9 - Spring barley - *1985 Harvest

	a.i./ha.	Cost/ha.
Dichlorprop	1500g	4.96
Cyanazine	250g	4.04
Difenzoquat	450g	24.00
Total Average Cost/ha.		33.00

TABLE 10 - Winter cereals - 1991 Harvest

	Winter wheat		Winter barley	
	a.i./ha.	Cost/ha.	a.i./ha.	Cost/ha.
Tri-allate	2250g	20.70		
Mecoprop	1200g	3.00	2400g	6.00
Isoproturon	375g)			
Diflufenican	37g)	8.30		
Fluroxypyr (headland 12%)	100g	8.50		
Chlorotoluron			2800g)	
Trifluralin			980g)	30.10
Total Average Cost/ha.		33.00		36.10

3. Mrs. S. Vicary, Dean Farm, Coln-St.-Aldwyns. Farm management taken over by C. G. Phillips for 1985 Crop year. Weed control was totally neglected by the previous management and there were heavy infestations of *A. myosuroides, Avena spp, Bromus sterilis, P. trivialis, E. repens, Agrostis gigantea and Viola sp.* on various parts of the farm.

TABLE 11 - Winter cereals - *1985 Harvest

	Winter wheat		Winter barley	
	a.i./ha.	Cost/ha.	a.i./ha.	Cost/ha.
Glyphosate	1080g	47.66	1080g	47.66
Chlorotoluron	1750g)			
Bifenox	477g)	23.85		
Isoproturon	1250g	17.20	1500g	20.65
Pendimethalin			1155g	20.85
Difenzoquat	450g	24.00		
Flamprop-M-isopropyl			400g	24.71
Total Average Cost/ha.		112.69		113.87

TABLE 12 - Spring barley - *1985 Harvest

	a.i./ha.	Cost/ha.
Glyphosate	1080g	47.66
Glyphosate	270g	11.91
Tri-allate	1680g	21.68
Dichlorprop	1750g	5.78
Bifenox	257g)	
Linuron	105g)	4.63
Total Average Cost/ha.		91.66

TABLE 13 - Winter cereals - 1991 Harvest

	Winter wheat		Winter barley	
	a.i./ha.	Cost/ha.	a.i./ha.	Cost/ha.
Tri-allate	2250g	20.70		
Chlorotoluron			2500g	18.50
Diflufenican	90g)		50g)	
Isoproturon	500g)	19.80	500g)	11.00
Trifluralin	880g)			
Fluroxypyr	100g	8.50	100g	8.50
Metsulfuron methyl			4g	8.50
Total Average Cost/ha.		49.00		46.50

No Spring Barley Grown in 1991

TABLE 14 - Summary of Herbicide costs for winter wheat/barley and spring barley

Year	Crop	Hinton Farm	Macaroni Farm	Dean Farm
1985	WW	14.91	35.67	112.69
1991	WW	14.60	33.00	49.00
1985	WB	13.02	17.87	113.87
1991	WB	14.60	36.00	46.50
1985	SB	7.62	33.00	91.66
1991	SB	not grown	not grown	not grown

CONCLUSIONS

Due to two very dry Springs, 1989 was a non-profit year and 1990 a loss making year for most brashland cereal growers in the upper reaches of the Thames Valley. From these figures it is obvious that maintaining a very high standard of weed management, which minimisie seed return is the way to minimise herbicide cost. This is achieved by using the 'target rifle' in place of the 'blunderbuss'. Short term savings in weed control costs have no place if the present low weed populations are to be maintained. Moreover, because herbicide expenditure is already low, savings would have relatively little effect on gross margins.

Where high standards of weed control are being maintained by a blunderbuss approach, it is possible to make some short term savings without jeopardising the profitability of the current crop, but care must be taken not to allow the more competitive weeds to put large amounts of seed into the soil bank. Due consideration must also be given to the effect of weed seed return causing weed control problems in other crops in the rotation.

OPPORTUNITIES FOR AND CONSTRAINTS ON THE REDUCTION OF HERBICIDE COSTS ON A HEAVY LAND ARABLE FARM - LONG TERM CONSIDERATIONS

J H ORSON
ADAS Boxworth, Boxworth, Cambridge, CB3 8NN, UK.

ABSTRACT

Arable systems of farming on the heavy soils are under pressure, both economically and from the fact that some of the herbicides used to sustain them are being found in water. This paper describes the rotation to be adopted on a heavy land arable farm and the intended cultural and herbicide weed control measures to minimise costs based on current information, much of it generated in experiments on the farm. In the future, further savings in weed control costs may be presented by refining weed thresholds, the identification of appropriate rates of herbicides which may be applied according to computerised maps or in response to real time remote sensing of weeds and the integration of chemical and mechanical control of weeds. However, limitations in current knowledge of weeds and their control and possible limitations on the availability of herbicides due to environmental concerns may be constraints to more economic weed control.

INTRODUCTION

Boxworth is situated 11 miles North East of Cambridge. The farm comprises 346 hectares of a heavy chalky boulder clay of the Hanslope series. Winter cropping is preferred and usually provides higher yields and minimises damage to the soil structure. The full yield potential of the farm was realised only after the introduction of cereal herbicides which effectively controlled the annual grass weeds that had been encouraged by systems of continuous autumn sown crops. The other two factors which are critical in the current system are adequate land drainage and adequate machinery to ensure a timely establishment of autumn sown crops.

OBJECTIVES

The objective of the farm is to optimise margins within the constraints of maintaining an R&D programme whilst, as far as current knowledge allows, minimising the environmental impact from pesticides. Therefore the aim of weed control within this overall objective is to use cultivations to control weeds that cannot be successfully or cheaply controlled by herbicides and to minimise the use of herbicides across the whole rotation.

Rotation

The rotation, now to be adopted over the whole farm, is winter oilseed rape/winter wheat/winter wheat/winter beans (*Vicia faba*)/winter wheat/winter wheat. Within the winter bean year of the rotation spring beans, linseed, dry peas and sunflowers may alternatively be grown on part of the area in order to provide trial sites. This rotation was selected after a detailed analysis of field yields over the last ten years. The analysis showed that with wheat at £110/tonne, oilseed rape at £230/tonne and beans at £150/tonne, various rotations would provide the same total gross margin (Table 1). The one selected offered the best compromise of optimising margins, whilst not over committing the farm to one particular crop, and providing trial sites. The rotation is under continual re-assessment, particularly at present because of the proposals for changes in agricultural support by the European Economic Community.

TABLE 1. Gross margins based on yields at Boxworth 1981-1990

	£/ha
First wheat after oilseed rape	710
First wheat after field beans	679
Second wheat after oilseed rape	582
Second wheat after field beans	615
Third wheat	518
Fourth wheat	500
Winter oilseed rape	473
Winter beans	421

Wheat quality

Potentially high yielding feed wheats will be grown as first wheats after a non-cereal break. The second wheats will be varieties grown for the "quality" market, either for export or bread-making. Boxworth enjoys good access to the East Coast ports and there are large flour mills nearby. As the real value of wheat decreases, the relative cost of transport increases and so it is intended to exploit these outlets. Second wheats are more likely to produce quality samples than first wheats in terms of protein content since the lower yield leads to less nitrogen dilution in the grain. Also the higher soil nitrogen released from crop residues in the first wheats tends to be too early to maximise accumulation in the ear. However, it is important that volunteer cereals from the preceding feed wheats will not affect the quality of second wheats.

Oilseed rape quality

It may be important in the future to keep volunteer oilseed rape under control in order to minimise genetic contamination and thus the level of glucosinalates in subsequent crops of rape.

Another quality objective is to avoid weed seeds contaminating harvested crops to such a degree that their value will be lowered. This is particularly true of Anthemis spp., Matricaria spp. (mayweeds) and Galium aparine (cleavers) in winter oilseed rape. The other common broad-leaved weeds on the farm are the Veronica spp. (speedwells) which die prior to harvest and therefore do not contaminate produce.

Cultivations

Minimising costs is a critically important component of the business plan. There can be a considerable inter-dependence between cultivation and herbicide costs and minimising herbicide costs *per se* will not necessarily minimise total costs. This is particularly so on the clay soils where any increased cost of annual grass weed control in winter cereals associated with disc/tine tillage may still offer a total saving over ploughing and subsequent seedbed preparation, which costs around £40/ha more in machinery costs. In addition, there is evidence at Boxworth that equivalent winter cereal and winter oilseed rape yields can be achieved by non-ploughing methods, even in the presence of unburnt straw. This encouraged the adoption on heavy soils of minimal tillage to establish continuous autumn sown crops in the 1970s and early 1980s. However, increased infestations of *Bromus sterilis* (barren brome) and *Bromus commutatus* (meadow brome) and volunteer cereals, which cannot be controlled reliably by cereal herbicides, have led to a very significant return to ploughing. The ban on burning of crop residues from 1992 means that the future of the plough on a significant area of heavy land farms seems assured. This is particularly true at Boxworth which has considerable populations of *B. commutatus* and has *Alopecurus myosuroides* (black-grass) populations which show some resistance to herbicides. It is assumed that the resistance was developed through the regular usage of herbicides for the control of *Bromus* spp. as well as for *A. myosuroides*. Strategies for containing the development of herbicide resistant *A. myosuroides* are being suggested. These are based on more reliance on cultural control, such as ploughing, in order to minimise herbicide use (Clarke & Moss, 1991).

On the other hand, non-ploughing techniques have been useful in the past at Boxworth in helping to exhaust the soil of viable seed of *Avena fatua* (wild-oats) by encouraging shed seed to germinate and emerge, as soon as innate dormancy allowed, by keeping them close to the soil surface. Populations are now at hand rogueable levels on the farm.

Whilst there is an overall policy for cultivations during the rotation, the farm manager has the right to vary from it in particular seasons when it is exceptionally dry or wet or for specific fields which are free from weed problems or have high infestation of weeds.

ROTATION, CULTIVATION AND CULTURAL WEED CONTROL

Primary cultivation

The intensity of ploughing required to reduce populations of *B. commutatus* is not known but the decision has been taken to plough three years in the six year rotation. It is envisaged that this intensity will be reduced if and when *B. commutatus* populations are reduced to a very low level, provided that the level of herbicide resistance of *A. myosuroides* does not become more severe. Ploughing will be adopted at strategic parts of the rotation to reduce weed levels and to maintain cereal quality.

Ploughing will be necessary before the second "quality" wheats to control volunteer cereals which could affect quality. This will also reduce populations of the Bromus spp. although the control of B. commutatus achieved by ploughing has been disappointing in practice. Limited experimental evidence suggests that its survival in the soil is similar to B. sterilis and hence it may need more complete burial.

Winter beans normally will be sown by ploughing down the seed in late October or early November. This operation is carried out in order to minimise the damage that occurs from rooks and crows. Not only will ploughing prior to establishing the winter beans be useful in terms of annual grass weed control but the time at which it is done may allow for some attempts at the adoption of stale seedbed techniques for the control of Bromus spp..

The establishment of oilseed rape in the presence of unburnt straw is a potential problem. A variety of methods are being developed, all of which involve shallow disc or tine cultivation.

It is intended that ploughing will not take place after the harvest of oilseed rape in order to maintain the shed crop seed close to the soil surface. Instead, the soil will be disced and/or tined to a depth of around 10cm.. There is limited evidence on the farm to suggest that avoiding ploughing after the harvest of oilseed rape will minimise volunteer oilseed rape problems in the future. Additionally, due to the efficiency of the herbicides that can be used in rape and the competitiveness of a full crop, there should be little or no annual grass weed seed shed in the crop to bury by ploughing, whilst there is a danger that some viable seed shed in the previous wheat crop may be brought closer to the soil surface. The decision not to plough after oilseed rape has implications for herbicide choice within the crop as well as disease implications. Phoma spores could spread from unburied residues and affect neighbouring crops and Sclerotinia fruiting bodies might have to be buried to minimise this disease. These aspects will be monitored on the farm.

Ploughing will not be carried out after the winter bean crop. The situation should be ideal for disc/tine tillage to a depth of around 10cm. This is because of a lack of significant crop residues and again, theoretically because of little or no annual grass weed seed shed in the crop due to the efficiency of herbicides that can be used.

Drilling dates of winter cereals

It is not intended to delay the establishment of winter cereals as an aid to weed control. The objective is to ensure that drilling is completed prior to mid-October. In practice this means that drilling starts at around 20 September, if the seedbeds and weather conditions are suitable.

Although delaying drilling of autumn cereals will reduce the establishment of A. myosuroides and B. sterilis within the crop, practical experience on the farm suggests that control of B. commutatus is less significant. Despite the possible advantages of later drilling for weed control, lower yields often occur and there is a risk to soil structure when later drilling has to be carried out in wet conditions. However, a full risk analysis has not been carried out.

Stale seedbeds

There is insufficient time to successfully carry out a stale seedbed technique prior to drilling of winter cereals and oilseed rape. Stubble cultivation does not appear to help in the control of A. myosuroides. Early cultivation after harvest mitigates against the control of freshly shed seed of A. fatua and, in some seasons, against the control of volunteer cereals. When the soil is moist, shallow cultivation after harvest will encourage B. sterilis to germinate. However, it is not fully understood how successful stale seedbeds will be for the control of B. commutatus and what is the relative efficiency of stale seedbeds or chopped straw as a mulch to encourage the germination of Bromus species in general.

Prevention of spread of weed seed

B. commutatus is late maturing and much of it is still not shed when winter wheat is harvested. Measures such as ensuring that a contaminated combine is not taken into a clean area of a field are employed. In addition, severe patches have been destroyed in May prior to the seed becoming viable.

WEED CONTROL WITH HERBICIDES

While it is necessary to minimise herbicide usage, there are occasions where it will be necessary to take an insurance approach. This is particularly true where significant populations of B. sterilis are expected in winter cereals and the use of a pre-emergence selective herbicide may be considered a worthwhile precaution. In all other situations, spray decisions are based on the weed species and numbers present. Non-selective foliage applied herbicides are commonly used to control emerged weeds, particularly the Bromus spp., prior to the final seedbed cultivation.

Annual grass weeds

The control of B. commutatus with herbicides in cereals is so variable that applications above the use of isoproturon which is applied to cereals for the control of A. myosuroides are not worthwhile.

The level of herbicide resistance in A. myosuroides on the farm does not appear to be significant for isoproturon but the activity of other herbicides is affected (Clarke & Moss, 1991). Therefore, isoproturon is the main herbicide used for the control of A. myosuroides in winter cereals. It is in a different chemical group and has a different mode of action from the herbicides likely to be used in the broad-leaved crops. However, it is essential to minimise its use to reduce any trend to resistance. This means trying to produce a fine firm seedbed so that weed roots are close to the surface and so that there is adequate distribution of the chemical to a moist soil. Best results are usually achieved from an autumn post-emergence application when the weed has one-two leaves and there in sufficient rainfall shortly after application to distribute the chemical through the top four cm of soil. Straw incorporation at Boxworth does not reduce isoproturon activity on A. myosuroides and B. sterilis when disc/tine tillage is carried out to a depth of 10 cm (Rule, 1991).

Avoiding ploughing after oilseed rape and winter beans means that propyzamide cannot be used and there will be a reliance on foliage applied herbicides, such as fluazifop-P-butyl or cycloxydim, for annual grass weed control in these crops. These come from the aryloxyphenoxypropionate and cyclohexanedione groups which share a similar mode of action on grass weeds as diclofop-methyl to which *A. myosuroides* already shows some resistance. Not only may the effectiveness of some of these herbicides be reduced but their use might accentuate herbicide resistance in *A. myosuroides* to these groups of herbicides and, by cross-resistance, to all groups of cereal herbicides. This is a dilemma that has not been resolved and the resistance of *A. myosuroides* will be kept under constant review.

Two herbicides which can be used in both oilseed rape and winter beans for annual grass weed control have been shown to retain their activity on herbicide resistant *A. myosuroides*. However, it is essential to plough after the use of propyzamide, and carbetamide alone will not always give the control required. If there is a detectable trend towards increased herbicide resistance in *A. myosuroides*, these herbicides may replace the foliage applied herbicides used for annual grass weed control. The could result in a return to ploughing after oilseed rape and hence a re-examination of the farm's cultivation policy.

Annual broad-leaved weeds

Annual broad-leaved weeds are cheaper to control in winter cereals than in beans and oilseed rape and so the aim is to achieve sufficient control in this crop to minimise herbicide usage in the broad-leaved crops. In particular, high levels of control of *G. aparine* are required in winter cereals as this weed is difficult and expensive to control in the other crops on the farm. This objective is best achieved by the use of a broad-spectrum residual broad-leaved weed herbicide applied with the isoproturon in the autumn and the use of the appropriate rate of a herbicide specifically for the surviving *G. aparine* in the spring. To achieve minimum costs in the spring it is important to treat *G. aparine* under good growing conditions. *G. aparine* competes later in the spring than other broad-leaved weeds and so application can usually be delayed until good conditions for herbicide activity whilst maintaining winter cereal yields.

The control of broad-leaved weeds in oilseed rape and beans is based on avoiding yield depressions and contamination of the harvested rape crop with seed of *G. aparine*, *Anthemis* spp., *Matricaria* spp. and *Papaver rhoeas* (common poppy). The latter weed occurs only occasionally on the farm and with *Anthemis* spp. and *Matricaria* spp. is usually controlled by isoproturon in winter cereals. The effect of weeds on the yield of winter beans and winter oilseed rape crops is not fully understood but it is clear that oilseed rape can tolerate relatively high levels of *Veronica* spp. and some *S. media*, provided that the crop is vigorous. Therefore a more relaxed view is currently taken concerning these two weeds in the winter cereal crop, particularly the *Veronica* spp.. In the absence of straw burning, a preferred method of oilseed rape establishment may be to broadcast seed onto the chopped cereal straw and immediately follow by a light cultivation. Experience shows that this method is successful provided that there are no vigorous broad-leaved weeds present at the time of broadcasting the seed. In addition crop plant population and vigour may be low, offering poor competition to weeds. Therefore, the control of broad-leaved weeds in the previous wheat crops will have to be kept under review.

Weed thresholds

To achieve further savings on herbicides, the forecasting of the viability of shed weed seed on specific soil types is required along with more information on the competitiveness of individual weeds in broad-leaved crops. It is not until then that the sensible use of weed thresholds can be adopted at Boxworth.

It is recognised that weed thresholds can be made to work in winter cereals and that they should be combined with applications of appropriate doses of herbicides (Proven et al, 1991). Current "spray or not spray" thresholds result in great accuracy being required in order to take decisions in marginal cases. A more flexible approach to thresholds, in which there are more than two options will mean that assessment of the problem may be less accurate, because in marginal cases the options will not be so extreme. Such an approach is more likely to be brought into practical agriculture. It should result in farmers applying an effective herbicide where there is a clear need but a cheaper less effective herbicide or a lower dose (i.e. appropriate dose) of an effective herbicide where the need is more marginal. Clearly no herbicide will be required where there are so few weeds to affect the yield and quality of the current crop and where shed seed will not result in more expensive treatments in future crops.

FUTURE POSSIBILITIES FOR AND CONSTRAINTS ON A REDUCTION IN HERBICIDE COSTS

Future cost savings are limited by a lack of current knowledge on aspects such as weed competition in the crops grown on the farm, the agro-ecology of some weeds, the appropriate rates of herbicides for the control of individual weed species in specified weather and crop conditions, the prediction of emergence of shed weed seed and the strategies to adopt in order to prevent the increase in herbicide resistance in A. myosuroides. In addition, any limitations in the availability of key herbicides due to environmental concerns could have a profound effect on the farm.

However, there are ideas now being tested which may enable the current system of production to be largely retained and herbicide use reduced. For instance, with the advent of computer mapping, patch spraying according to weed maps with an appropriate rate of herbicide or herbicide mixture may be possible. Eventually, real time remote sensing of weeds and the application of appropriate rates of herbicides or herbicide mixtures may be possible. The information available on weed competition and appropriate rates of herbicide is not yet sufficient to exploit fully this application technology.

Another possibility is the re-assessment of mechanical weed control. Experiments at Boxworth in winter beans have shown that this late autumn sown crop has few weeds and weed control by cultivation is a possibility. Mechanical weed control may not reduce total costs but may reduce herbicide use to a level more acceptable to the general public and the legislators. It is not likely to be sufficient to avoid the use of herbicides altogether, given the type of soil at Boxworth. Mechanical and chemical weed control may have to be integrated to ensure that effective control will be achieved in all the crops grown at Boxworth.

CONCLUSIONS

The system adopted at the moment is designed to minimise the combined cultivation and herbicide costs whilst capitalising on the advantages offered by winter cropping. Rates of herbicides used are often below those recommended by the manufacturer but more information on this and other aspects of weeds and weed control is required before further reductions in costs can be made. It is heartening to see new ideas being investigated by weed scientists. The prospects are exciting and it is hoped that farms such a Boxworth can reap the benefit. Heavy land farming has been transformed by the ability to control weeds and hence grow crops that are best suited to the land and the market, and its future depends to a very large extent on effective weed control measures continuing to be available.

ACKNOWLEDGEMENTS

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THE EFFECT OF REDUCED NITROGEN FERTILIZER INPUTS ON THE COMPETITIVE EFFECT OF CLEAVERS (*GALIUM APARINE*) ON WHEAT (*TRITICUM AESTIVUM*).

J M BAYLIS AND A R WATKINSON

School of Biological Sciences, University of East Anglia, Norwich, NR4 7TJ

ABSTRACT

A Competitive Index is used to determine how the effect of *G.aparine* on wheat is affected by nitrogen inputs. Results indicate that the effect of *G.aparine* on wheat yield increases as nitrogen inputs increase. This is discussed in the context of how reduced nitrogen fertilizer inputs may affect the future importance of *G.aparine* as an arable weed.

INTRODUCTION

Galium aparine is a competitive and widespread weed of winter wheat, and can cause considerable yield reduction at very low densities (Peters 1984, Froud-Williams 1985, Wilson and Wright 1987). Several studies have indicated that *G.aparine* is more competitive on heavier soils with high moisture retention, and under conditions of high nitrogen availability (Nieman 1977, Wilson 1984). This is therefore an example of a weed which may decline in importance in a reduced input farming system, where nitrogen fertilizer inputs are likely to be lower and related more closely to the nutrient requirement of individual crops (Jorden *et al.* 1990).

Nitrogen uptake studies have shown that *G.aparine* produces more dry matter per unit nitrogen than wheat at high levels of nitrogen, but less than wheat when nitrogen availability is low (Rooney *et al.* 1990). The aim of this study is to quantify how this differential response to nitrogen is translated into the effect of the weed on crop yield, using a Competitive Index to describe the effect of the weed on the crop.

MATERIALS AND METHODS

The competitive effect of *G.aparine* on wheat was determined for each of five nitrogen levels at three densities of wheat. Each treatment was replicated four times.

The experiment was carried out in an unheated glasshouse from March to July 1990 using seeds of *G. aparine* from Herbiseed and spring wheat var. Tonic. All nutrients were supplied as a modified Long Ashton Nutrient Solution (Hewitt 1966). Nitrogen was supplied as ammonium nitrate at 5 concentrations; x1/6, x1/3, x1, x3 and x6 the normal nitrogen concentration in the nutrient solution (corresponding to 0.6, 1.7, 5.0, 15.0 and 30.0 mM NH_4NO_3 litre^{-1}). Plants were grown in vermiculite, an inert growth medium.

G.aparine seeds were imbibed at 5°C for two months to break dormancy, planted in seed trays of vermiculite, and watered with the nutrient solution that the plants would subsequently receive. Wheat was planted in seed trays four days after the *G.aparine* and treated in the same way. After emergence, seedlings were transplanted into 18cm diameter pots of vermiculite in seven species combinations: (a) 1 *G.aparine* plant per pot, (b) 1 *G.aparine* surrounded by 4 wheat, (c) 5 wheat plants per pot, (d) 1 *G.aparine* surrounded by 9 wheat, (d) 10 wheat per pot, (e) 1 *G.aparine* surrounded by 19 wheat, and (f) 20 wheat per pot. The wheat densities in monoculture are equivalent to 196, 393 and 786 plants m^{-2}. Each pot was watered with 700ml of the appropriate nutrient solution to attain field capacity, placed in an individual saucer and arranged in an unheated glasshouse in a fully randomised design. Pots were maintained at field capacity with deionised water, and supplied with fresh nutrient solution at weekly intervals. At maturity the plants were harvested and dried at 70°C. The wheat plant material was partitioned into yield components.

Calculation of Competitive Index.

The 'competitive ability' of a plant can be quantified in terms of the 'competitive effect' a plant exerts on its surrounding neighbours (Goldberg and Werner 1983). Here the competitive effect of *G.aparine* on wheat is quantified using a Competitive Index described below.

The species combinations used were chosen to determine an index of competitive effect (CI) of *G.aparine* on wheat at each of three total densities for each nitrogen treatment.

The index for the competitive effect (CI) of *G.aparine* on wheat was calculated for each treatment combination using the equation:

$$CI = \frac{W_A \text{ (mix)}}{W_A \text{ (mono)}} \times 100$$

where W_A (mix) is the mean weight per plant or plant part of wheat in mixture, and W_A (mono) is the mean weight per plant or plant part of wheat in monoculture. For example a CI at density 5 (ie 5 plants per pot) is calculated from species combinations (b) and (c) described above. Values of less than 100 indicate that the presence of *G.aparine* reduces the wheat yield component in question, and that a *G.aparine* plant exerts a greater competitive effect on its neighbouring wheat plants than a wheat plant. This index is closely related to the competition index (α) in Firbank and Watkinson (1985) and varies with density.

The index was calculated for each wheat yield component expressed as a mean value per plant, for each of the 5 nitrogen levels and each wheat density. The index was then analysed to determine treatment effects.

RESULTS

Response of *G.aparine* to Nitrogen Availability and Wheat Density.

The individual plant weight of *G.aparine* (Table 1a) showed a marked response to nitrogen and density of neighbouring wheat plants, with a significant interaction between the two factors ($P<0.001$). In monoculture, plant weight levelled off at about nitrogen level x1, whilst in mixture with wheat, the weight of *G.aparine* showed a greater response to nitrogen between levels x1 and x3.

Response of Wheat to Nitrogen Availability.

The mean total weight per plant, vegetative weight per plant and number of ears per plant rose as nitrogen increased to a maximum at nitrogen level x3 (Table 1b). Grain weight per ear reached a maximum at nitrogen level x1, but then declined as the nitrogen level increased. Grain number per ear increased to a maximum at nitrogen level x1. All components of individual plant weight were significantly affected by plant density.

				NITROGEN LEVEL		
	TOTAL PLANT DENSITY	x1/6	x1/3	x1	x3	x6
				Mix (Mono)		
(a) *G. aparine*						
VEGETATIVE WEIGHT (g)	1	(2.8)	(9.2)	(15.9)	(17.3)	(17.6)
	5	0.4	0.4	5.7	9.9	9.0
	10	0.1	0.5	2.1	5.0	1.7
	20	0.1	0.2	0.4	2.5	3.7
(b) Wheat						
TOTAL WEIGHT (g)	5	1.2 (1.0)	2.5 (2.3)	4.6 (5.4)	4.1 (6.7)	4.9 (5.9)
	10	0.7 (0.6)	1.5 (1.2)	2.7 (2.6)	2.8 (3.8)	3.8 (3.5)
	20	0.4 (0.4)	0.8 (0.8)	1.4 (1.4)	1.7 (1.7)	1.8 (1.8)
VEGETATIVE WEIGHT (g)	5	0.6 (0.5)	1.6 (1.3)	3.3 (3.2)	3.2 (4.4)	3.3 (4.1)
	10	0.4 (0.3)	0.8 (0.7)	1.6 (1.6)	2.0 (2.5)	2.3 (2.3)
	20	0.2 (0.2)	0.4 (0.4)	0.8 (0.8)	1.1 (1.1)	1.1 (1.1)
EAR No	5	1.0 (1.0)	1.1 (1.1)	2.3 (2.3)	2.6 (3.4)	3.0 (3.3)
	10	1.0 (1.0)	1.0 (1.0)	1.3 (1.2)	2.0 (1.7)	2.3 (2.1)
	20	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)	1.1 (1.0)	1.1 (1.1)
WEIGHT PER EAR (g)	5	0.5 (0.4)	0.6 (0.7)	0.7 (0.7)	0.1 (0.5)	0.3 (0.3)
	10	0.3 (0.2)	0.5 (0.4)	0.7 (0.7)	0.2 (0.5)	0.4 (0.3)
	20	0.1 (0.1)	0.3 (0.3)	0.4 (0.5)	0.3 (0.3)	0.4 (0.4)
GRAIN No PER EAR	5	11 (12)	18 (19)	22 (24)	16 (23)	18 (20)
	10	8 (7)	15 (11)	18 (19)	10 (21)	20 (17)
	20	4 (5)	9 (8)	13 (13)	12 (13)	18 (18)

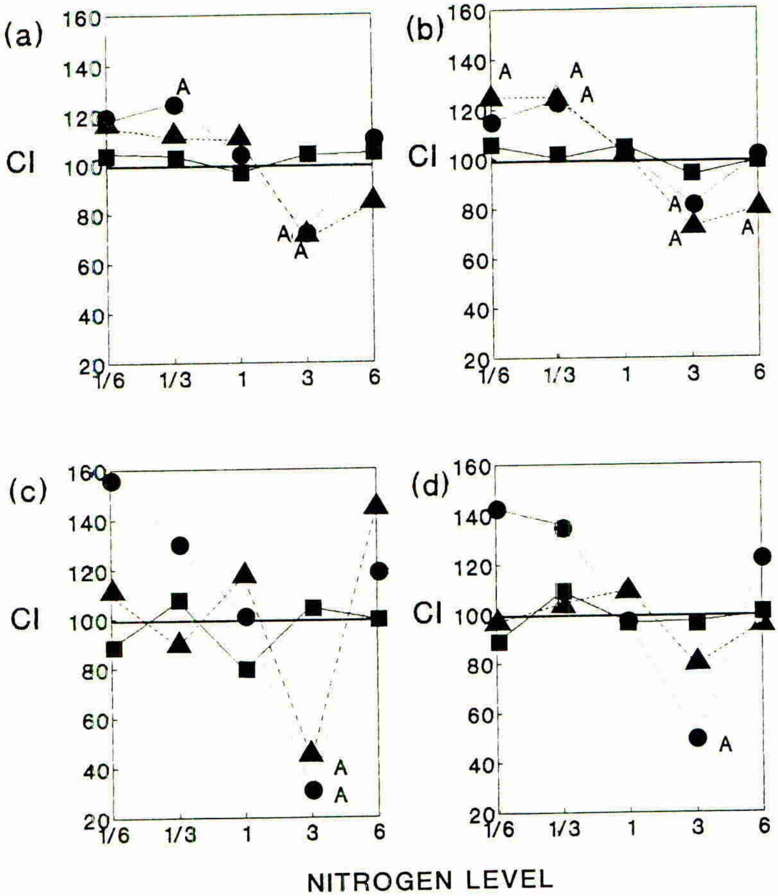
Table 1. *The mean effect of nitrogen level and plant density (5, 10 and 20 plants per pot) on components of mean weight per plant of: (a)* G.aparine. *and (b) wheat in monoculture and mixture.*

Competitive effect of *G.aparine* on Wheat.

Analysis of variance was used on $\log_{10}$ transformed data to determine how the Competitive Index was affected by treatments. The overall effect of *G.aparine* on the total weight per wheat plant showed significant effects of nitrogen and density, with a significant interaction between the two ($P<0.01$) (Fig 2a). Below nitrogen level x1 the Competitive Indices were over 100, significantly so at density 10 ($P<0.05$). As the nitrogen level increased, the index decreased to a minimum for densities of 5 and 10 at nitrogen level x3. This corresponds to a maximum competitive effect of *G.aparine*. As the nitrogen level increased to level x6, *G.aparine* had no significant effect on total plant weight. At the highest density, density 20, nitrogen level had no effect on the Competitive Index.

The effect of *G.aparine* on the vegetative weight of wheat (Fig 2b) showed a similar trend. Figures 2c-2d show the competitive effect of *G.aparine* on grain weight and number per ear. In each case the competitive effect of *G.aparine* was greatest at nitrogen level x3. *G.aparine* had a greater effect on grain weight per ear (Competitive Index of 31% and 44% for densities 5 and 10 respectively), than on all other parameters.

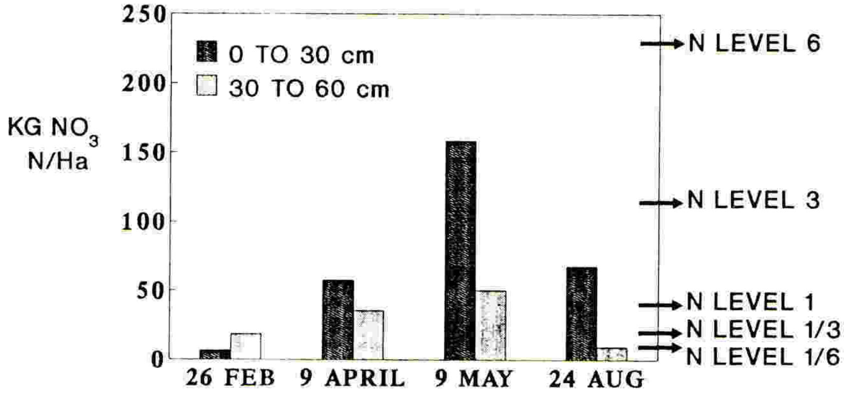
Figure 2: *Competitive Index (CI) to show the effect of* G.aparine *on (a) wheat total weight per plant: (b) vegetative weight per plant: (c) grain weight per ear and (d) grain number per ear. 3 densities are shown; 5 (▲--), 10 (●··) and 20 plants per pot (■—). See text for details. Treatments marked 'A' are significantly different from 100 (at P=0.05).*



DISCUSSION

The Competitive Index used here is a clear and concise method of directly describing the effect of the weed on the growth of the crop. It is a more informative method than analysis of the raw data. If the competitive effect of *G.aparine* on total plant weight is broken down into the effect of the weed on the components of wheat plant weight, we have a more complete picture of how the weed competes with the crop during the growing season. *G.aparine* had a greater affect on the components of wheat ear weight (grain number and weight) than on wheat vegetative weight. This suggests, as others have found (Peters 1984), that the weed is competing with the crop throughout the growing season, reducing grain number early in the season and reducing grain fill of those remaining.

Figure 3: Levels of available nitrogen in the soil for samples taken at intervals, at two depths, during the growing season of a crop of winter wheat. 240 KgN ha^{-1} was applied as 3 split applications. Arrows show how the experimental nitrogen treatments relate to field conditions.



Nitrogen availability in this experiment is obviously not directly equivalent to field conditions, since nitrogen was available at a constant level throughout the year. However a comparison in Figure 3 indicates how the nitrogen levels in this experiment correspond to likely field conditions.

The results indicate that at the lowest levels of nitrogen in the experiment (x1/6 and x1/3), wheat plants were more competitive than *G.aparine*. These conditions are below nitrogen levels expected in the field under any wheat production regime during the main growing season. Nitrogen availability levels in the field approximately correspond to nitrogen levels between x1 and x3 here. It is between these two levels that the competitive effect of *G.aparine* responds most to nitrogen. At nitrogen level x1 the Competitive Index is not significantly different from 100; thus, at this level of nitrogen a wheat plant and a *G.aparine* plant are roughly equivalent in terms of the effect on growth of neighbouring plants. As nitrogen level increases to level x3, *G.aparine* is able to respond more rapidly to the available nitrogen at the expense of the wheat. This effect is a result of the greater relative uptake of nitrogen by *G.aparine* than by wheat (Rooney *et al.* 1990). The wheat can only compensate for this when nitrogen increases above nitrogen level x3, higher than could be expected in field conditions.

The results clearly show that the Competitive effect of *G. aparine* is dependent on crop density as well as nitrogen level. At density 20, the Competitive Index did not differ from 100 at any nitrogen level, indicating that at this very high plant density, wheat and *G.aparine* do not differ in the effect they have on surrounding plants.

The impact of *G.aparine* on wheat yield is very dependent on nitrogen fertilizer inputs. Since the competitive effect of *G.aparine* responds most to nitrogen within the range of levels of nitrogen that can be expected in the field, reduced nitrogen inputs are likely to reduce the effect of this weed, as suggested by Nieman (1977). In contrast, field experiments at low densities of *G.aparine* (Lintell-Smith *et al.* 1991) are inconclusive. Nitrogen may have other effects on this weed-crop complex, such as the stimulatation of germination (Froud-Williams 1985). Clearly the effect of *G.aparine* needs to be considered in terms of the population dynamics of the weed, the whole wheat production system, and other factors, such as water availability, that may affect the competitive effect of this weed (Nieman 1977). Whilst the competitive effect of *G.aparine* may decrease in reduced nitrogen systems, it is unlikely to disappear as a weed problem.

Other weed species may also be less competitive under reduced nitrogen inputs; for example sterile brome (*Bromus sterilis*) has a greater effect on wheat yield at higher rates of nitrogen fertilizer (Lintell-Smith *et al.* 1991). Investigations of the type described here would help determine how the importance of these and other weeds may change in reduced nitrogen input systems.

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THE EFFECTS OF REDUCED NITROGEN AND WEED-WEED COMPETITION ON THE POPULATIONS OF THREE COMMON CEREAL WEEDS.

G. LINTELL-SMITH, A.R. WATKINSON

School of Biological Sciences, University of East Anglia, Norwich NR4 7TJ

L.G. FIRBANK

Department of Applied Sciences, Anglia Polytechnic, Cambridge CB1 1PT

ABSTRACT

An experiment to study the effects of reduced nitrogen fertilization and herbicide application on populations of Bromus sterilis, Galium aparine and Papaver rhoeas in winter wheat (Triticum aestivum cv. Hornet) is described. The experiment consists of three replicates of each of seven different weed treatments and a weed free control at each of two levels of nitrogen fertilizer. The results show that the initial weed infestations had no effect on wheat yield at the low nitrogen level, but yield was reduced by the presence of B. sterilis at the high level of N. Using data on various life cycle parameters of the weeds it has been possible to evaluate the effects of nitrogen and weed species combination on the rate of population increase of these weeds in the absence of herbicide applications.

INTRODUCTION

With the current trend towards reduced inputs of herbicides and fertilizers in agricultural systems, it is important to gain an understanding of how these changes are likely to affect the populations and impacts of weeds on crops. Most studies to date on the interactions between weeds and crops have concentrated on competition between a single weed and a crop (Firbank & Watkinson, 1990), and very few studies have examined multiple weed-crop systems. This study aims to evaluate the competitive effects of mixtures of weeds on a crop of winter wheat, and to investigate their potential rates of increase in the absence of herbicide applications and under different nitrogen regimes.

MATERIALS AND METHODS

A field experiment was set up at Broom's Barn Experimental Station in Suffolk in October 1989 using winter wheat cv. Hornet and seeds of B. sterilis, G. aparine and P. rhoeas supplied by Herbiseed. Forty-eight 3x3 m plots were marked out in an area of field (36 x 48 m) which had been drilled with wheat at a rate of 370 seeds/m^2 on 23rd October. The plots were separated by a 3 m discard area. Three replicates of each of eight weed treatments (all three species, all pairwise combinations, each species alone and weed free) at each of two nitrogen levels (120 and 240 kgN/ha) were then allocated at random to the experimental plots. Weed seeds were broadcast by hand at a rate of 50 seeds/spp./m^2 on 24th October. Nitrogen fertilizer was applied on 8th March, 10th April and 9th May at rates of

20:50:50 or 40:100:100 kgN/ha. Seedling establishment in the central 1m^2 of each plot was monitored at two weekly intervals until April and any undesired weeds were removed by hand. The discards were surveyed on 29th March to determine the extent of any natural infestation of the weeds. All weeds in the central 1m^2 of each plot were harvested during August 1990, along with a random sample of 10 wheat plants per plot. The second year's crop was drilled on 2nd October after shallow cultivation and the weed population was allowed to establish naturally from seeds shed during the summer. Seedling establishment was monitored as for the first year.

Weed seed production was estimated from an allometric relationship between shoot biomass (or capsule weight in the case of P. rhoeas) and the number of seeds produced. Seed input to the soil (seed rain) was calculated from (estimated seed production/m^2)-(number of seeds harvested/m^2).

After the second year's crop had been drilled, three samples of soil, each consisting of two cores of diameter 4.75cm, were extracted from each plot and subdivided to provide separate samples for depths of 0-5, 5-10 and 10-15 cm. Seeds of B. sterilis and G. aparine were then extracted from the soil by wet sieving using a sequence of Endecotts sieves. The residue from the smallest aperture (0.425 mm) sieve was collected, the organic matter (which included seeds of P. rhoeas) was separated using a density flotation method (a solution of 250g/l $MgSO_4$), and seeds of P. rhoeas were counted. Soil cores were also taken from the discards before the weeds set seed in the first year to evaluate the naturally occurring seed bank in the field.

RESULTS

The seed bank

The survey of the discards revealed that there was no infestation of either B. sterilis or G. aparine in the field plot prior to the start of the experiment. However, there was a small area with a number of seedlings of P. rhoeas which affected several of the experimental plots. The first analysis of soil cores to determine the extent of the seed bank of this species failed to yield any seeds, and it was concluded that there were less than 100 seeds/m^2 remaining in the soil even in the most heavily infested areas.

The soil cores taken and analysed after the second year's cultivation demonstrated the effect of the cultivation on the vertical distribution of seeds in the soil. It also enabled estimation of seed loss from the soil since the seeds were shed. The vertical distribution of seeds in the soil was similar for all species and treatments, with 63% of seeds remaining in the top 5cm of soil, 23% between 5 and 10cm and 14% between 10 and 15cm. However, the proportion of the seed rain which was incorporated into the soil and subsequently recovered in the soil cores varied between species, being 87% for B. sterilis, 80% for G. aparine and 22% for P. rhoeas.

Seedling establishment

Seedling establishment was generally low in the first year, with an average of 30 seedlings of B. sterilis and 6 of G. aparine m^{-2}. Seedling establishment of P. rhoeas was patchy, ranging from 1 to 100/m^2, and reflected the distribution of a naturally occurring population in the field. There were no significant differences in establishment between treatments. In the second year there were marked increases in seedling populations, as well as differences in seedling establishment between treatments. Populations of P. rhoeas were generally greatest where they were the only weed species, G. aparine numbers were generally higher in plots without B. sterilis but B. sterilis populations showed no differences between treatments. Table 1 shows the mean number of seedlings of each species for each treatment in both years.

	Weed Treatment			
a) Bromus sterilis				
	BGP	BG	BP	B
1989-90	30	27	29	32
1990-91 low N	807	765	743	690
1990-91 high N	770	677	915	678
b) Galium aparine				
	BGP	BG	GP	G
1989-90	7	7	6	5
1990-91 low N	25	29	118	56
1990-91 high N	18	57	38	46
c) Papaver rhoeas				
	BGP	BP	GP	P
1989-90	22	4	11	9
1990-91 low N	24	4	23	85
1990-91 high N	47	3	27	114

Table 1. Mean numbers of weeds/m^2 for each weed species in each weed treatment which established during 1989-90 and 1990-91. The letters indicate the weed species combination and are the initial letters of each weed species.

Differences between nitrogen levels are also apparent. The increase of B. sterilis in plots with mixtures of weed species was greatest at the low nitrogen level, the increase of P. rhoeas was significantly higher in the single species plots at the high nitrogen level, but G. aparine population increases showed no consistent response to nitrogen level.

The date of drilling of the crop and times of emergence of the weeds relative to that of the crop differed between years. In the first year the time of emergence of the weeds in relation to the crop was at least partly determined by the time of sowing of the weed seeds. In the second year,when the crop was drilled earlier and the weeds were allowed to reseed naturally, emergence of the weed seedlings was earlier in the season (Figure 1).

Seed production and wheat yield

Wheat yield was significantly higher at the high nitrogen level (p=0.003). At the low level of nitrogen mean yield was 480g/m^2 (equivalent to 4.8t/ha), and was unaffected by the presence of weeds. At the high nitrogen level, yield was significantly reduced by the presence of B. sterilis (p=0.006), being 700g/m^2 (7.0t/ha) without B. sterilis, and

(550g/m^2 (5.5t/ha)) with *B. sterilis* infestation. There were no significant differences in weed seed production per m^2 between treatments for *G. aparine* or *P. rhoeas*, but *B.sterilis* produced significantly more seeds/m^2 on the high nitrogen plots compared with the low nitrogen plots ($p=0.046$). Mean seed production was 2600/m^2 and 3500/m^2 for *B. sterilis* at low and high nitrogen respectively, 500/m^2 for *G. aparine*, and 14,400/m^2 for *P. rhoeas*, but it should be noted that seed production of both *G. aparine* and *P. rhoeas* showed large variations between plots.

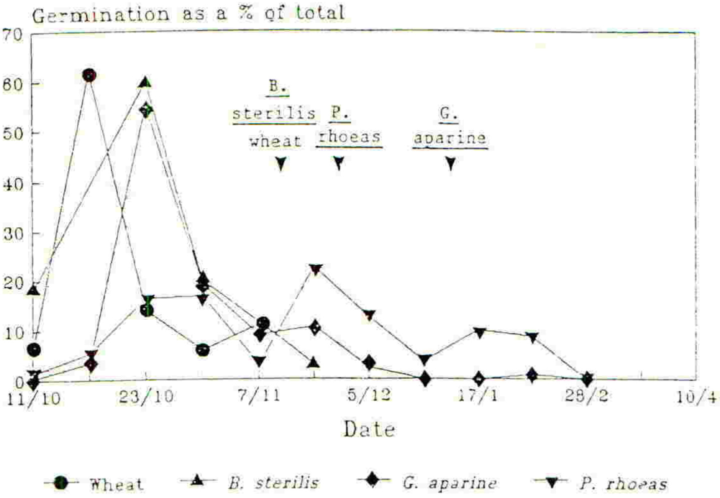

Figure 1. Seedling emergence as a proportion of total emergence during the second year. Peak emergence times of wheat and weeds in the first year are indicated by the arrows.

DISCUSSION

In the absence of the use of herbicides, the populations of all three weeds showed large increases over two seasons (figure 2). Increase in *B. sterilis* populations of a similar magnitude to those found here were reported by Firbank *et al* (1985). Initial infestations of 1 or 10 plants/m^2 in wheat increased to 786 and 647 plants/m^2 respectively within three seasons, and an initial infestation of 1000 plants/m^2 showed little increase over the same period, indicating that the maximum density of *B. sterilis* in a crop of wheat is in the region of 1000 plants/m^2. It is likely, therefore that the populations of *B. sterilis* on all of the plots in this experiment are close to the maximum possible in the presence of wheat and that the rate of increase in the second year will be very much less. Clearly neither *G. aparine* nor *P. rhoeas* have any competitive effect on the abundance of *B. sterilis* (figure 2). Seedling establishment as a proportion of seed input to the soil was low, (0.35). This cannot be explained by dormancy or low viability as *B. sterilis* seeds have little innate dormancy (Froud-Williams, 1985) and dormancy is not enforced by burial (Froud-Williams, 1981) and studies have shown that seed viability in this species approaches 100% (Froud-Williams *et al*, 1984; Froud-Williams, 1985). Instead most of the losses are likely to be a result of germination of seeds prior to cultivation, and their subsequent death by burial after cultivation, or burial of seeds to a depth from which germinating seedlings fail to emerge. *B. sterilis* seeds have been shown to emerge from depths of up to 13 cm, but optimum emergence arises from seeds buried less than 7 cm

(Froud-Williams et al, 1984), and results from analysis of the seed bank showed that about 40% of seeds were buried to a depth greater than 5cm.

The populations of G. aparine which established during the second year showed marked variations between treatments (see table 1), with a maximum number of 215 plants/m^2 occurring on a single species plot. Populations in excess of 800 plants/m^2 in wheat with shallow tine cultivation have been reported (Wilson & Froud-Williams, 1988) which suggests that, on the single species plots, the numbers will continue to increase. The populations on plots with a mixture of weed species, particularly those where B. sterilis is present, are in general much lower, suggesting competition from B. sterilis, and indicating that the maximum density attainable by G. aparine will be lower on these plots. This effect of B. sterilis on the rate of increase of G. aparine is clearly demonstrated in figure 2 which shows rates of increase of up to 25 fold on plots without B. sterilis a figure close to the 23 fold annual increase reported by Wilson & Froud-Williams (1988), in contrast there was less than 10 fold increase on plots where B. sterilis was present.

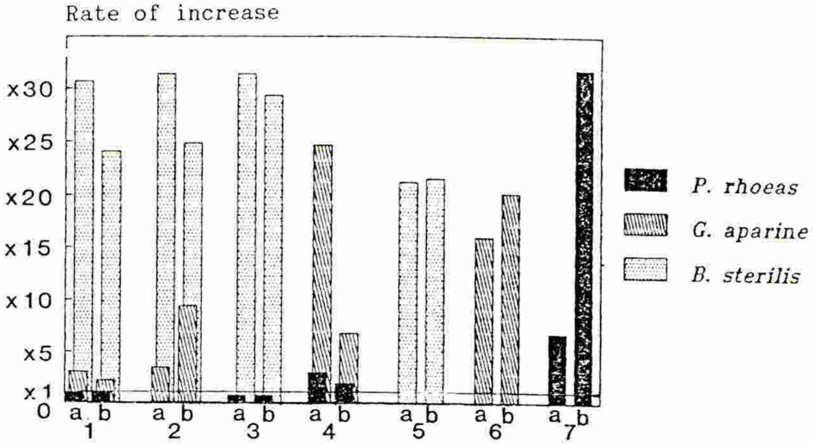

Figure 2. Rates of increase in seedling establishment between the first and second years for each treatment. The weed treatments are: 1. all three species; 2. B. sterilis and G. aparine; 3. B. sterilis and P. rhoeas; 4. G. aparine and P. rhoeas; 5. B. sterilis; 6. G. aparine; 7. P. rhoeas. and the nitrogen levels are: a. low nitrogen; b. high nitrogen.

There is little recent literature on populations of P. rhoeas in wheat as its significance as an arable weed has declined since the introduction of selective herbicides (McNaughton & Harper, 1964). However, its importance as an arable weed is likely to increase with a reduction in the use of herbicides as its seeds remain dormant and viable in the soil for long periods of time (Chancellor, 1986). The numbers of plants present on the plots during the first and second years varied markedly between plots as a result of a natural infestation affecting part of the field. However, the rates of increase show consistent responses to the weed treatments (figure 2). In particular it can be seen that P. rhoeas populations showed very little increase where it was in competition with G. aparine, and population size remained static or decreased on plots with B. sterilis. This contrasts with a 30 fold increase in the high nitrogen plots in mixture with wheat alone. Clearly the numbers of seedlings emerging in the second year are very low when compared to the number of seeds produced in the previous season, but as 97% of its seeds are initially dormant (Harper 1977) this may be expected. Densities of P. rhoeas of up to 70-80 plants per sq. foot (about 700-800/m^2) have been reported in disturbed habitats (McNaughton & Harper, 1964).This suggests that, in plots where P. rhoeas is the only weed, the populations are below the maximum that may be attainable, but in plots where P. rhoeas is in competition with either of the other two species of weed, it appears likely that populations will remain low.

Although the weeds had little effect on crop yield in the first year, the large increases in populations that have resulted from an absence of control measures suggest that yield reductions are likely to be evident in the second season. Additionally the weeds emerged earlier in relation to the crop in the second year which may increase their effects on crop yield (eg. O'Donovan et al, 1985).

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