HGCA

RESEARCH REVIEW No. OS2

WEEDS IN OILSEED CROPS

AUGUST 1991

Price £7.00

HGCA RESEARCH REVIEW No OS2

WEEDS IN OILSEED CROPS

by

P.J.W. LUTMAN

AFRC-IACR Rothamsted Experimental Station, Harpenden, Herts AL5 2JQ

This review has been supported by a grant from the oilseeds levy of the Home-Grown Cereals Authority. It has been prepared in collaboration with **Mr P. Bowerman** and **Mr G. Sansome** of ADAS and **Dr K. Davies** and **Ms G. Whytock** of SAC.

CONTENTS

HGCA RESEARCH REVIEW NO. OS2

WEEDS IN OILSEED CROPS

P.J.W. LUTMAN

AFRC-IACR Rothamsted Experimental Station, Harpenden, Herts, AL5 2JQ

ABSTRACT

This Review has been prepared by an 'ad hoc' group of weed specialists from the Institute of Arable Crops Research (AFRC), the Agricultural Development and Advisory Service and the Scottish Agricultural College, under the leadership of Dr P.J.W. Lutman, and considers, problems arising from weeds in oilseed crops. It is based on a review of the scientific literature, 83 references are quoted, and on discussions with relevant experts in the UK and elsewhere in Europe. Most of the Review is concerned with winter oilseed rape but mention is also made of weed related problems in spring rape, linseed and sunflower.

The most detailed sections of the Review are concerned with the adverse effects of weeds on the growth and yield of the crops, and the related justification for expenditure on their control. The Review also considers 'problem weeds', those species that are not easily controlled with current herbicides, including volunteer rape, and discusses the possibilities for improving control. The difficulties arising from the lack of herbicide products for minor oilseed crops are also reviewed. Finally, recommendations are made for future research funding to solve the outstanding problems.

Winter Oilseed Rape

* Weed Competition

The crop is very competitive and data from the UK and Germany, suggest that weed control in 30 - 40% of crops is not economic.

Grass weeds Tentative threshold weed densities, based on 43 detailed experiments, have been developed for grass weeds (volunteer cereals). The level of competition is related to the vigour of the crop in the autumn, which in turn is related to the date of sowing. For example, crops sown on 26 August will tolerate 100 barley plants/m^2 without economic loss of yield, whereas those sown on 9 September only 10 plants/m^2. Timing of control of competitive populations is not critical as both early and late autumn herbicide applications have not

resulted in detectable loss of yield.

Broad-leaved weeds There is less information, but it is already clear from the 40 experiments reported, that even high populations, in excess of 200 plants/m^2, of the low growing species such as chickweed and speedwell have little effect on the yields of well-established rape.

* **Research needs** The main requirement is to develop systems of prediction of the likely effects of weeds, particularly the broad-leaved species, based on autumn assessments of crop and weed growth. This is not easy, because of the crop's ability to compensate. A research programme to study the interaction between weed density and vigour, and crop vigour in the autumn, is essential to provide the basis for predicting yield losses from weed competition.

* Low-dose herbicide treatments

  When weed populations are low it may be more attractive to the farmer to use a low-dose herbicide treatment, rather than omitting the treatment completely. It is already clear that low doses of some herbicides can be very effective; for example, 40% of the full metazachlor dose has achieved an average of 80% control of chickweed.

* **Research needs** The low-dose approach to weed control needs further study, as it is not yet possible to predict accurately the performance of low doses, nor the effects of partially killed weeds on the crop and on weed seed return.

* Other adverse effects of weeds

  Although the alleviation of weed competition is the primary aim of weed control, the contamination of harvested rape seed by weed seeds, harvesting delays caused by green weeds and the potential for weeds to act as foci for rape diseases, may all be important in some situations. Seed return from untreated or partially dead weeds may influence the longer term weed population. The significance of these effects to the farmer is largely unknown.

* **Research needs** Research to evaluate the importance of these effects would be valuable.

* Problem weeds

  Winter rape is adequately served by the chemical industry and it is possible to control most weed species. Exceptions are cleavers and weed species in the Cruciferae, such as charlock and runch, which are difficult, if not impossible, to control.

* **Research needs** A small research programme to study the optimisation of the

performance of herbicides that are currently available for these 'difficult to control' species, particularly cleavers, would be of direct help to practical farming.

Linseed

* The amount of information available on the effects and control of weeds in linseed is limited. The crop is slow to establish and vulnerable to competition, so weeds must be controlled to maintain yields. Only eight herbicides are approved for use and consequently control of some weeds (eg. charlock, fat hen) can be difficult.
* **Research needs** Research is needed to quantify the adverse effects of weeds and improve the control of the less easily controlled species.

Spring Oilseed Rape

* Spring rape is more competitive than many other spring crops and so weeds do not often have an appreciable effect on yields. As only eight herbicides are available, some weeds are difficult to control, particularly once they are emerged (eg fat hen).
* **Research needs** Better guidance on weed control strategies is needed, in order to ensure that herbicides are not used uneconomically. Research is also required to develop treatments to control the more intransigent species.

Sunflower

* This is an even smaller acreage crop than linseed and spring rape, but if the climate continues to warm, it could be successfully grown in the south of England. Once established, it is a competitive crop and will suppress many weed species. As only four herbicides are available, some species are difficult to control. Broad-leaved weed control is based solely on two pre-emergence products and so activity can be poor in dry conditions.
* **Research needs** More herbicide treatments are needed for the control of broad-leaved weeds.

Volunteer Oilseed Rape

* The control of this weed in many broad-leaved crops is very difficult and the presence of volunteer rape can pose a threat to the purity of subsequent rape crops. There is little research information on the persistence of this 'weed' and virtually none on the effects of cultural practices on this persistence. Farmer experiences suggest some rape seed can persist for at least five years.
* **Research needs** A research programme is needed to provide guidance on the best

agricultural practices to minimise persistence and to predict the length of rotations required to minimise the contamination of the next rape crop.

<u>'Minor uses'</u>

* The small number of herbicides available for use in spring-sown oilseed crops is an example of a situation now common in many 'minor' crops. Few products are approved and the current MAFF reviews of pesticides may result in the withdrawal of existing herbicides. The manufacturers alone are unlikely to develop minor crop uses for their new products, because of the cost of registration. The only possibilities for maintaining or extending the number of approved products is for the manufacturers, government funded research organisations and growers to collaborate in the development of new approvals.

This review, completed in August 1991, and with 70 pages in the full article was funded by the HOME-GROWN CEREALS AUTHORITY, Hamlyn House, Highgate Hill, London N19 5PR, from whom copies may be obtained at a price of £7 each (postage and packing included).

1. INTRODUCTION

The control of weeds has been the major constraining factor on agricultural productivity since neolithic times. The amount of land that the farmer could cultivate was limited by his ability to control weeds. This constraint still controls the productivity of many third world farmers but is not so evident with modern western agriculture. The development of mechanised weed control and, more critically, the use of herbicides has reduced the importance of weeds to the modern farmer. In the last 40 years, when maximising output has been the main driving force behind European farming, it has been generally accepted that weed control was essential to optimise yields. Indeed the economics of arable agriculture in the 1970s and 1980s clearly showed that maximum yields with high inputs of pesticides and fertilisers led to maximum profits. In this scenario herbicides were nearly always used, often in a prophylactic fashion, in the belief that a 'clean field' was likely to give the grower the best and most profitable crop.

The situation over the last five years has changed. Western Europe is overproducing arable crops and as a consequence support prices are being lowered, reducing the profitability of crops. National and international concern over environmental pollution is leading to greater restrictions on the use of pesticides in arable agriculture. Both these factors will increasingly drive European farmers, to reduce the use of herbicides, insecticides and fungicides in their arable crops. In order to maintain profitability in this changing situation the farmer must improve his crop management. With hindsight, it can be said that arable crop production aimed at maximising output requires a lower level of management expertise than that required where pesticide and fertiliser use has to be tailored to ensure maximum profitability and minimum environmental pollution. Recent legislation relating to the use of pesticides requires that they should only be used when the weed, pest, or disease is having a 'significant' effect on the crop. This is aimed at encouraging growers to use threshold and integrated systems of pest management. In order for the farmer and his advisors to operate such threshold systems they must be able to predict when a pesticide will be needed. In the context of weed control the farmer must judge whether the weed populations present in a field are above or below an 'economic threshold', ie. will they adversely affect the profitability of this or subsequent crops. This is not an easy decision to make. Some progress has been made for cereals but the data for oilseed crops, even oilseed rape, are very sparse. There is also evidence from the cereal work that the 'farmer threshold' is often not the same as the economic threshold. For example, one wild oat/m^2 may have little effect on the profitability of winter wheat but may be unacceptable to the farmer because of the visual appearance of the crop in mid-summer.

Pride in a clean crop and a belief that this 'cleanliness' will have economic benefits in the future, influences the attitude of many farmers to weed control.

Although weeds do not exert the constraint on modern farming that they do on less advanced agricultural systems, they can still have a major effect on crop profitability, and as a consequence herbicides represent an appreciable proportion of the variable costs of arable crop production. Nix (1990) quotes the variable costs for winter oilseed rape to be £230/ha, of which 'sprays' account for £100/ha. Using ADAS figures it can be estimated that 50% of this £100 can be attributed to herbicides. Thus, herbicide costs are approximately 20% of all variable costs. There is considerable potential for economic savings in relation to the control of weeds, but in order to be successful a high level of expertise is required.

The aim of this review is to consider the factors that contribute to the adverse effects of weeds on oilseed crops and to summarise, as far as possible, the current extent of knowledge relating to these various factors. Inevitably most of the information relates to the major oil crop, oilseed rape, but some data have been collected for the minor oil crops. As well as considering the need for weed control, in relation to the economics of crop production and the risks of environmental pollution, the review will also consider the practical problems of weed control that currently exist in these oil crops, identifying those species that are most difficult to control. It will also consider problems arising from volunteer rape and the reasons for its persistence.

2. WEED OCCURRENCE

In order to assess the potential national needs for weed control it is of considerable value to have information on the species and density of weeds that occur within crops. If this information is amalgamated with the research data on their effects on the yield of the crop, some estimate can be produced of the national requirement for weed control.

2.1 WINTER OILSEED RAPE

Recent surveys of weeds in winter rape provide a good basis for estimating the species distribution in the crop but provide no data on the density of the weeds. The survey in 1988 reported by Whitehead & Wright (1989a) simply recorded the presence of species in 842 rape fields, in the autumn prior to herbicide application. They reported that common chickweed (Stellaria media), mayweeds (Matricaria/Tripleurospermum spp.), annual meadow-grass (Poa annua) and volunteer cereals were almost ubiquitous, occurring on at least 80% of fields (Table 1). It is of interest to note that the frequencies of the different weed species in this survey were very similar to those recorded in a survey reported by the same two authors in winter cereals (Whitehead & Wright, 1989b). This is perhaps not too surprising as rape is very frequently grown as a break crop in winter cereal dominated rotations. Thus, the weeds in rape are likely to be similar to those in the previous crop of cereals. The frequency of weed species in Scotland was found to be slightly different in a survey of 84 fields in autumn 1988 by Whytock & Carnegie (1990). The commonest species in their survey were common chickweed, annual meadow-grass, volunteer barley, mayweeds and field pansy (Viola arvensis), all of which occurred on more than 75% of fields (Table 1). Their survey included an approximate estimate of the density of the weeds and it was only chickweed and annual meadow-grass that regularly occurred at densities exceeding 50 plants/m^2. The latter was clearly the commonest weed. A survey in France carried out by CETIOM (Centre Technique Interprofessionel des Oleagineux Metropolitains), based on the weed flora present on untreated plots of a large number of experiments, concluded that in northern France (5710 observations) the commonest weed species were black-grass (Alopecurus myosuroides), volunteer barley, speedwells (Veronica spp.), common chickweed and shepherds purse (Capsella bursa-pastoris), but none of these occurred in more than 35% of fields (Regnault & Adam, 1989). The flora in northern France seems more varied than that in the UK, but the major species are similar. Reports of weed problems in Germany emphasise black-grass, common chickweed, speedwells, dead nettle (Lamium spp.), field pansy and shepherds purse (Küst, 1989). Thus, there is a

Table 1

Incidence of Weeds in Winter Oilseed Rape in Great Britain (autumn 1988)

Weed Species	**% Occurrence**	
	Whitehead & Wright (1989a)	Whytock & Carnegie (1990)
common chickweed	98	100
mayweeds	81	75
common field-speedwell	71	25
red dead-nettle	53	26
cleavers	46	-
shepherds purse	39	55
field pansy	38	75
charlock	34	16
ivy-leaved speedwell	25	-
common poppy	23	7
common hemp-nettle	10	59
volunteer cereals	88	77
annual meadow-grass	80	98
black-grass	40	-
wild oats	40	5

reasonable consensus as to the commonest species to occur in winter rape in northern Europe.

In all the British surveys perennial weeds have not been found to be very common. Only common couch (Elymus repens) and creeping buttercup (Ranunculus repens), which were found in 23 - 24% of fields, were recorded. Other broad-leaved perennial weeds, such as creeping thistle (Cirsium arvense) and field bindweed (Fallopia convolvulus), which cause severe problems in other arable crops, were not present in the sampled fields.

Few research projects have attempted to monitor the average weed density in arable fields, except as incidental information arising from herbicide evaluation trials. Using this type of data from rape experiments carried out in the UK, by Government funded research groups, over the last ten years (40 trials) the average weed density was found to be 102 plants/m^2. As it is likely that herbicide evaluation trials would have been carried out in fields with a higher density of weeds than normal, this estimate is probably too high. In contrast, this density is based mostly on trials investigating general broad-leaved weed control and so fields with high densities of barley and other grass weeds would have been avoided. Populations of volunteer barley can exceed 800 plants/m^2 and black-grass 2000 plants/m^2 but average populations would be much lower. Precise values are not available.

2.2 SPRING-SOWN OILSEED CROPS (linseed, spring rape, sunflower)

The weed species that occur in these crops tend to be similar, as species that either have no specific annual emergence pattern or which emerge primarily in the spring will predominate. However, time of planting can modify the weed flora. Early-sown crops are more likely to contain a remnant of the winter germinating flora, such as cleavers (Galium aparine) and black-grass, whilst late-sown ones will suffer from the presence of summer germinating species, such as black nightshade (Solanum nigrum). Detailed surveys of weed occurrence have not been done in spring oilseed crops but extrapolation from experiences in other spring crops, such as peas, beans, sugar beet and potatoes, along with anecdotal evidence from spring oilseed crops, would suggest that a considerable number of species are common. The diversity of the weed flora is greater in spring-sown crops than it is in autumn-sown ones. The most widespread species are given in Table 2. Redshank (Polygonum persicaria), fat hen (Chenopodium album), knotgrass (Polygonum aviculare), black bindweed (Bilderdykia convolvulus), charlock (Sinapis arvensis), thistles (Cirsium/Sonchus spp) and hemp nettle (Galeopsis tetrahit) (in Scotland) are suggested by Turner (1987) to be the most serious in linseed. Charlock poses particular problems in oilseed crops because it is difficult to control. The same

Table 2

The Most Common Weeds of Spring Sown Crops

annual meadow grass	corn marigold
black bindweed	fat hen
black nightshade	knotgrass
charlock *	mayweeds
common chickweed	redshanks
common fumitory	volunteer oilseed rape *
	wild oats

* Few selective herbicides available for the control of these weeds.

applies to volunteer oilseed rape. The weed flora will vary considerably from field to field as a result of soil type variation and differences in the date and weather at sowing. Turner (1987) reports that grass and broad-leaved weeds were present in assessable numbers in only 60% of 49 linseed crops, indicating that some fields contain few weeds and so would not require a herbicide treatment.

3. ADVERSE EFFECTS OF WEEDS ON OILSEED CROPS

3.1 GENERAL

Weeds can have a range of adverse effects on the growth and yield of crops, the most important being their competitive effects on yield. But, they can also affect harvesting, the quality of the harvested seed and may influence the levels of disease in the crops. Finally, weed control strategies in the oilseed crops may adversely affect subsequent crops. Each of these effects is reviewed for the main oilseed crops in the subsequent sections of the review. Inevitably, most of the available information relates to winter oilseed rape.

In order to provide a sound background for the detailed consideration of the competitive effects of weeds, the following section is a short summary of the background to weed competition and the theory of thresholds.

3.2 WEED COMPETITION

The competitive effects of weeds on the growth and yield of crops, have been studied for many years and the fundamental principles are well understood (Harper, 1977). The basic assumption is that plants growing in proximity to each other compete for light, nutrients and moisture. These resources are limited and consequently the outcome of this 'competition' is the greater success of one plant over another. Thus, the growth of a plant will be influenced by the density and vigour of its neighbours. Although production per unit area may increase as plant density increases, up to a maximum, production per plant will decrease (Fig 1). Where more than one species is involved the outcome of the competition between them will be more complex, depending not only on the density of each species and their spatial arrangement, but also on their competitive ability. Some species are more aggressive than others.

3.2.1 Competition models

Population ecologists have carried out many experiments which illustrate how plants of one species react to the presence of another (eg. de Wit, 1960). Many of these have been based on 'replacement' designs, where the total plant population per unit area is kept constant and individuals of one species are replaced by another, giving a series of relative proportions from 0 - 100% (eg 0,100; 25,75; 50,50; 75,25; 100,0) . The productivity of the two component species in the differing proportions indicates the response of one species to another (eg. de Wit, 1960; Firbank & Watkinson, 1985). The agricultural relevance of this type of design is limited as, in the context of crop/weed competition, weeds do not replace the crop but are added to the basic crop population.

Fig 1

Diagrammatic Representation of the Influence of Plant Density on Plant Dry Weight/m² (——) and Dry Weight/Plant (- - -)

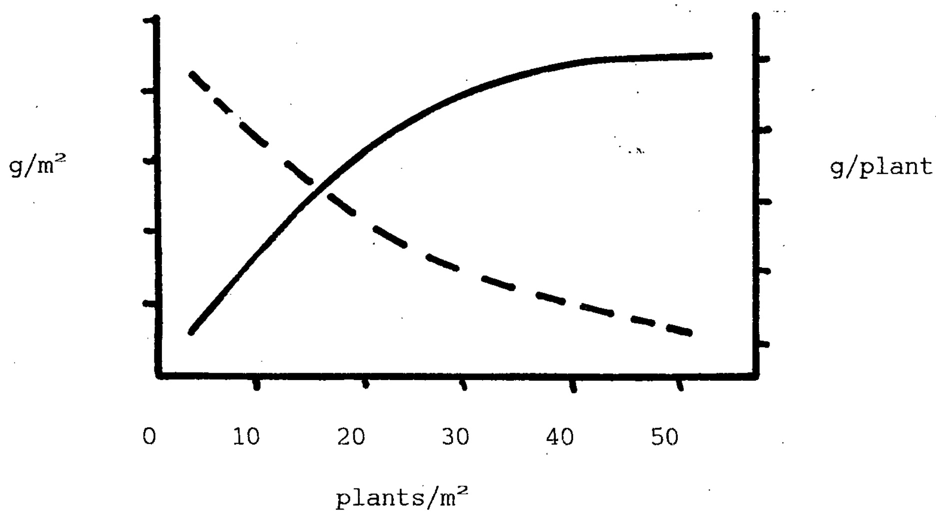
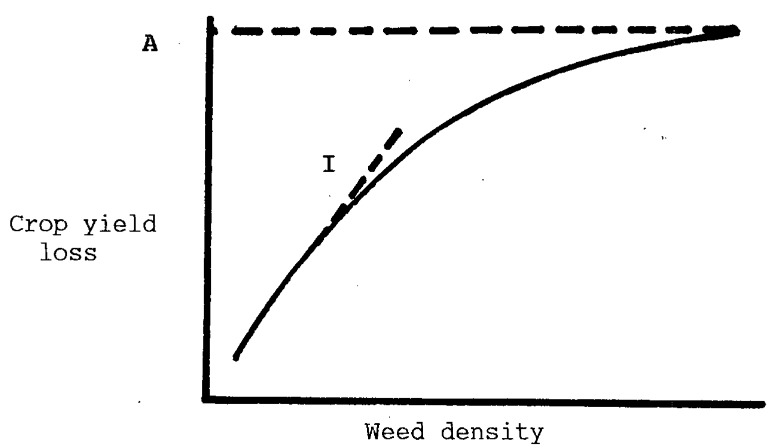


Fig 2

Relationship between Crop Yield Loss and Weed Density based on the Rectangular Hyperbolic Model



A = Asymptote

I = Yield loss/weed plant at low weed densities

In recent years many 'additive' experiments have been done to try to establish the response of a constant population of one species (crop) to increasing densities of another (weed) (eg Cousens et al., 1988). This work has led to more discussion of the optimum design of such experiments (Poole & Gill, 1987; Connolly, 1988; Roush et al., 1989). Even so, the results of additive and some replacement experiments are now being incorporated into competition models predicting the influence of weed populations on the growth and yield of crops.

Data derived from additive design competition experiments can be plotted so that a growth parameter of the crop (eg seed yield) is related to the density of the weed. The precise shape of this response curve has been the subject of much argument over the last five years but although not fully resolved, it is generally agreed that the best model both biologically and mathematically is the rectangular hyperbola (Fig 2) (Cousens, 1985). This model assumes that there is a maximum loss of crop yield caused by the competing weed species (A = maximum yield loss) and that at low weed densities there is a linear relationship between yield loss and weed density (I = % yield loss/weed plant). The rectangular hyperbola is now widely used as the basis for more detailed investigations of the influence of other factors on weed competition.

Detailed information on the effects of weeds on crop growth does not have to be derived from experiments with increasing densities of hand-sown weeds, as has been described in the previous paragraph. It is possible to collect similar information from natural weed infestations by comparing the yield of a large number of paired plots set out in fields containing a variety of densities of the studied weed species. One of each pair is kept weed free, whilst weeds are left in the other. The growth and yield of the crop in both plots can be compared and the competitive effects of a range of weed densities calculated. Hand weeding can be used to create plots of single species or desired multi-species. This technique has been widely used in Germany.

Weed species differ in their competitive abilities, some species (eg cleavers) are very competitive, whilst others (eg Viola arvensis (field pansy)) are less so. Wilson & Wright (1990) and Gerowitt & Heitefuss (1990) have produced detailed lists of the relative competitive abilities of a range of weed species in winter cereals in the UK and Germany, respectively. These indices are based on the ability of the weed to replace the crop, thus reducing yield. As it is rare for crops to be infested with a single weed species it is necessary to combine the competitive effects of the individual species to provide an overall picture. This is done by adding the product of the densities of the individual species and their competitive indices. It is clear from their work that the relative competitive effect of each species stayed quite constant but the absolute values varied from year to year. This variability could be due to differences in a number of factors including; climate, site (soil type), fertiliser, crop density and vigour, crop cultivar, date of sowing, relative time of emergence of crop and weed and patchiness in the distribution of the weeds. In order to predict how a particular weed population is going to affect crop yield, it is necessary to model the effects of these factors on the basic crop/weed competition relationship. This has been done with some success by the Göttingen research group in Germany (Gerowitt & Heitefuss, 1990), where the model includes indications of crop and weed growth stage and vigour, as well as assessments of weed number and/or ground cover.

3.2.2 Thresholds

Once the effect of a particular weed population on the crop has been calculated, it is relatively simple to model the economic consequences of controlling (or not controlling) the weeds. This has led to the concept of thresholds. Thus, the economic threshold is the density of weeds causing a loss in yield with a value that is balanced by the cost of treatment (Cussans et al. 1986). Several decision models now exist which incorporate predictions of the likely effect of weeds on crop yield with the cost of treatment and thus are able to tell users of the system when it is economic (and when it is not) to apply a herbicide (Gerowitt, 1990; Cussans & Rolph, 1990). However, models are only as good as the data that have been used in their construction and there is still a great deal to be done to clarify how many agronomic and climatic factors affect the competitive effects of the weeds.

In addition, the economic threshold, as defined above, is based only on the events in one season and no account is taken of the seed return from untreated weeds in fields below the spray threshold. Cussans et al. (1986) suggested that the long term threshold (economic optimum threshold) should be considerably lower (x 0.14 - 0.25) than the single year one, to take account of seed return. In contrast, Wahmhoff (1990a) has reported increased weed problems in only 5 of 35 sites, where weed control had been based on single year economic thresholds, indicating that it is often not necessary to adjust threshold values to take into account longer term effects. Detailed information on weed seed production and longevity in the soil is being collected from competition experiments in winter cereals in the UK, but it is not yet complete. Preliminary conclusions suggest that seed shed by one species will behave differently to seed from another, thus having differing effects on threshold values (Cussans, 1991).

3.2.3 Winter oilseed rape

The amount of information on the effects of weeds on winter oilseed rape is limited, as most research has studied weeds in winter cereals. However, some competition experiments have been done on rape by ADAS, SAC and AFRC research groups in the UK, and the German group in Göttingen have extrapolated their wheat competition model from cereals to oilseed rape (Küst, 1989). It is also possible to extract competition data from standard herbicide evaluation trials, provided that the experimenters have included information on the weed densities on the untreated plots. This type of information is not as valuable as that derived from specifically designed competition trials but can provide some useful data. For example, Wahmhoff has recently reached some interesting conclusions from a re-examination of data from 249 herbicide trials carried out on rape in W.Germany since 1971 (Wahmhoff, 1990b).

As the control of weeds in oilseed rape tends to fall into two categories, grass weed control and broad-leaved weed control, the following sections will also consider the competitive effects of these two groups of weeds separately.

3.2.3.1 Volunteer Cereals and other Grass-weeds

The most serious grass weeds to infest winter rape are volunteer cereals. Not only are they very common as discussed in Section 2.1, especially where rape is sown following non-inversion cultivations, they are also very aggressive weeds. Volunteer barley tends to be more of a problem than volunteer wheat, as it is more competitive and more rape follows winter barley rather than wheat. Over the past ten years an appreciable number of experiments have been done in the UK and Germany and also to a lesser degree in France, to investigate the effects of natural and artificially sown populations of volunteer cereals on the growth and yield of rape. Initial experiments in the UK indicated that sometimes volunteer cereals had a serious effect on the yield of rape and sometimes not (Lutman, 1984: Orson, 1984). Analysis of all the published data from UK experiments with volunteer cereals (43 experiments) (Davies, 1987a; Davies, Walker & Whytock, 1989; Lutman & Dixon, 1985, 1986, 1990; Ogilvy, 1989; Roebuck & Flint, 1985; Walker, Whytock & Davies, 1990; Ward & Turner, 1985) relating weed density in the autumn to yields of the weed infested plots, expressed as a percentage of those of the weed free crop (which eliminates variation due to differences in the absolute yields of different experiments), indicates a similar lack of pattern in the yield response (Fig 3). However, if these data are studied in a little more detail, it becomes clear that the responsiveness of the crop to weed competition is related to date of sowing. The earlier the crop is sown, the less the effect of the weeds. Regression analyses based on the experiments which included a range of barley densities (26 experiments), using the rectangular hyperbolic model ($Y = A + B/(1 + DX)$) (see Fig 2: section 3.2.1) show this most clearly. The most useful value to be derived from these regression analyses is the yield loss/weed plant (I). When Log I for each experiment is plotted against drilling date,

Fig 3

Relationship between Volunteer Cereal Density (plants/m² in the autumn) and % Yield Loss

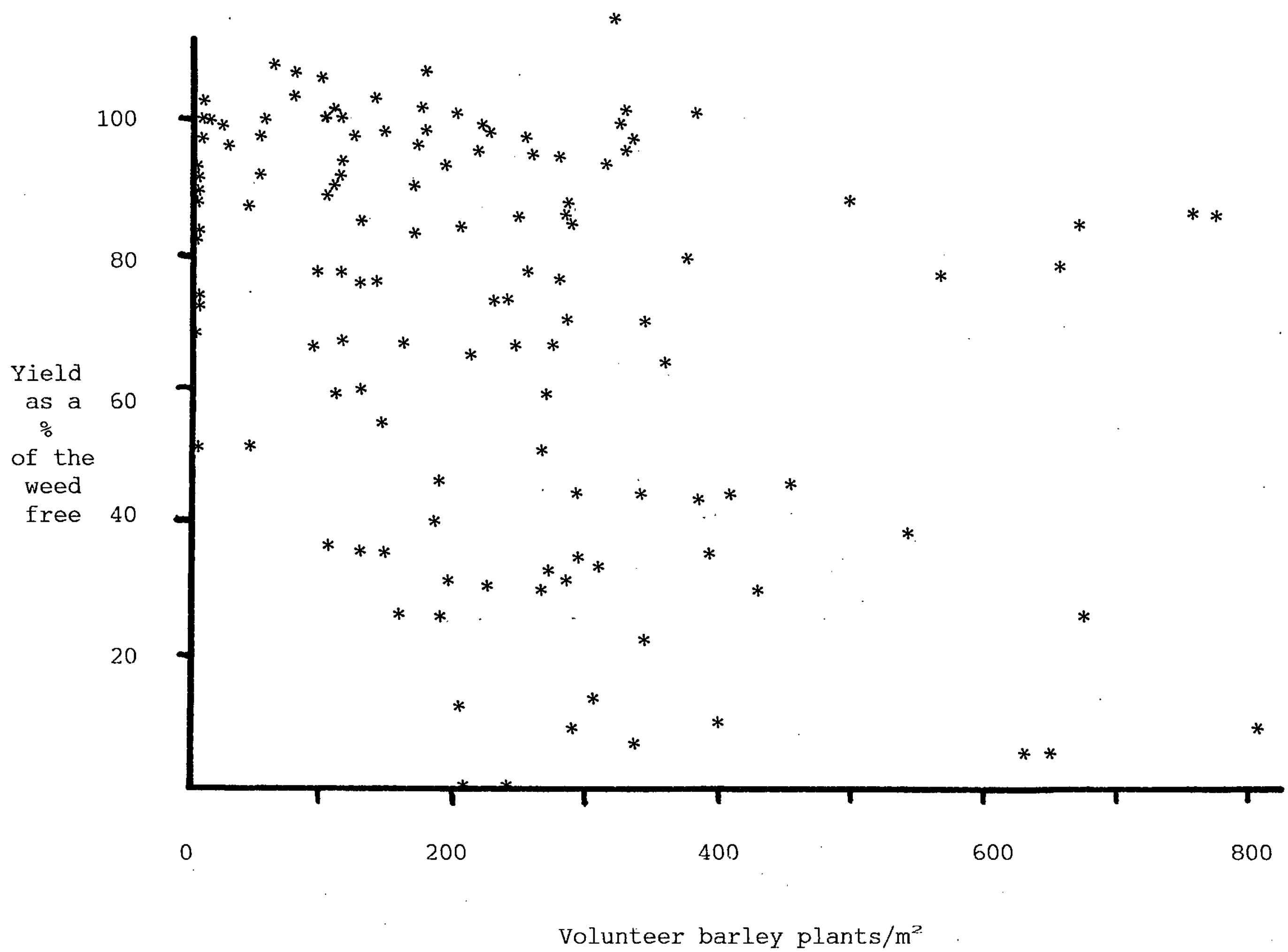


Fig 4

Relationship between Drilling Date and Yield Loss / Volunteer Barley Plant (I)

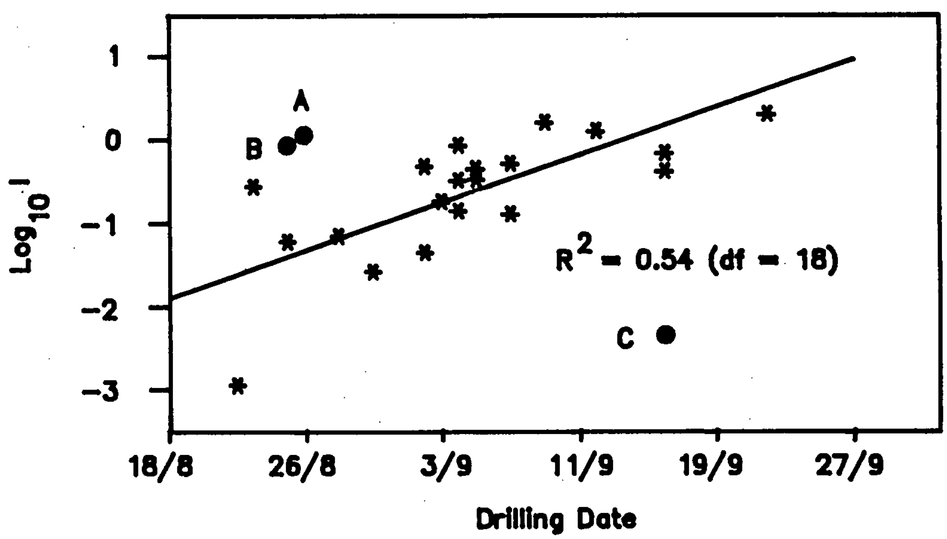
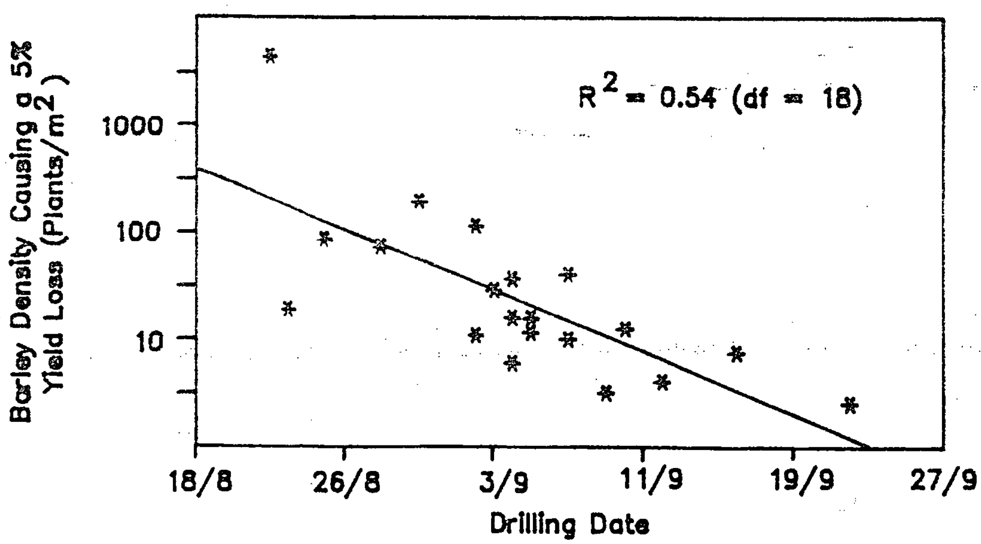


Fig 5

Influence of Drilling Date on the Number of Volunteer Barley Plants/m² to Cause a 5% Loss in Rape Yield



there is a clear linear relationship (Fig 4), of increasing yield loss/weed plant with delay in drilling. This analysis shows one of the problems of using non-biological values, such as drilling date, in assessments of biological effects. It is obvious that it is not the drilling date that is controlling the competitiveness of the weeds but the effect that the drilling date has on the vigour and competitiveness of the crop. In turn this is more related to emergence date than drilling date. In the data presented in Fig 4 three values are particularly aberrant. Values A and B indicate a much more competitive population of volunteer cereals than the drilling date would have predicted. This was because the emergence of these crops was delayed by drought. Thus they responded to weeds in the same way as later sown crops. The experiment providing the third aberrant value C indicates much less sensitivity to the weeds than predicted. The reason for this was that, in this experiment, severe winter weather killed the barley thus removing all weed competition in the spring and summer.

Re-interpretation of these data, so that drilling date is plotted against the number of weeds/m^2 causing a 5% yield loss provides a clearer picture of the economic consequences of not controlling volunteer cereals (Fig 5). For this analysis it has been assumed that a 5% loss of yield equates to an economic threshold, based on a conservative estimate of herbicide cost of ca £35/ha, plus £6/ha application costs (Nix, 1990), a crop yield of 3.0 t/ha and a crop value of £290/t. On this basis a 5% yield loss will be caused by 100 barley plants/m^2 when the rape is sown on 26 August and by 10 plants/m^2, when sown on 9 September. Because of the nature of the analysis, it is not sensible to extrapolate beyond the 20 August to the middle of September. If the crop has a higher yield the percentage of yield equivalent to the cost of herbicide treatment will decrease, as will the threshold weed population. Similarly, if the crop is low yielding the threshold will increase.

Research in France has compared the yields of herbicide treated weed free plots with untreated ones and related yield loss to volunteer cereal density (Regnault, 1984). This analysis assumes that the percentage yield loss caused by a given number of weeds remains the same irrespective of crop yield, so absolute yield loss increases as yields increase. At a crop yield of 3 t/ha a 5% yield loss is predicted to be caused by 14.5 weeds/m^2. This study takes no account of drilling date or other crop factors. I would question this analysis as it is my belief that the percentage yield loss caused by a given population of weeds declines as crop vigour and yield increases. However, the calculated values from this analysis do equate with UK calculations.

Studies of the competitive effects of volunteer barley in Germany by Küst (1989) compared the effects of 0, 50 and 150 barley plants/m^2 on the yield of rape sown early and late at up to three densities (30-60 plants/m^2), over three years. This work showed considerable year to year variation, as in the first year even 150 barley plants had no detectable effect on yield but in the second year 50 plants/m^2 reduced yields by 0.3-0.4 t/ha. In general, higher rape densities tended to reduce competition, although the effects were not large, and delayed drilling increased it. An approximate threshold of 20 barley plants/m^2 is suggested, which averages the effects of density and drilling date. This is in agreement with the values suggested in France and for some sowing dates in the UK. Data from the assessments of crop and weed ground cover on these experiments indicated that ground cover might be a better predictor of weed competition effects than weed numbers. Küst et al. (1990) concluded that where the relative ground cover in the autumn between rape and barley was less than 3:1 for 'normal' rape crops and 6:1 for late-drilled ones, the barley should be controlled.

Unfortunately, many of the UK experiments have not included assessments of crop and weed ground cover in the autumn or winter. However, some data are available. Comparison of the percentage ground cover of the rape in winter with the final yield of those crops does indicate that yield increases by about 0.3 t/ha for every 10% increase in ground cover in the winter (Fig 6). There is considerable variation in the data, so although statistically significant the precision of this estimate is poor (R^2 = 0.46). Similarly, if the percentage reduction in ground cover in winter caused by the volunteer barley, compared with the ground cover on the weed free crop, is plotted against the percentage reduction in yield caused by the same weeds, it can be concluded that there is a 0.7% loss of yield for every percentage decrease in relative ground cover (Fig 7). Again the precision of this estimate is poor (R^2 = 0.53), but both analyses do support the conclusion from Germany (Küst et al., 1990) that ground cover in autumn or winter could be a useful predictor of likely yield loss from weeds.

The competitive effects of wild oats (Avena fatua, A. sterilis ssp ludoviciana) and barren brome (Bromus sterilis) are thought to be similar or greater than cereals. Black-grass is considerably less competitive on a per plant basis than the above grasses but in contrast, densities of this weed can be much higher than for the other grass species. Wilson & Wright (1990), working in winter wheat, quote a competitive index of 2.67 for wild oats (A. fatua) and 0.34 for black-grass. Annual meadow-grass is even less competitive than black-grass and in consequence the Göttingen research group include it amongst the less competitive broad-leaved weeds (Gerowitt & Heitefuss, 1990). They suggest that the competitive index for annual meadow-grass should be 0.02, equivalent to parsley piert (Aphanes arvensis).

Timing of control of grass weeds The availability of several post-emergence grass weed herbicides provides the farmer with the tools to control grass weeds at any time between September and the end of January. This causes a dilemma, if he treats the

Fig 6

Relationship between Rape % Ground Cover in Winter and Rape Yields (t/ha)

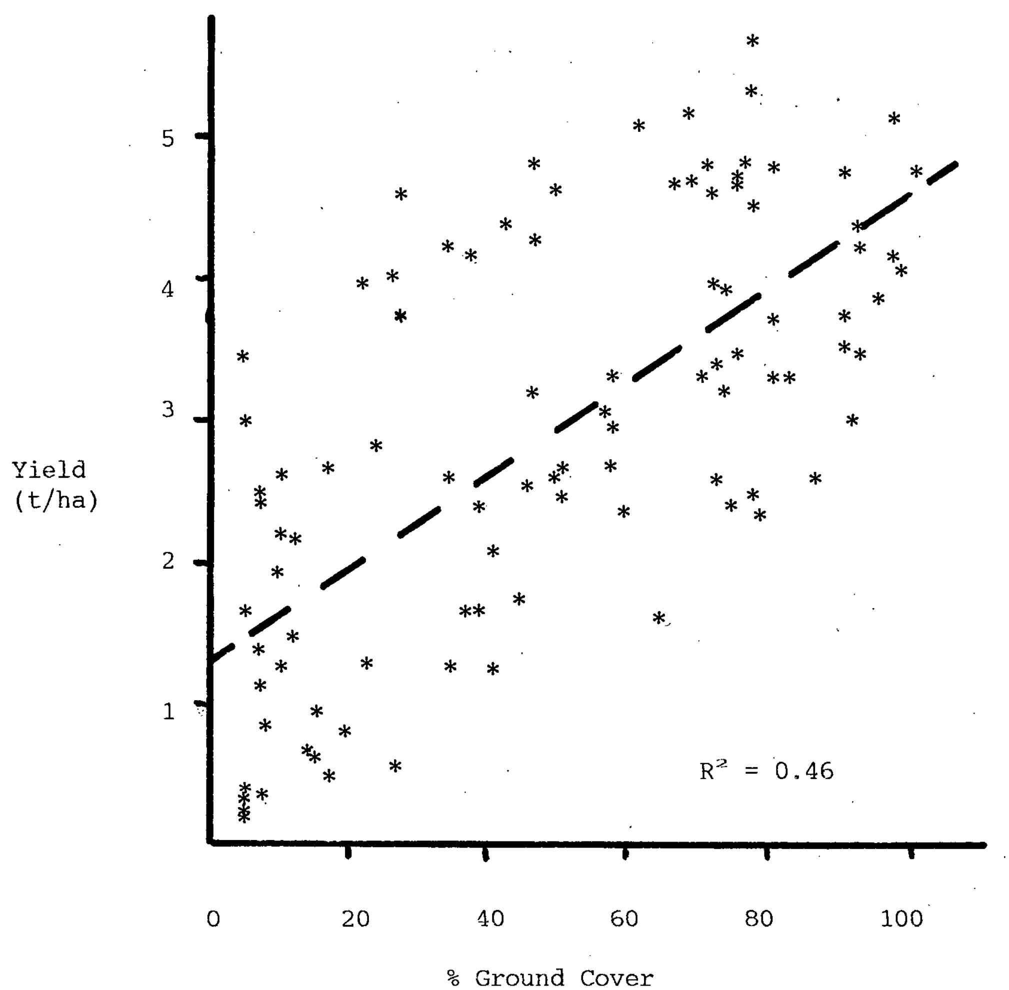
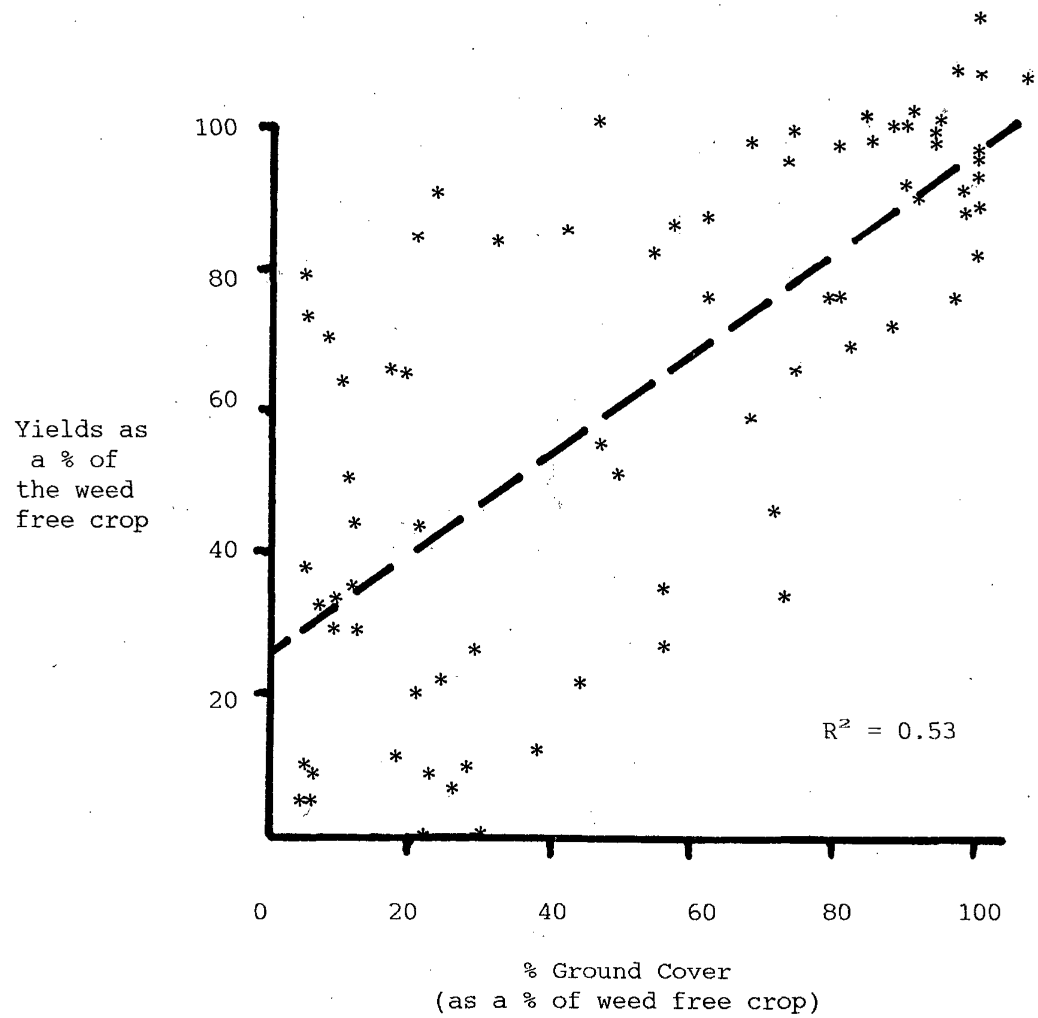


Fig 7

Relationship between the Ground Cover of the Rape (expressed as a % of the ground cover of the weed free crop) and Yields of Rape (expressed as a percentage of the weed free yields)



grass weeds early to minimise any possible effect they may have on yields, he risks the necessity of having to repeat the treatment to control later emerging plants. If he delays treatment to avoid this problem, the risk of yield loss would appear greater. In defense of early spraying, the competitiveness of weeds emerging after the rape is much less than that of weeds emerging before or with the crop. This has been investigated by Klostermyer (1989) for broad-leaved weeds in rape (see below) but there is no information for grass weeds. Detailed studies from Canada on the effects of wild oats on wheat and barley (Cousens et al., 1987) clearly show the decrease in weed competition with delay in emergence. Even a delay in weed emergence of only 8 or 12 days was sufficient to dramatically reduce the competitiveness of the wild oats.

The effects of delaying treatment of grass weeds on yields has been studied in France (Regnault, 1984), Germany (Gräpel & Schiller, 1988; Dingebauer, 1990) and the UK (Lutman, 1984; Lutman & Dixon, 1986; Ogilvy, 1989; Roebuck & Flint, 1985). The majority of these experiments demonstrated that pre-emergence, early post-emergence and even the late autumn post-emergence treatments for the control of grass weeds all resulted in yields not detectably lower than those of the weed free plots. In 9 of 11 trials in the UK there was also no yield penalty from delaying treatment until December or January, but in all cases the untreated plots produced significantly lower yields (Lutman & Dixon, 1991). There are indications in some trials that later sown, less vigorous crops were somewhat more sensitive to delay in treatment than early sown ones.

The reason for the rape's ability to recover from inhibitions to growth resulting from delayed herbicide treatment seems to lie in its growth in the following spring. It appears that rape plants exposed to weed competition in the autumn, despite their smaller size at the end of the winter, have the ability to grow faster in the spring and summer than larger plants which had not been exposed to competition (Lutman, 1989). Despite this vigorous growth the weed 'damaged' rape does not produce as many pods as the undamaged plants but it seems that this loss of pods does not result in lower yields. Evidence from other competition trials suggests that 'normal' rape produces too many pods which are not well filled with seeds. Rape that had previously been suppressed by weed competition produces fewer pods, better filled with seeds (Lutman & Dixon, 1990). However, rape severely inhibited in the autumn and winter by weed competition tends to mature slightly later than undamaged rape. Thus, there seems to be no need to apply herbicide treatments pre-emergence, or in the early autumn, in order to maintain yields. The only situations where early weed control is more vital is when the crop is late drilled and very uncompetitive or where the cereal density is very high, as in swathes from the previous cereal harvest in direct drilled or minimally cultivated crops. In this situation the weed density may be so high that substantial losses of rape plants will occur. With well established rape the 5% yield loss threshold may be as high as 500 plants/m^2 on herbicide treated plots. Above this density yield loss may occur even if a herbicide is used early in the autumn.

This absence of effects on yield from delayed weed control seems to conflict with the data shown in Fig 5, where the later sown, smaller, crop was more sensitive to weed competition. The critical difference between the effects of delayed weed control and delayed drilling lies in the continued presence of the weeds in the spring and summer in the unsprayed crop. In the absence of healthy weed plants in the spring and summer, as on even the late sprayed plots, the rape recovers, whereas if the weeds remain the rape does not.

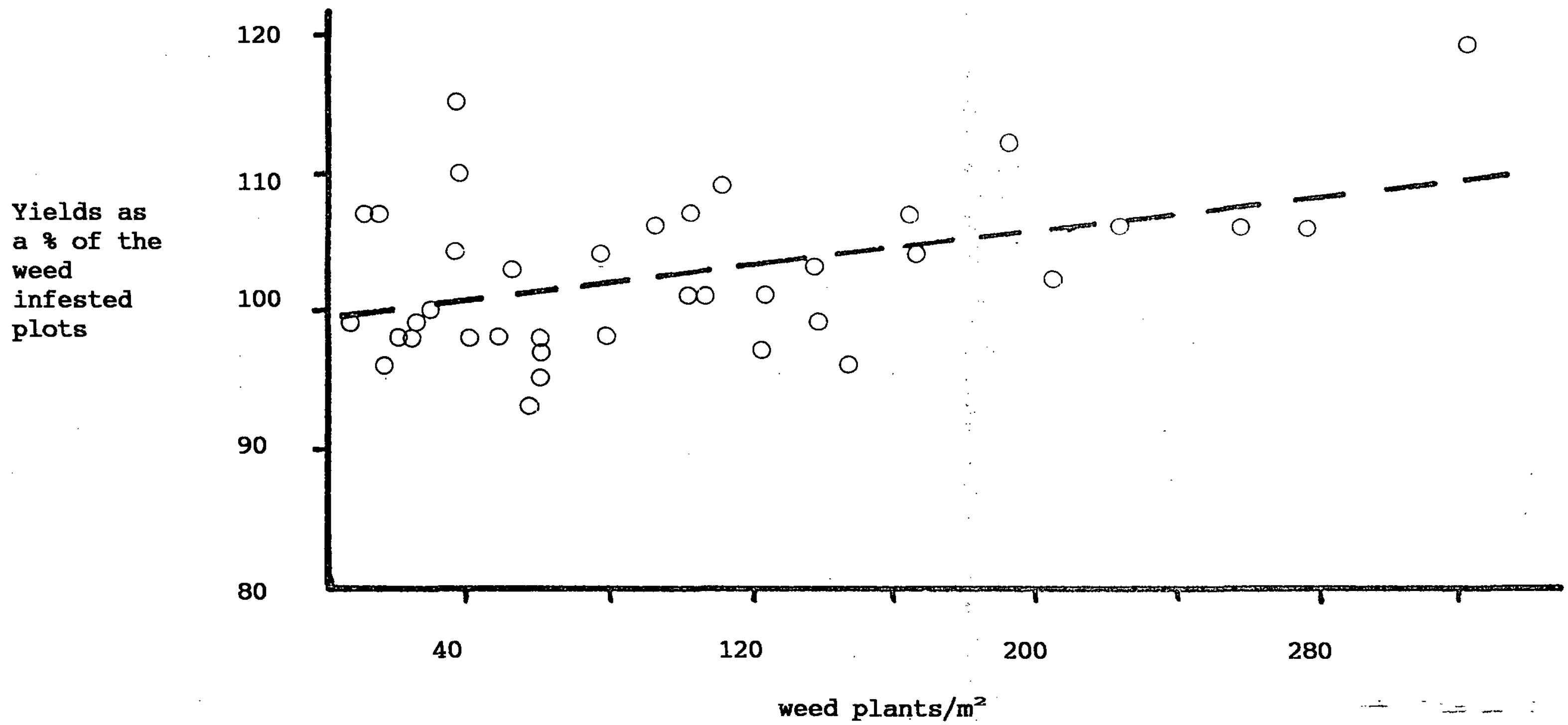
3.2.3.2 Broad-leaved weeds

The amount of information on the effects of broad-leaved weeds on the growth and yield of rape is much less than that available for grass weeds. Early work concentrated on the latter because of their substantial effects on the autumn and winter growth of the crop. Research in other crops has shown that grass weeds are more vigorous competitors than broad-leaved weeds (eg Wilson & Wright, 1990). In consequence, the control of grass weeds in oilseed rape is likely to be more essential than the control of broad-leaved weeds. Conversely, the potential for reducing costs by not treating broad-leaved weeds is much greater.

General analysis of the herbicide performance trials carried out in the UK by ADAS and SAC since 1983, provides coarse information on the effects of mixed broad-leaved weed populations on the yield of rape. An analysis of 40 experiments, based on the herbicide trials reported by Bowerman (1989), Davies (1987a), Davies et al. (1989) and Walker et al. (1990) and some unpublished results of Sansome (ADAS) and Whytock (SAC), shows a very poor relationship between total weed density and percentage yield loss (Fig 8). The regression line indicates a 1% yield loss per 33 weeds/m^2 but the statistical analysis shows that the line is not significantly diverging from the horizontal. Approximately 45% of treatments resulted in yields the same or less than the untreated yield. If the 5% yield increase used in the calculation of grass weed thresholds, is used as a basis for deciding if a herbicide should have been used, only 32% of fields would have benefitted from treatment. No account is taken in this analysis of the weed species concerned nor of the relative vigour of the crop. A similar survey in Schlesswig-Holstein by Dingebauer (1990) indicated that 30% of surveyed fields did not justify treatment. A more detailed analysis of 249 herbicide trials in Germany indicated an average yield benefit of 0.31 t/ha from weed control, equivalent to a 10.2% yield increase (Wahmhoff, 1990b). Economic analysis based on herbicide costs and crop value

Fig 8

Relationship between broad-leaved weed density and yields of herbicide treated plots, expressed as a % of the untreated, weed infested plots



showed that 44% of treatments were not profitable. The relationship between weed coverage and yield was poor, accounting only for 8% of the variation in the data. A similar graph of the UK data (mainly from Scotland), of weed percentage ground cover in early spring against yield as a percentage of the weed infested plots (Fig 9) demonstrated a stronger relationship than with the general weed number comparison (Fig 8). For every 5% increase in weed ground cover there was an approximate 1% increase in yield of the herbicide treated plots, over the untreated ones. As in Germany, the fit of the data to the line is still poor (R^2 = 0.27).

More detailed investigations with single weed species or with closely monitored mixed species have been carried out in recent years in UK and Germany. Küst (1989) calculated the competitive effects of a range of broad-leaved and some grass weed species. These values (yield loss/plant), which were derived from a series of 18 small plot experiments, identified chickweed to be the most competitive, followed by black-grass and mayweeds (Table 3). Cleavers, which are considerably more competitive than chickweed, were not included in these experiments but were assigned an arbitrary value of 1.0 by Klostermyer (1989). Incorporating these German relative competitive values into the UK weed number/yield comparisons in Fig 8 did not improve the quality of the regression analysis, indicating that either the competitive values calculated in Germany do not apply in the UK and/or other factors were having a greater influence on the effects of the weeds than their number and species. The relationships calculated by Küst are similar to those derived by Gerowitt (Gerowitt & Heitefuss, 1990) for wheat in Germany but do not agree with those of Wilson & Wright (1990) for weeds in winter wheat in England, where mayweeds and black-grass tended to be more competitive than chickweed (Table 3).

It is clear from the studies on the effects of cereals that crop vigour can have a great effect on the reductions in yield caused by a given weed population. The German experiments with grass weeds in rape also suggested that the relative ground cover of crop and weed is a good estimate of likely yield effects. In turn, ground cover of the crop and weeds will depend on their relative time of emergence. Klostermyer (1989) working with chickweed and scentless mayweed (Tripleurospermum inodorum) demonstrated that weeds emerging with the crop were much more competitive than those emerging 10 or 20 days later. He also found from crop dry weight assessments in April that the vigour of the crop at the beginning of the spring, recorded as percentage reduction in rape dry weight, relative to the weed free crop, tended to overestimate the likely effects of the weeds. During the summer the crop compensated and yield losses were very much smaller than expected from the April assessment. This conclusion agrees with the information collected from the grass weed trials (Lutman & Dixon, 1990) and

Fig 9

Relationship between the % Ground Cover of the Weeds in Spring and the Yields of all Herbicide Treated Plots expressed as % of the Untreated Weedy Plots

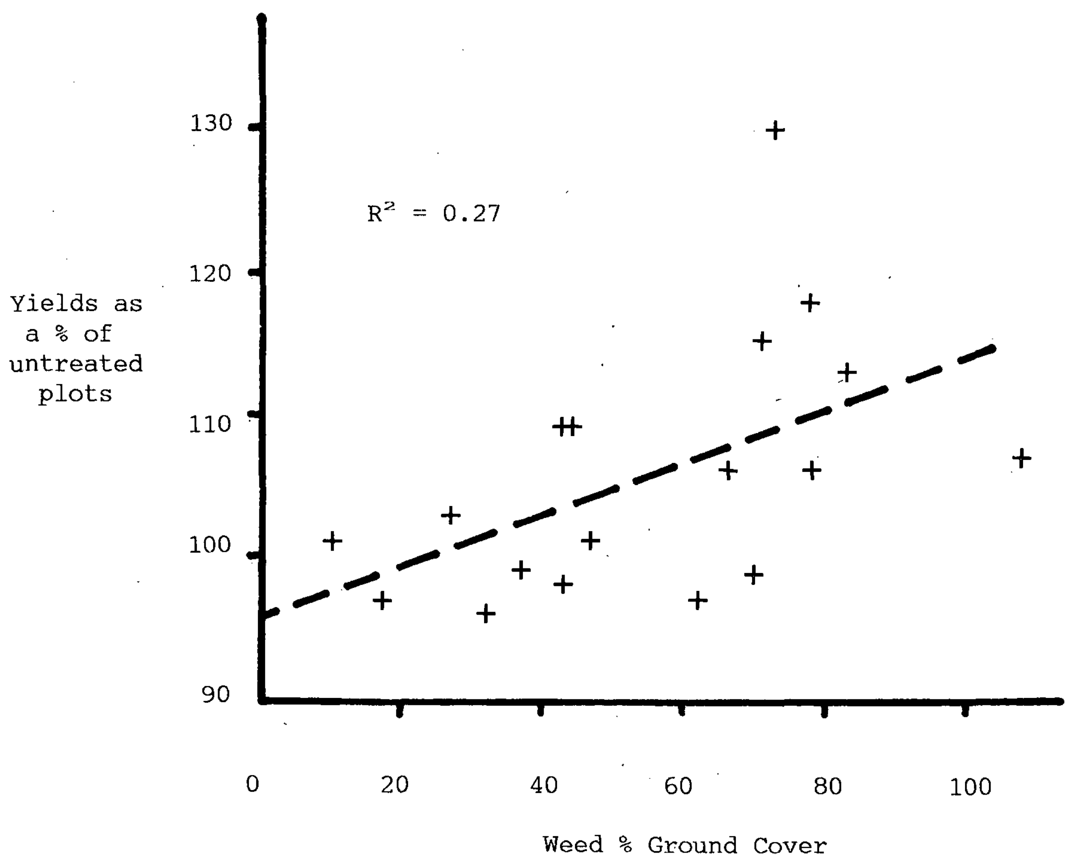


Table 3

Comparison of the 'Competitive Indices' Calculated for Weeds in Rape (from Küst, 1989) and Winter Wheat (from Gerowitt & Heitefuss (1990) and Wilson & Wright (1990))

Weed Species	Competitive Indices (% crop loss/weed plant/m^2)		
	Küst	Gerowitt Heitefuss	Wilson Wright
cleavers	1.0*	0.16	1.24
common chickweed	0.3	0.08	0.16
mayweeds	0.05	0.03	1.31
red dead-nettle	0.03	0.06	0.09
field pansy	0.03	0.03	0.02
forget-me-not	0.03	0.04	0.61
shepherds purse	0.03	0.02	-
annual meadow-grass	0.03	0.02	-
black-grass	0.08	-	0.25

* arbitrarily assigned value from Klostermyer (1989)

from experiments on broad-leaved weeds by Whytock (unpublished) and by Lutman (unpublished).

The density of many crops influences their ability to compete with weeds, the denser the crop the less competitive the weeds. In 13 recent ADAS experiments Sansome has attempted to study this aspect of competition in rape. The crop was sown at three densities, 50, 100 and 150 seeds/m^2 in 1988 and 89, and 30, 100 and 170/m^2 in 1990. These seed rates produced mean densities of 34, 61 and 81 rape plants/m^2 in the autumn (range 18 - 116 plants/m^2). Increased rape density decreased the density of weeds. Interim data are presented in a paper by Sansome (1989). The precise effect varied from site to site but on average there was a reduction in 0.78 weeds/m^2 for every increase of one rape plant/m^2 (range 0.14 - 1.70). Averaging over all trials there were 83, 68 and 57 weeds/m^2 at the three rape densities (34, 61, 81 plants/m^2). There was no indication that rape yields on the weed free plots were affected by rape density. For individual experiments, there were no clear relationships between weed density and yield increases on herbicide treated plots, compared to the untreated ones (Fig 10), nor was there an obvious interaction with crop density. Fig 10 shows that the majority of points on the graph (30 out of 39) lie above the 100% value, indicating benefits from weed control but these were not related to weed density. However, if the results for the experiments in each year are meaned there appears to be quite a good correlation between % yield increase due to weed control and rape density (Fig 11), higher densities resulting in less yield loss. These results tend to support those of Küst (1989) who demonstrated slightly less competition from volunteer barley at higher rape densities (see above). An experiment carried out at Long Ashton Research Station in 1989/90 with speedwell also showed that weeds were less competitive at high crop densities (Lutman, unpublished), but again the differences were small. High crop density reduces the competitive effects of weeds, although it may not influence seed yields in the absence of weeds.

Cleavers have not been widely studied, but it is clear that their smothering growth habit makes them a very competitive weed. Research in cereals would suggest that they were almost as competitive as wild oats (Wilson & Wright, 1990). A single experiment of my own showed very little competition from cleavers until mid summer, when the weed started to overtop the rape. Yields were not recorded.

<u>Timing of control of broad-leaved weeds</u> The previous section indicates that the yield benefits from the control of broad-leaved weeds tend to be much lower than those from the control of grass weeds. In many trials it has been difficult to record yield differences between treated and untreated plots and so the effects of early v late treatments have been largely ignored. The two experiments by Whytock (unpublished)

Fig 10

Effect of the Density of Broad-leaved Weeds on the Yield of Herbicide Treated (weed free) Rape expressed as a % of the Yields of the Untreated (weedy) Crops

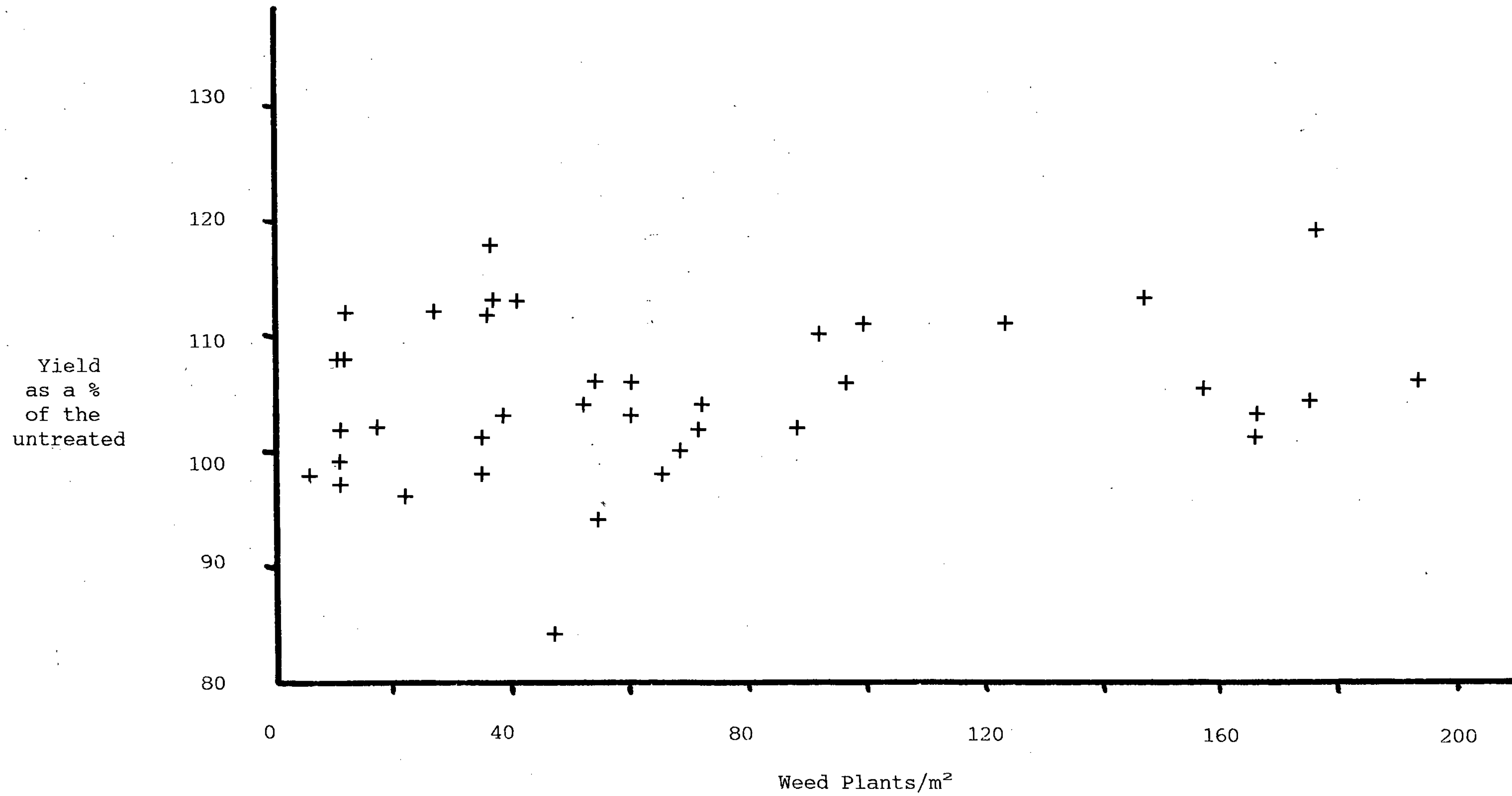
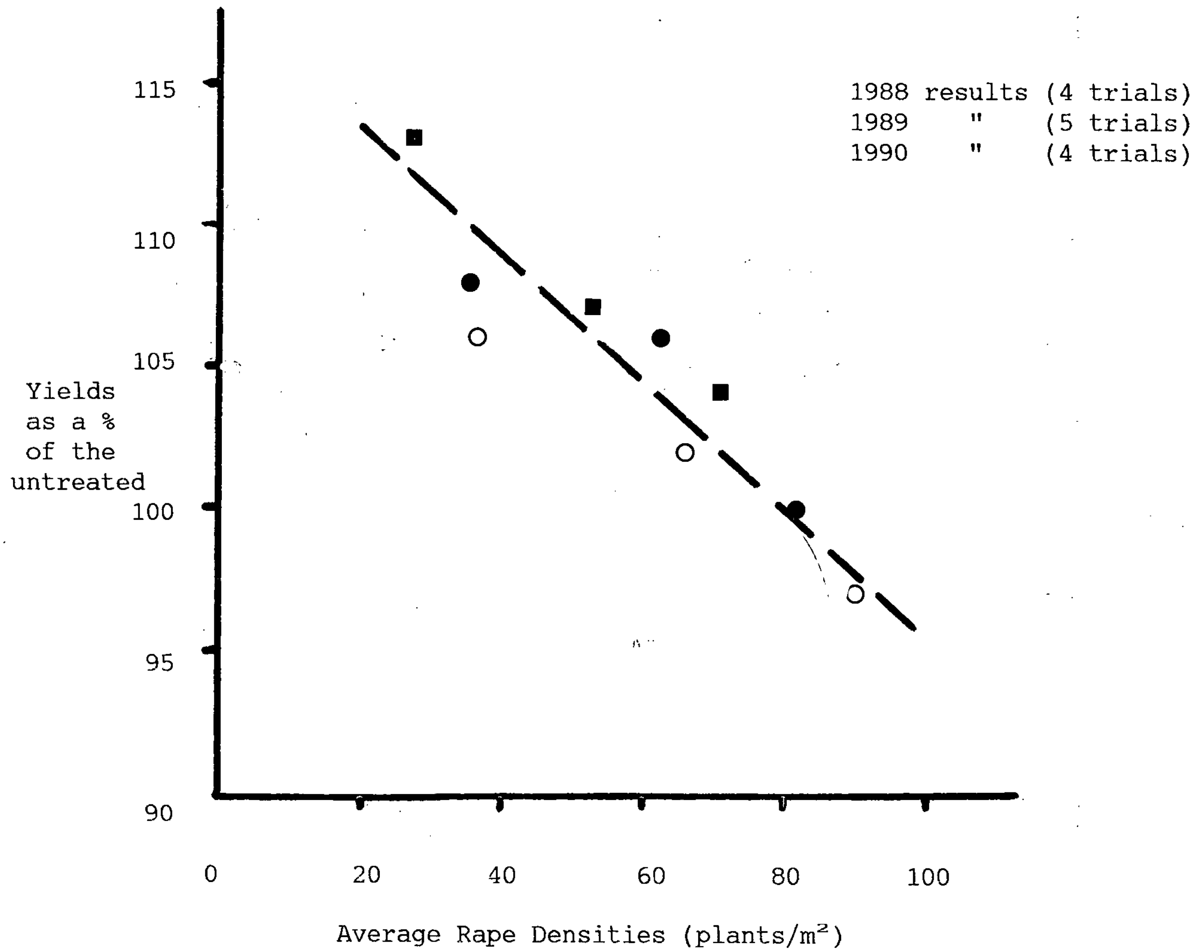


Fig 11

Relationship between Rape Density and the Average Yields of the Herbicide Treated (weed free) Plots expressed as % of the Untreated (weedy) Plots



in 1988/89 and 1989/90 both attempted to compare autumn v spring control of a mixed infestation of broad-leaved weeds. There was an effect from the time of removal of weeds on weed biomass in spring but no significant effect on rape weights in spring or on seed yield. Results from my own early work (Lutman, 1984) with natural mixed weed infestations followed a similar pattern. Plots treated pre-emergence or early post-emergence with herbicides tended to have a similar or slightly greater biomass of rape in the spring, compared to plots treated in January or February, but there were no detectable differences in seed yield.

In practice the timing of broad-leaved weed control is often controlled by the weed species present. With currently approved herbicides many species are only controlled pre-emergence or very early post-emergence. Control is not satisfactory once the weeds become established. This restriction does not apply to chickweed or mayweed but weeds such as shepherds purse (Capsella bursa-pastoris), field pansy and poppy (Papaver rhoeas) are much more susceptible to pre-emergence herbicides. New broad-spectrum herbicides are currently in development which will permit the later treatment of a wider range of weed species (see section 5.2.1.2).

3.2.3.3 General Overview

The preceding two sections have reviewed in some detail the relative effects of grass and broad-leaved weeds on the yields of oilseed rape. It is clear that grass weeds, particularly volunteer cereals can cause serious loss of yield, especially when the crop is late sown and uncompetitive. Tentative economic single year thresholds of approximately 100 volunteer barley plants/m^2 for crops sown at the end of August and 10 plants/m^2 for those sown in mid September are suggested. It must be remembered that weed germination is stimulated by cultivation and so a late-sown rape crop, where the cultivations were done just prior to drilling, or where a stale seedbed technique was employed, will have later germinating and less vigorous weeds as well as less vigorous rape. Consequently, weed competition will not increase as much as might be predicted from the reduction in rape vigour. There is some evidence from my own work that rape growth is more affected by the declining temperatures that occur in September than weeds. Klostermyer (1989) believed that rape and volunteer barley were similar in their competitive effects early in the autumn but after October the rape became more competitive.

Similar threshold values for broad-leaved weeds are not available because of the lack of research data, but it can be concluded that, in general, these weeds are less competitive than the grass weeds. The relative competitive indices calculated for winter cereals in the UK by Wilson & Wright (1990) do not concur with the values for oilseed rape calculated by Küst (1989). There is insufficient data from the UK to suggest thresholds for even the commoner broad-leaved weeds, with confidence, although Bowerman (1989) has proposed 40 plants/m^2 in the spring as a possible threshold for chickweed. This seems a little conservative, in the light of more recent experiments. It appears, however, that the very high competitive value given to chickweed in Germany is not appropriate for the UK. In order to provide a system for assessing the competitive effects of mixed infestations, especially of broad-leaved weeds, some indication of relative competitive abilities is needed.

Thresholds based on weed density are not very satisfactory for practical use for a number of reasons. Firstly, assessments of weeds based on plant counts are time consuming, particularly if the weed flora in the field is close to possible threshold values or is aggregated in patches. Secondly, data from the grass weed experiments and to a lesser extent from those with broad-leaved weeds, all demonstrate that weed number is poorly correlated with competitive effects. The grass weed research clearly shows the importance of crop vigour in determining the competitive effects of weeds. The model of Küst (1989) (Fig 12) which calculates the economic consequences of controlling/not controlling weeds, is primarily based on weed density and the relative competitive effects of the different species. This basic information is then modified by taking into account crop vigour and the relative time of emergence of the weeds. More recent work by Munzel (personal communication) in Göttingen, who has been validating this model, confirms that crop vigour is the overriding factor in determining the yield effects. The correction factors for crop vigour in the Küst model (0.8 - 2.0) are underestimating the crop's ability to compete with weeds.

Küst's programme also investigated the possibility of using crop and weed ground cover in the autumn to predict potential yield effects. This work was primarily aimed at volunteer cereals and has been considered in section 3.2.3.1. He suggested that the ground cover of crop and weed should be compared and proposes that the threshold values should be adjusted according to the date of sowing (and emergence) This type of assessment has a number of attractions: it is faster than counting weeds and preliminary conclusions are that it provides a more accurate estimate of likely yield effects. It is relatively simple to use with single species infestations, as with Küst's work with volunteer barley, but is more complex when attempting to assess the effects of mixed weed infestations. Dingebauer (1990) modified his weed percentage ground cover according to the proportion of strongly competitive weeds making up the weed flora.

There is a fundamental problem with oilseed rape in trying to predict from an assessment of the growth of crop and weed in the autumn, what will happen in the following summer. Even biomass measurements (plant dry weights) in spring tend to

<u>Fig 12</u>

<u>Threshold Model for Deciding on Weed Control in Winter Rape (after Küst, 1989)</u>

	BLACKGRASS	CHICKWEED	MAYWEED	DEAD NETTLE	FIELD PANSY	SHEPH PURSE	OTHERS
Quadrat number							
1							
2							
3							
4							
.							
.							
29							
30							
Total							
Number/m^2							
X competition index (% yield loss/weed)	0.08	0.3	0.05	0.03	0.03	0.03	0.03
TOTAL							

GRAND TOTAL [ ]

Quality of stand of the rape crop: very good = 0.5
good = 1
average = 1.2
poor = 2 X ___ [ ]

Rel. emergence time of rape and weeds: simultaneous = 1
weeds 10 days later = 0.6
weeds 20 days later = 0.3 X ___ [ ]

Final % yield loss from weeds [ ]

Expected yield dt/ha (0.1 t/ha)

Value of crop loss due to weeds

Cost of weed control (herbicide + application)

Comparison of yield loss and herbicide cost

NB When cleavers exceed 0.2 plants/m^2 and volunteer barley 20 plants/m^2, these weeds should be treated with a herbicide over-estimate, in many trials, the effects on yield (Klostermyer, 1989; Lutman, 1984; Lutman & Dixon, 1990; Whytock, unpublished). Where the proportion of crop dry weight to weed dry weight is high (ie there are few weeds), the prediction of yield effects is not difficult. Where the proportion is low the prediction is much less accurate and the risk of advising weed control when none is needed is quite high. In practice this error is more acceptable than advice not to spray resulting in loss of yield. Obviously weed control decisions in rape cannot be made in April, they have to be made in the previous autumn, but the April data do emphasize the difficulty of prediction. Predictions from relative dry weights in the autumn are prone to greater error. For example, rape and volunteer barley having a relative proportion of 1:5 based on dry weights in November only caused an 11% loss of yield in one experiment and in another a proportion of 1:4 caused a 39% loss (Lutman & Dixon, 1990). Despite this variability some progress on prediction should be possible, based on relative ground cover, provided it is accepted that there will be a certain level of error in the calculation that will increase the risk of predicting the need for treatment when final yields are not increased sufficiently to exceed the cost of the treatment.

Interactions with agronomic factors In the 1980s most crops were sown following stubble burning and minimum cultivation. Burning the cereal straw is an effective way of reducing viable cereal seeds and consequently the number of volunteers. With the imminent banning of straw burning it is likely that densities of volunteers will increase, especially if straw is incorporated by intensive tined cultivation and not by ploughing.

The vigour of the crop is clearly influenced by its date of drilling, provided there is adequate moisture to ensure speedy emergence and a close relationship between crop emergence and sowing date. An early sown crop whose emergence is delayed by drought will respond to weeds in the same way as a late sown one. As discussed in Section 3.2.3.2, crop density may also have some influence on weed competition, the higher the density the lower the competitive effect of the weeds. The fertility of the soil in the autumn will also affect crop and weed growth but there is little detailed information on, for example, the effects of autumn applications of NPK on weed competition in rape. It is well known that autumn nitrogen increases crop vigour and there is some debate as to the advantages/disadvantages of this. Some weeds (eg chickweed and cleavers (Galium aparine)) are known to be nitrophyllic and have been found to be more competitive at high nitrogen levels (Mahn, 1988). Few similar studies have been carried out in rape. Two of my own experiments investigated the effects of seedbed nitrogen on the competitive effects of volunteer barley (Lutman, 1989). Barley competition reduced rape growth in the autumn and nitrogen increased it, but nitrogen level had no effect on the balance of competition.

3.2.4. Spring oilseed rape

Spring oilseed rape, once established is a very vigorous crop and is much less sensitive to weed competition than non-competitive spring crops such as peas and beans. However, because of its short growing season, compared to the autumn-sown rape, its ability to compensate for inhibitions to growth in its establishment phase is much lower. Consequently, the limited research data on the spring crop would suggest that it is somewhat more sensitive than the autumn crop. Most weed competition studies on spring rape have been done in Canada, where spring rape is a major crop.

Two groups of workers in Canada have studied the competitive effects of volunteer cereals on spring rape. Both groups found that 20-30 cereal plants/m^2 reduced yields by at least 10% and in many experiments by 30-35%. (O'Donovan et al., 1989; Marshall et al., 1989). O'Donovan calculated an overall 'I' value (% yield loss/weed plant) of 1.19 for his six experiments, which is considerably higher than those calculated for winter rape in the UK. A third group in Canada also showed that barley was very competitive against spring rape when it emerged before the crop but it was less competitive when emerging 8 days after the crop (de St Remy & Vanden Born, 1989). Even so the less competitive late emerging barley still reduced rape yields by 35%. In contrast, experiments in Europe have shown a much lower sensitivity to weeds. Research in Denmark (Melander, 1990) indicates only 0.2% yield loss per couch shoot, much less than the cereal competition data from Canada. Similar experiments of my own in the dry summers of 1989 and 1990 showed little yield response from the competitive effects of oat densities as high as 50 plants/m^2. This disparity in the apparent competitiveness of weeds between the UK and Canada probably relates to climatic differences between the two countries. Canadian rape is grown under much hotter and drier conditions than UK rape experiences even in a dry summer. Consequently, competition for water is very important in Canada. Many Canadian crops are also grown at lower plant densities, thus increasing the potential for weed competition.

Canadian research also shows the broad-leaved weeds fat hen and charlock to be very competitive. Twenty charlock plants reduced yields by 19-36% and a similar number of fat hen plants reduced it by 20-25% (Blackshaw et al., 1987). Their work confirmed that the weeds exerted their competitive effects early in the life of the crop. Again research in Europe has demonstrated lower competitive effects. Jensen concluded from his work in Denmark that a similar density of charlock (20 plants/m^2) would reduce rape yields by 0.08 t/ha but the same density of other weeds would only reduce it by 0.038 t/ha. He re-interprets these data, concluding that the threshold for charlock is 30-35 plants/m^2 and 65-80 plants/m^2 for other species (Jensen, 1987). Gummesson (1985) in his review of weed control in spring rape in Sweden concludes that under good conditions weed control in spring rape can often be omitted, if the weed numbers are not too high. In Denmark mayweeds and charlock are considered to be the worst weeds and most crops are treated with herbicide (Bowerman pers. comm). In the UK grass weeds and volunteer cereals are usually less common in spring rape than they are in the winter crop. Consequently, the commoner species tend to be the less competitive broad-leaved weeds (see 2.2).

It is clear that a proportion of spring rape crops in the UK receive no herbicide because the growers believe, often correctly, that the weeds will be smothered by the crop.

3.2.5 Linseed

This crop is more sensitive to weed competition than oilseed rape, despite its greater plant density/m^2, because the individual plants are slow to establish and the final height and biomass of the crop is much less. Consequently, as is emphasised by Engelmann (1989) in his review of weeds in flax, this crop does not compete well in its early stages with the more aggressive spring emerging broad-leaved weeds such as chickweed. It is also vulnerable to tall-growing weeds such as fat hen, mayweeds, redshank and charlock, later in the season (Anon, 1983). Research in Canada, where this crop is grown extensively, has also shown that weed control is critical. But, it must be remembered that a drier climate is likely to exacerbate the competitive effects of weeds on linseed, as it does on rape. In 25 out 26 experiments reported by Friesen (1986) weed control increased seed yields, on average by 79%. More detailed studies of the effects of volunteer cereals on flax, demonstrated that 30 volunteer barley plants reduced flax yields by 50% and the same number of wheat plants reduced it by up to 67% (Friesen et al.; 1990). Their work suggested that linseed was twice as sensitive to competition from volunteer cereals as spring oilseed rape. Similar experiments in Scotland (Hack, unpublished) also confirmed that competition from volunteer barley at densities as low as 40 plants/m^2 significantly reduced both fibre and oil production. There is a lack of detailed information on the effects of weeds on linseed in the UK but Turner (1987), summarising a survey of 49 UK linseed crops, showed that crops containing weeds were rarely high yielding.

3.2.6 Sunflower

Once established, the sunflower is a very vigorous plant, producing a dense and relatively tall leaf canopy. Consequently, the main period when weed competition is important is from crop emergence until the plants have about 4 pairs of leaves. This conclusion is supported by research from the USA where Johnson (1971) showed that the crop needed to be kept weed free for 4-6 weeks after emergence and from France where CETIOM advises that the crop be kept weed free until it has 5 pairs of leaves. Although low densities or less competitive weeds may not need to be controlled, aggressive weeds cannot be ignored, as is shown by work in Italy by Covarelli & Tei (1984), which showed that even 14 charlock plants/m^2 could reduce sunflower yields by 12-22%. The same situation is likely to apply in England.

3.3 CROP CONTAMINATION

3.3.1 Oilseed Rape (winter and spring)

The presence of weeds in the crop at harvest provides the possibility for weed seeds and flower heads to contaminate the harvested rape seed. Little survey data exists for rape contamination. Jensen in surveys of spring rape seed in Denmark, started in 1976, found that seeds from the weed members of the Cruciferae, which contain oil impurities, initially reached 1% but in later years fell to 0.2% (Jensen, 1990). These figures are relatively low but the crops concerned could still incur extra cleaning costs. Nix (1990) quotes cleaning costs for cereals of £10/t and costs for rape would be similar. Rape seed with greater than 2% contamination will not be accepted for crushing. Some weed species pose more of a problem than others. Volunteer barley, for example is relatively easily removed but seeds of other smaller seeded species are more difficult, as their size is similar to rape seed. Cleavers and seeds of charlock (Sinapis arvensis) and runch (Raphanus raphanistrum) are particularly difficult to remove. Seeds of the latter two species pose an extra problem related to their glucosinolate content. Both belong to the Cruciferae, the same family as rape and as a consequence their seeds contain high quantities of glucosinolates. Their presence, like that of volunteer high glucosinolate rape plants, may increase the average glucosinolate level of the seed to such an extent that it is rejected (Diepenbrock & Lean, 1988). This will be particularly critical when the EC limit decreases from 35 to 20μM/g. Regnault & Adam (1989) quote 85μM/g for charlock in France but Booth (SAC, unpublished) and Sansome (unpublished) both quote approximately 150μM/g for this species and 134μM/g for hedge mustard (Sisymbrium officinale). Whytock also reported that the glucosinolate content varied with the sulphur status of the soil. Sansome calculates that 8% contamination from the charlock would increase the average glucosinolate level from 15μM/g on the clean rape to 25μM/g in the mixture. Similarly, a 2% contamination would increase the glucosinolate level to a little over 17%. Hence the presence of seeds of this weed in the harvested rape could affect the marketability of the seed, as it might result in the sample exceeding the EC glucosinolate limit. However, practical experience suggests that these weeds do not pose too much of a threat to the purity of rape seed, as in many years most of the plants would have shed the majority of their seeds before the rape was harvested.

3.3.2 Linseed and sunflower

Weeds pose the same seed contamination problems for linseed as they do for oilseed rape, except that the problems associated with glucosinolates are not of concern. In addition, some weed seeds such as cleavers and charlock are not so difficult to remove from linseed as they are from rape.

3.4 HARVESTING EFFICIENCY

3.4.1 Oilseed rape (winter and spring)

The presence of green weeds in the crop as it approaches harvest can affect harvesting efficiency. Patches of weeds can cause variable ripening, the weedy areas ripening later than the weed free ones, thus making decisions on the timing of swathing, desiccation and harvesting more difficult. If the crop is to be swathed the green material from the weeds will inhibit the subsequent drying of the crop and will delay harvest. Similarly, if it is to be direct combined the wet fleshy weed plants have the potential to clog the augers and will slow harvesting. These problems are particularly acute with cleavers and mayweeds. As a consequence of the effects of cleavers on harvesting efficiency and crop contamination the Küst (1989) model includes a single threshold value of 0.2 plants/m^2 in his model.

Data from winter cereal experiments demonstrated that grain moisture was higher, there was more matter other than grain (MOG) passing through the combine and separation losses were greater in weedy crops (Sheppard et al., 1989). However Hallgren (1990) points out that modern combines have a high ability to harvest crops containing considerable amounts of weed without loss of efficiency. He found with barley that only when the weed content of the harvested material exceeded 50%, equivalent in his experiments to 2 kg/m^2, were there appreciable effects on seed loss and combine speed. There is no equivalent research data available for oilseed rape, but the same can be expected to occur in oilseed crops. The use of diquat or glyphosate to desiccate the crop will reduce weed effects on harvesting, but throughput of matter other than grain will still be higher from weedy crops than from weed free ones. The associated risks of seed loss from the combine will also be greater. The basic thesis that the presence of weeds in a crop at harvest is likely to adversely affect harvesting efficiency and increase drying costs is widely accepted. It is not clear when this effect is critical and at what biomass/density the effects of the weeds become 'significant'.

3.4.2 Linseed and sunflower

Uniform ripening is critical for the successful harvesting of linseed, so the presence of patches of weeds in the crop will be unwelcome because the weedy crop will mature later than the weed free. Even if the crop harvest is delayed, threshing of the weedy areas may be more difficult. These problems are alleviated to some extent by the use of a desiccant pre-harvest. Weeds may also increase lodging in the crop, again making harvest more difficult.

The taller growth of sunflower and the normal use of a desiccant in the UK to bring the date of harvest forward, makes the presence of weeds at harvest not too serious a problem for this crop. However, if weeds cause the crop to lodge or are particularly tall (eg thistles, hedge mustard) weeds can cause problems, as they do in oilseed rape.

3.5 EFFECTS OF WEEDS ON PESTS AND DISEASES

3.5.1 Oilseed rape (winter and spring)

Weeds can be hosts of rape pathogenic fungi and can modify the microclimate in favour of the pathogens. A number of research workers have reported that many rape diseases will also infect a wide range of other species, including common weeds (Table 4). The most frequently infected species being those in the Cruciferae, such as runch (Raphanus raphanistrum), charlock (Sinapis arvensis) and shepherds purse (Capsella bursa-pastoris), which are closely related to rape (Kayser & Heitefuss, 1990; Regnault & Adam, 1989; Saur & Löcher, 1986). The host range varies, depending on the disease, the obligate parasites such as downy mildew (Peronospora parasitica) having a narrower range than the facultative types such as grey mould (Botrytis cinerea). The potential for weeds to become important foci for disease will be greater for polycyclic diseases (several generations/year) than for monocyclic ones. However, although diseases can occur on weeds present in rape fields, there is some doubt as to their importance as sources of infection for the crop. Lucas (pers comm) has demonstrated that pathotypes of downy mildew found on one species of Brassica are not very virulent on other closely related species. Therefore, it is unlikely the pathotypes on Crucifer weeds would seriously infect the rape crop. Similarly, although Kayser & Heitefuss (1990) reported that sclerotia of stem rot (Sclerotinia sclerotiorum) were present in mayweeds, cleavers and shepherds purse, the sclerotia in these species were much smaller than those found in rape plants. Consequently, as sclerotia size would be related to ability to infect other plants, the weeds were of lesser importance than infected rape plants. An isolate of Verticillium dahliae from rape has been found to infect a range of broad-leaved weeds but only caused symptoms on rape and red dead-nettle (Lamium purpureum)

Table 4

Host Ranges of Oilseed Rape Diseases

Diseases	Hosts
Sclerotinia sclerotiorum (stem rot)	very wide host range
Phoma lingam (leaf spot/canker)	Cruciferae
Verticillium dahliae (wilt disease)	very wide host range
Alternaria brassicae (dark leaf/pod spot)	Cruciferae
Pyrenopeziza brassica (light leaf spot) (Cylindrosporium concentricum)	Brassica
Botrytis cinerea (grey mould)	very wide host range
Peronospora parasitica (downy mildew)	Cruciferae
Erysiphe cruciferarum (powdery mildew)	Cruciferae
Pseudocercosporella capsellae (white leaf spot)	Cruciferae

(Kayser & Heitefuss, 1990). The importance of weeds as a source of this disease, which is common in Germany, is not clear.

The presence of weeds in the rape crop will increase the humidity at the base of the crop. This will favour the pathogenicity of most of the fungi that can infect rape. For example, there is some evidence from Germany that rape infection with grey mould was more severe in plots containing chickweed than in weed free ones (Küst et al., 1988). Similarly very humid conditions will favour attack by slugs. This, combined with the weaker growth of rape suffering from dense weed competition, especially from volunteer cereals, can result in severe loss of crop plants. Conversely, Schwerin (1989) has reported that increasing weed cover in winter rape increases the numbers of beneficial ground beetles.

Weeds are also reported to be infected with diseases that, so far, have not been found in rape crops. For example, Albugo candida is known to infect a range of weed species including shepherds purse (Regnault & Adam, 1989). Although it has not yet been found to infect rape the potential for crop infection in future from wild Cruciferae cannot be ignored. Some weed species, especially those in the Cruciferae have an effect on insects. It is believed that pollen beetle, for example, is attracted to such species but it is not yet clear as to the significance of their presence around the edges of rape fields. Preliminary research is in progress at Rothamsted Experimental Station (Blight, pers. comm.)

The presence of volunteer cereals in rape crops may not increase the threat of disease attack on the rape. Indeed the work of Kayser & Heitefuss (1990) suggests that the presence of volunteer cereals decreased disease and pest levels in the rape. But, the volunteers may pose a hazard to neighbouring crops of cereals. For example, there is some evidence that these plants increase the risk of infection of neighbouring barley crops by harbouring aphids infected with barley yellow dwarf virus. The aphids may not migrate directly from the volunteers to immediately adjacent barley crops, as a hedge or ditch minimises aphid transfer, but will increase the source of inoculum for all crops in the neighbouring area.

3.5.2 Linseed and sunflower

Little is known in the UK as to the importance of weeds in relation to pests and diseases in these two crops. Both crops can be attacked by Sclerotinia, so the presence of weeds infected with this disease may be important (see 3.5.1). Similarly, both crops can be infected with Botrytis, but the significance of weeds as a source of this disease is unknown.

3.6 LONGER TERM EFFECTS OF WEEDS ON SUBSEQUENT CROPS

The weed control strategies used in oilseed rape and other oilseed crops can have repercussions for subsequent crops and so should be considered in relation to the whole rotation. Again because of the small area of spring rape, linseed and sunflower, longer term effects are only of significance for winter rape. For example, low infestations of grass weeds may not justify treatment in the rape crop, if their effects on rape yields are the sole criterion for treatment, but may be justified on the basis of minimising weed levels in subsequent cereals, where control is more difficult. The importance of seed return from untreated weeds in the rape crop in relation to weed infestations in subsequent crops is unknown. Some research is in progress in winter cereals in the UK and it is already clear that it is not possible to generalise over all weed species. For 'long cycle' species with a high degree of dormancy, seed return in one year has little effect on weed plant numbers in the next. Seed return is much more important for 'short cycle' weeds with less dormancy (Cussans, 1991). Wahmhoff (1990a), also studying weed thresholds in cereals, has found little effect of seed return from weeds on the longer term weed population in 35 threshold experiments. In contrast, anecdotal evidence with the 'long cycle' weed, common poppy (Papaver rhoeas) indicates that failure to control this weed in one rape crop leads to higher densities in the next rape crop, even if complete control is achieved in the intervening cereals. Effects of weed seed return cannot be ignored but further work is needed, not only in rape but also in other crops, to determine more accurately the significance of seed return on the need for weed control.

4. HERBICIDE USAGE

4.1 WINTER OILSEED RAPE

The most recent information on herbicide usage in oilseed rape in England and Wales comes from the 1988 MAFF survey (Davis et al., 1990) of 592 farms. Their survey of 249 rape fields showed that all crops were treated with herbicide and that on average each crop was treated 2.1 times, but it is not clear whether this value includes pre-harvest desiccation. The latest figures from the British Agrochemicals Association (Anon, 1990) indicate that each rape crop received 1.74 treatments. The discrepancy may be due to the exclusion/inclusion of desiccants but it is clear that all farmers are treating their fields with herbicide. According to the MAFF survey the most widely used herbicides were propyzamide (average price £39/ha), selective grass weed herbicides (predominantly fluazifop-p-butyl (£34/ha)), benazolin + clopyralid (£26/ha) and metazachlor (£45/ha). It is difficult to be precise about herbicide costs as the on farm costs will depend on individual merchant's prices and the actual doses used. In the above examples I have assumed those recommended by the manufacturers. As many crops have received two products this suggests that they are being treated separately for both grass and broad-leaved weeds. At a conservative cost of £30/ha/treatment (including application), 1.7 treatments/ha and a national area of 390,000 ha, herbicides for weed control in oilseed rape cost British farming almost £20 million in 1990. Even a modest reduction in herbicide use would have an appreciable effect on national expenditure on weed control and on the pesticide load on the environment. This could be achieved by using cheaper products, reducing doses, or not spraying fields or parts of fields with low weed populations.

4.2 SPRING-SOWN OILSEED CROPS

Although these minor oilseed crops have only a limited number of approved herbicides they are covered by the FEPA 'off label' arrangements, which for an interim period following the introduction of the Food & Environment Protection Act (FEPA) permit the use of some herbicides approved for oilseed rape on other minor oilseeds. Only those approved from spring use on rape, can be used on the other spring-sown oilseed crops. As these recommendations are at the users risk there is no guarantee that they will control the weeds, nor that they are safe to the crop.

4.2.1 Spring rape

Herbicide usage surveys in rape tend to amalgamate winter and spring rape and as the area sown to the spring crop is only approximately 5% of the winter area it is not possible to separate uses in the spring crop (Davis et al., 1990). The number of herbicides fully approved for this crop is more limited than it is for the winter one and the most widely used products are thought to be benazolin + clopyralid and trifluralin.

4.2.2 Linseed

According to the 1988 MAFF survey all linseed crops are treated with herbicides. There are only eight products approved directly for this crop but even so most crops are treated with two products. The most widely used are bromoxynil ± clopyralid and bentazone. In 1988 metsulfuron-methyl was also used extensively. Currently, this is **not** approved, and so cannot be used, although the manufacturer hopes to obtain approval by 1992.

4.2.3 Sunflower

Under the provisional FEPA arrangements appropriate oilseed rape herbicides can be used on sunflower. There is also direct approval for trifluralin and pendimethalin. These two, together with linuron, which is not currently approved, have formed the basis of weed control in this crop.

5. WEED CONTROL

If the control of weeds is required in an oilseed crop, either to prevent yield loss or some other adverse effect from the weeds, the farmer has to decide on the treatments to use. These may be based on cultural control and/or on herbicides.

5.1 CULTURAL CONTROL

5.1.1 Winter oilseed rape

Pre-sowing cultivations can have a marked effect on the weed population that occurs in the rape crop. This is particularly important for volunteer cereals. Ploughing after the harvest of the previous crop of cereals and before sowing the rape, will minimise infestations of volunteer barley or wheat. However, it will also reduce soil moisture and jeopardise the early establishment of the rape crop. The farmer has to balance the advantages of reducing volunteer cereal densities with the disadvantage of possibly poor and late crop establishment. Light non-inversion cultivations will preserve moisture but will leave many cereal seeds on the soil surface. Other weed species will also be influenced by cultivations. Short cycle weeds (eg cleavers, black-grass) with little dormancy will be most favoured by non-inversion cultivations, whilst long cycle weeds (eg field pansy, common poppy) will be favoured by ploughing. In the past stubble burning had a marked effect on weed seed survival, reducing weed numbers, volunteer cereals in particular. As stubble burning will not be permitted after 1992, the method of straw incorporation will influence weed density. If the straw is incorporated by ploughing volunteer numbers will be low, as discussed above, but if straw is shallowly incorporated with rotary cultivation or tines and discs, weed numbers are likely to be higher.

Using a stale seed-bed technique can cause a flush of weeds to germinate prior to drilling, provided that there is sufficient time between harvest and sowing and there is adequate rain to stimulate seed germination. The emerged weeds can be killed with a desiccant herbicide pre-sowing. As rainfall in August, in recent years, has been uncommon the benefits of preparing a seed bed 10 -14 days pre-sowing have been small. On balance early establishment of the crop is probably of greater advantage than delaying drilling to minimise weed populations.

5.1.2 Spring oilseed crops (rape, linseed and sunflower)

Stale seedbed techniques also play a part in minimising the number of weeds appearing in these spring crops. It is probably most appropriate for the later sown sunflower than it is for rape where the delay in drilling required for the stale seedbed system to work may cause a greater loss of yield than the weeds the technique was used to control. However, it must be remembered that if drilling is delayed until conditions are warmer, crop emergence and establishment will be faster and hence crop competition with weeds will be greater. This is true for all these crops but is particularly well shown by sunflower. For example, crops sown in late March reached full emergence in 20-30 days whereas those sown in early May took 7-12 days (Dixon & Lutman, 1991). The establishment of linseed also tends to be quicker and more even in the warmer conditions of April, than it is from sowings in March (Turner, pers comm.). Even establishment simplifies the timing of herbicide treatments. Steerage hoeing is used in France for weed control in sunflower, the wide 60-75 cm rows used with this crop, permitting such operations. Hoeing for weed control in rape and linseed is not so easy, because of the narrower rows, but some 'organic' growers are using tractor hoeing for weed control. Technical improvements to hoes and other mechanical weeders in Denmark and Germany has resulted in less crop damage and acceptable levels of weed control (Parish, 1990). The weed control brush developed in Denmark is of particular interest. For hoeing to be successful it must be done when the soil surface is dry.

5.2 WEED CONTROL WITH HERBICIDES

The standard method of controlling weeds in oilseed crops is with herbicides, except in 'organic' crops. Most crops receive one, if not two, treatments, as discussed in Section 4. A range of products is available, particularly for winter oilseed rape, but the spring crops are less well served by the agrochemical industry. Weed control is not always needed, as discussed in Section 3, but in many circumstances a herbicide or herbicides will be required. In this section I will not attempt to outline the advantages and disadvantages of competing products but will attempt to highlight those areas where control of certain species is impossible or very difficult, and where other problems exist.

5.2.1 Winter Oilseed Rape

5.2.1.1 Grass weeds

A range of herbicides has become available to the rape grower in recent years for the control of volunteer cereals and other grass weeds. All of these new 'graminicides', such as fluazifop-p-butyl, along with the older propyzamide are used post-emergence, giving the farmer the opportunity to assess the severity of the weed problem prior to application. They have superseded the older herbicides TCA and dalapon which were less effective and caused a marked degree of crop damage (Lutman, 1985). The graminicides are very effective on all annual grass weeds, provided they have emerged. The main exception is annual meadow-grass, which is only well controlled when established, by propyzamide and carbetamide. Propyzamide is mainly soil-acting and so its performance can be adversely affected by soil conditions. Soils with high levels of adsorptive burnt straw residues (high Kd) can inactivate this herbicide in the same way they inactivate isoproturon and other soil-acting cereal herbicides (Moss, 1985). In general, there are no serious weed control problems relating to grass weeds, provided users remember that annual meadow-grass is not controlled by the graminicides.

5.2.1.2 Broad-leaved weeds

The control of broad-leaved weeds in rape is less straight-forward than the control of grasses. There is only a limited number of herbicides available. The most widely used herbicide, propyzamide, only controls a small range of weed species. A number of common species (eg common poppy, cut-leaved crane's bill (Geranium dissectum)) are only well controlled with currently available products that are applied pre-emergence or very early post-emergence. The farmer needs to know if these species are present prior to sowing so that he can make the correct decision on control before the weeds are too large. Two products based on mixtures of benazolin, dimefuron and clopyralid are being developed and these two should improve the weed spectrum of the truly post-emergence herbicides (King & Turner, 1989; Mayes et al., 1989). Both control a range of species not well controlled by propyzamide or by benazolin and clopyralid alone. Neither are yet available to UK farmers although the manufacturers have applied for approval.

Some species, particularly those belonging to the Cruciferae (closely related to rape), such as charlock and wild radish (Raphanus raphanistrum), are difficult if not impossible to control in oilseed rape, even if the two products mentioned above are included. Charlock is only susceptible to high rates of benazolin + clopyralid and to cyanazine, and wild radish is only controlled by cyanazine. Even these herbicides give unreliable control. The pre-harvest weed survey by Froud-Williams & Chancellor (1987) also found weeds belonging to the Umbelliferae (eg hemlock (Conium maculatum)) to be present in rape fields. There are no recommended herbicides for this and related species. Fortunately, although they seem to be increasing, they are not yet common in rape. Prickly sow-thistle (Sonchus asper) which was also quite common in the survey is a very aggressive weed, although it tends to emerge late in the season, and because of this late emergence is difficult to control. Field pansy (Viola arvensis), a very common weed is also difficult to control but because of small size and low competitive index usually does not cause serious problems.

The control of cleavers in rape is a major problem. None of the currently available herbicides will give reliable control, although metazachlor, high rates of benazolin + clopyralid and pyridate all have some effect. In three ADAS trials a mixture of benazolin + clopyralid and pyridate gave the best control, but even with this mixture control varied from only 63% to 88% and some crop damage was noted (Bowerman, pers comm.). As this tank mixture is not supported by either manufacturer it is not 'Approved' and so cannot be used. Pyridate is probably the most effective herbicide that is currently available but its performance is notoriously variable, sometimes giving good control, sometimes causing crop damage and on other occasions giving poor control. It is clear that as this is a contact acting herbicide good cover of the cleavers with the herbicide is essential. So if the rape leaves are covering the cleavers control will be poor. Activity is also favoured by warm conditions. The mixtures of dimefuron, benazolin and clopyralid appear from the manufacturer's data to offer the potential for improved control but these herbicides are not yet available. The herbicide quinmerac (BAS 518) is also being developed for cleaver control (Nuyken et al., 1985) but it will be at least three years before it might become available. Further research is needed to identify those environmental and biological factors that will maximise the performance of current herbicides against this weed.

Many rape herbicides are expensive so there is interest in the use of cheaper products or lower doses to minimise weed control costs, particularly as the evidence for yield loss from many populations of broad-leaved weeds is poor. The cheaper herbicides trifluralin and cyanazine have been studied by ADAS and SAC. Both can be used with success but both have drawbacks. Trifluralin should be incorporated for optimum activity, a time consuming operation, and can cause crop thinning (Davies et al., 1989). Cyanazine has the advantage of controlling charlock (Sinapis arvensis) but its crop safety is questionable (Ickeringill, 1985; Bowerman, 1989), as it can cause severe scorch to poorly waxed rape leaves.

5.2.1.3 Low doses of herbicides for broad-leaved weed control

Because of the lack of yield benefits seen from the control of broad-leaved weeds, as described in Section 3.2.3.2, there has been considerable interest in recent years in the development of cheaper alternatives to the standard herbicide treatments. These studies have involved cheaper products and lower doses of more expensive ones. The problems associated with the use of cheaper herbicides have been briefly described above and as a consequence most interest has focused on the use of low rates of the more expensive products. The research programmes have concentrated on metazachlor, as this herbicide seems to have a shallow dose response curve and controls a wide range of weed species. Davies et al. (1989) and Bowerman (1989) have shown that even very low doses, less than 40% of the recommended dose, can give acceptable levels of weed control (Table 5). It must be remembered that at these low doses the risks of failure due to adverse

Table 5

Percentage control of chickweed and other broad-leaved weeds by low rates of metazochlor

(Data from Davies et al., 1989; Bowerman, 1989)

Site		Weed Species	Dose of metazachlor (kg/ha a.i)		
			0.50	0.75	1.25*
Davies	1986	common chickweed	90	95	100
	1988i	"	96	98	98
	1988ii	"	94	96	98
Bowerman	11	"	96	97	100
	12	"	71	80	90
	13	"	**16**	53	62
	15	"	97	97	100
	16	"	100	97	88
	18	"	75	99	95
	20	"	66	79	89
	21	"	67	92	96
	22	"	97	85	100
	11	field poppy	**0**	58	50
	17	"	91	91	82
	16	cleavers	44	44	72
	12	red dead-nettle	**12**	73	64
	16	speedwells	64	67	96
	17	"	65	77	100
	12	mayweeds	95	100	96
	21	"	97	100	99

* = full recommended rate

climatic or soil conditions are greater and some weed species are more (or less) sensitive to a particular herbicide. The data for metazachlor in Table 5 clearly exemplifies these two points. Chickweed is well controlled by low doses, at 11 of the 12 sites. Poppy and red dead-nettle are less sensitive and so control declines at lower doses. If the weed population is low and uncompetitive poor control is probably of minor importance, as the main aim of the treatment may not be to maintain yields but to reduce seed return. This can be achieved by suppressing the weeds rather than by completely killing them. Lower doses of other herbicides (eg benazolin + clopyralid, cyanazine) have also been studied with the aim of reducing the cost of treatment and/or the risk of crop damage. Some progress has been made but it is not yet clear how much weed suppression is needed to ensure that the weeds do not affect yields and that the competitive effect of the crop minimises seed return. Nor is it clear how to predict good/poor activity from the herbicides.

5.2.2 Spring oilseed rape

The weed problems arising in this crop tend to stem from the lack of herbicide products. If broad-leaved weed problems are thought to be serious the crop should be treated with a broad spectrum pre-emergence herbicide such as trifluralin or propachlor, because if this treatment is omitted the later control of some species such as fat hen and knotgrass may be difficult. Only clopyralid ± benazolin are available for post-emergence treatment of broad-leaved weeds and these only control a narrow range of species, admittedly including chickweed and mayweeds.

5.2.3 Linseed

There is only a very limited range of products recommended specifically for linseed, although under the interim FEPA arrangements it is possible to use some of those recommended for other oilseed crops (ie oilseed rape). Three problems come to the fore when discussing weed control in this crop. Firstly, there are difficulties in controlling some weed species because of the small range of herbicides available, secondly the crop is easily damaged by herbicides and thirdly the time available for the application of post-emergence products is limited.

Crop damage from the pre-emergence herbicides trifluralin and linuron, has not been reported as serious, although some crop thinning can occur (Davies & Richards, 1984; Dover et al., 1987; Turner, 1987). However, because of perceived risks of crop damage and the critical importance of good crop establishment, these herbicides are not widely used. The standard post-emergence treatments of bromoxynil/clopyralid + bentazone is not reported to cause high levels of damage but it is not without crop effects. Turner (1987) states that crop damage increases as the dose of bromoxynil/clopyralid increases, whereas price increases most noticeably with the increase in bentazone. Where weeds are small and species are particularly susceptible, lower than recommended rates of bromoxynil/clopyralid will minimise the risk of crop damage, whilst maintaining weed control. The other post-emergence herbicide, MCPA, is more damaging (Dover et al., 1987). Although both the pre- and post-emergence herbicides can cause visual symptoms of damage this has not always been reflected in lower yields. This is not unusual for such studies as in many crops foliar damage is not always converted into detectable yield loss. There has also been considerable interest in the use of metsulfuron-methyl in this crop. Crop damage can occur, but early applications (crop 30 mm high) seemed not to affect yields, although flowering and maturity was sometimes delayed. Later applications (crop 150 mm high) had a greater effect on yields, although damage symptoms were less (Dover et al., 1987; Davies, 1987b).

The standard bromoxynil/clopyralid + bentazone controls quite a range of weed species, although each herbicide on its own only controls a limited number. The mixture is weak on several species including speedwells, knotgrass, charlock and field pansy and will only control these when the plants are very small. Improvement in the weed spectrum by the addition of MCPA is not really practicable because of the increased risk of crop damage. The currently unapproved metsulfuron has a wider weed spectrum than the currently available products (and is cheaper), but gives no control of cleavers or fumitory (Fumaria officinalis). The selective graminicides, (eg sethoxydim) will give good control of the grass weeds such as wild oats, and triallate, which also controls wild oats, or trifluralin will control annual meadow-grass. If both grass and broad-leaved weeds are present the timing of the post-emergence sequence can be difficult. Tank mixtures are not approved and as at least seven days must lapse between treatments to minimise crop damage, rapid growth of the linseed may take it beyond the safe growth stage for treatment before the second of the two treatments can be applied (Turner, pers comm.).

5.2.4 Sunflowers

Broad-leaved weed control in sunflowers depends almost entirely on pre-emergence pendimethalin or pre-plant, incorporated trifluralin and so is likely to be less reliable in dry conditions. However, as the crop is quite competitive, poor weed control is seldom disastrous. Late emerging species, such as black nightshade, which tend not to be well controlled by pre-emergence treatments can become very large in uneven, gappy crops and may hinder harvest as well as affecting crop growth. Good rapid crop establishment is an important basis for good weed control. Grass weeds can be controlled, under the interim FEPA agreements, by some of the post-emergence graminicides.

6. VOLUNTEER OILSEED RAPE

6.1 THE PROBLEM

As the area sown with oilseed rape has increased rape volunteers have become an increasing problem. Cussans (1978) estimated that 0.1 - 0.5 t/ha of rape seed may be lost at harvest. These figures are supported by more recent studies of harvest losses reported by Bowerman (1984) who concluded that crop losses could be up to 400 kg/ha. It has been speculated that under extremely adverse harvesting conditions losses can be in excess of 1 t/ha. Comparison of combine harvested and hand harvested yields on experiments at Rothamsted Experimental Station between 1985 and 1989 showed that harvesting losses, reflected in the lower yields of the combine harvested plots, varied from less than 0.1 t/ha to 1.3 t/ha, in 1985 when harvest was delayed by wind and rain (Leach, pers comm). Bowerman's studies suggested that most losses occurred at the cutter bar, or indeed before the combine entered the field, and losses from the back of the harvester were relatively small. Consequently, improvement in harvester design to minimise losses would have little effect on the numbers of volunteers. At an approximate 1000 seed weight of 5g, the loss of 0.5 t/ha of rape seed would result in the presence of 10,000 seeds/m^2 on the soil surface after harvest. This population of seeds will result in the presence of large numbers of seedlings in the next autumn, most of which can be controlled culturally or with herbicides. Although many of the seeds germinate, are infected with disease or are predated it is clear that a percentage survive, particularly if the rape stubble is ploughed and the rape seeds buried. These surviving seeds form the basis of the longer term problems caused by volunteer rape. Data from the surveys of sugar beet fields carried out by British Sugar in 1989 and 1990 shows that 7-9% of beet crops were infested with volunteer rape. If these values are extrapolated to other arable crops, it follows that in the region of 400,000 ha of arable land is infested with volunteer rape.

6.2 BIOLOGY OF VOLUNTEER RAPE

Burial experiments reported by Garrett & Orson (1989) showed that vigorous, competitive rape plants emerged from seed sown down to 7.5 cm. Some emergence occurred from 10 cm but the plants were not competitive. A confirmatory experiment by Lutman & Risiott (unpublished) indicated that emergence declined at depths greater than 5 cm but a small percentage of seedlings emerged from 9 and even 11 cm. Excavation of the pots showed that a proportion of the seeds had germinated at these deeper depths but had not reached the soil surface. Some seeds had not germinated and when washed and sieved from the soil, were found to be dead and not dormant. Further work is needed to clarify the reasons for the persistence of rape seed.

Anecdotal evidence suggests that rape seed can persist in the soil for at least 5 years. It appears that persistence is longest if the rape seed is ploughed in after harvest and then left undisturbed for several years. If 10,000 seeds/m^2 are present on the soil surface after rape harvest it does not require a very high percentage survival to cause substantial numbers of seedlings to emerge even 5 years after the rape crop.

6.3 CONTROL

Improved combine design to reduce the amount of seed left in the field may help to reduce the problem but, as discussed in section 6.1, this would have no effect on seed shed prior to harvest, as a result of wind-induced pod shatter. In exposed areas swathing is favoured over desiccation and direct combining, in order to minimise seed shedding but even with swathed crops seed shedding prior to harvest can be appreciable. The breeding of rape varieties with more leathery, less shatter-prone, pods would also help to minimise the problem but breeders are currently more concerned with glucosinolate levels and yields than they are with other attributes of the rape plant. Experiments with the pod sealant di-1-p-menthene also failed to reduce harvest losses (Bowerman, 1984).

6.3.1 Cultural control

Ploughing which will bury most seeds too deep for successful emergence is an effective way of eliminating the problem for the first crop after the rape. However, this may not be the most appropriate strategy in the longer term as it may maximise persistence, as discussed in paragraph 6.2. Harrowing the rape stubble will kill a proportion of seedlings and will maximise germination in the autumn. Unless the rape crop is to be followed by another broad-leaved crop where control of rape is difficult, it would probably be a better strategy to not plough and leave the rape seed on the soil surface to encourage the maximum percentage to germinate so that it can be killed by seedbed cultivations (or with a herbicide, see below). This suggestion may conflict with other agronomic advise; for example, stubbles must be ploughed after the use of propyzamide to prevent residue damage to following crops.

The propensity of the seedlings to emerge in several flushes means that seed bed cultivations (or herbicide treatments) may have to be repeated several times.

6.3.2 Control with herbicides

Prior to crop emergence a total desiccant herbicide such as paraquat, glyphosate or glufosinate can be used successfully to control the emerged seedlings. Once the crop is emerged a selective herbicide must be used. This poses no problem if the following crop is a cereal, as there is a range of alternative products available. The problems arise when the rape appears in another broad-leaved crop. There is only a limited range of products available for rape control in peas, beans, linseed, potatoes and sugar beet (Table 6). In addition, even the 'effective' post-emergence herbicides, such as bentazone, are able to kill only small rape plants and the appearance of seedlings in flushes may necessitate expensive re-treatment. It is clearly not possible to control rape within rape, so once emerged in a rape crop the volunteers cannot be eliminated. Their potential effects on rape seed quality discussed above (3.3.1), make it essential that the persistence of this weed is minimised, so that the potential for it to occur in the next rape crop is very low.

Table 6

Effective herbicides for the control of volunteer oilseed rape

Crop	Herbicides
Cereals	various
Peas	pendimethalin; bentazone/MCPB + cyanazine
Beans	bentazone
Linseed	bentazone
Potatoes	metribuzin
Sugar beet	lenacil sequenced with phenmedipham phenmedipham + metamitron phenmedipham + ethofumesate

7. CONCLUSIONS

7.1 GENERAL

Weeds pose a continuing problem to the successful and economic cultivation of oil crops. It is rare for weeds to cause a complete crop failure in the way that can happen with pests and diseases but to use a medical metaphor the effects of weeds are 'chronic' rather than 'acute'. They are always present to a greater or lesser extent and always have the potential to reduce crop yields or cause other adverse effects, as has been outlined in the previous sections. It must also be remembered that approximately 50% of all arable crop protection costs are attributable to herbicides so the potential for cost saving is considerable. Weeds and their control fall into two contrasting groups. There are those weeds where control is very difficult and a high level of control is essential, as exemplified by the control of brome or black-grass in cereals and cleavers in rape, and there are those weeds that are not so damaging and where control is not too difficult. In the latter case the aim of control strategies should be to minimise herbicide use. Most of the situations experienced in oilseed crops fall into the second category. It is only linseed that is not very competitive, winter and spring rape and sunflowers, once established, are strong competitors and will suppress most weed species. Thus, weed control is only needed to assist the crop to suppress the weeds.

There are two main weed control problems currently facing those growing oilseed crops. As outlined above, in winter rape there are herbicides available for the control of most weed species and the most pressing problem is to decide when it is economic to control them and when it is not. The only exceptions relate to the control of cleavers and some of the Crucifer weeds, where there remains a need for more effective herbicides. For the smaller acreage spring oil crops the main problems relate to the lack of herbicides, although guidance on when weeds need control is still required. As there are few recommended herbicides, the farmer has little choice of alternative products and it is extremely difficult to successfully control some weed species. This problem is particularly acute with linseed. Consequently, there is a need to investigate the selectivity and safety of other herbicides that might be appropriate for these crops. This work is unlikely to be done by the chemical manufacturer alone, because of the costs of registration and the small return from small acreage crops like linseed or even spring rape. In addition, it must be mentioned that it is likely the range of products available to all crops will decrease as a result of MAFF reviews of current pesticides. Some currently available products will be withdrawn because the manufacturers will not be willing to undertake the generation of new data to meet more stringent modern registration requirements. Further, it is also likely that herbicides found frequently in groundwater, such as chlorotoluron, simazine and mecoprop will be withdrawn, or usage will be restricted to certain times of the year. Consequently, there is a need to ensure that any potentially useful herbicides for the minor oilseed crops are thoroughly investigated and approvals sought where appropriate. In horticultural crops the growers are supporting the Horticultural Development Council, which is able to organise collaborative research with ADAS, AFRC and the chemical manufacturers to achieve off-label clearances for products in crops where there are serious problems. The same procedure may need to be set up for 'minor' arable crops such as linseed and sunflower, otherwise these crops may have no approved herbicides in the foreseeable future.

7.2 WINTER OILSEED RAPE

The main area of concern relating to weed control in winter oilseed is deciding if and what level of weed control is required. It is clear that in many situations broad-leaved weed control is not justifiable in purely economic terms, as the yield improvement from control does not match the cost of treatment (see 3.2.3.2). The same is true to a lesser extent with grass weeds, but with these species there is already some data to provide guidelines on likely threshold densities. Similar information is not available for broad-leaved weeds, where the potential for cost saving is greater.

Two problems require answers before clear guidance can be given to growers. Firstly, how can one estimate the likely effects of a mixed infestation of broad-leaved weeds on rape yields, from assessments of the crop and weeds made in the autumn, when decisions on herbicide applications have to be made. Secondly, what are the effects of low doses of herbicides that do not completely kill the weeds, but only suppress their growth. In order to answer the first question two alternative (complementary ?) systems need study ; i) assessments based on weed numbers and ii) assessments based on weed ground cover. The first is more laborious but provides more detailed, quantitative information, whilst the latter is quicker and takes into consideration the vigour of the weeds, but is qualitative. The results from both types of assessment may need qualifying with estimates of crop vigour. These alternative systems need testing experimentally and then 'in practice' to assess their accuracy and predictability.

The answers to the second question relating to the effects of low doses, will depend on identifying situations where no control of broad-leaved weeds results in predictable yield losses. Once these situations have been identified it will be possible to extend the competition studies to cover the effects of partial weed control from herbicides. Preliminary studies of the effects of low doses on weed growth would be essential, in order to establish the dose response curves of the herbicides. Some work has already been done in this area (see 5.2.1.3) but more is needed.

The previous paragraphs assume that effective post-emergence herbicides are available for the control of all the weeds present. At the moment broad-leaved weed control decisions are often made before the crop emerges, because the herbicide with the widest weed spectrum, metazachlor, needs to be applied pre- or early post-emergence. Threshold systems will operate satisfactorily provided the weeds present are sensitive to the late post-emergence herbicides such as propyzamide, benazolin and clopyralid. The potential for post-emergence threshold systems will increase once the new broad-spectrum dimefuron mixtures (King & Turner, 1989; Mayes et al., 1989) become available. Some weeds in winter rape are not well controlled by currently available herbicides, Crucifer weeds and cleavers are especially difficult to control. There is a need for research to try to improve the reliability of control of these weeds, particularly cleavers, which can be extremely competitive, can hinder harvesting and can contaminate the harvested rape seed. The performance of pyridate, arguably the most effective herbicide on cleavers, is extremely variable (see 5.2.1.2) and studies of the reason for this variability would be of considerable value. Although more effective products are being developed (eg quinmerac), there is no guarantee that these will gain approval, even in the long term. Crucifer weeds, although also difficult to control and posing a potential threat to the glucosinolate levels of the harvested rape seed, are of less concern than cleavers. This is because some control can be achieved with cyanazine and with benazolin + clopyralid, severe winter weather will damage and kill the plants and seed shedding by these weed species tends to occur before the rape harvest, minimising the contamination problem.

Although the competitive effect of weeds is the main reason for wishing to control them, the other adverse effects of weeds should not be completely ignored. Arguably of greatest concern, is the effect of not controlling weeds in one crop on the weed problems in the subsequent ones. Although this is theoretically a serious problem, the research that has been done indicates that it is not too critical. However, rape and other oilseeds have a value as cleaning crops. The control of grass weeds, such as black-grass for example, is particularly valuable in order to minimise infestations in subsequent cereal crops. This may assume even greater significance with the advent of the ban on straw burning. Other adverse effects, such as effects on disease or harvesting efficiency, appear to be of less importance.

7.3 SPRING OILSEED CROPS

The main problems with the three spring-sown oilseed crops (spring rape, linseed and sunflower) stem from the limited range of products available for the control of weeds in these crops. As outlined earlier in this section (see 7.1) this problem is likely to become worse rather than better, unless the industry can establish some 'off-label' uses. The most serious problems arise in linseed, because of its lack of vigour and poor competitive ability in its early stages. The other two crops, especially spring rape, are vigorous and will suppress many weeds. So although both crops only have two or three broad-leaved weed herbicides approved, and consequently some weeds are hard to control, practical problems resulting from poor weed control are not common. With linseed the problems are more severe and some independent investigations of alternative herbicides that are not damaging to the crop would be extremely valuable.

7.4 VOLUNTEER OILSEED RAPE

Volunteer rape plants arising from seed shed by oilseed rape crops are causing serious problems for subsequent rape crops, as a result of contamination, and to growers of broad-leaved crops, where vigorous rape plants are very difficult to control. Substantial amounts of seed are left in the field at harvest, providing an appreciable source for subsequent weed problems. More efficient harvesting, and/or the breeding of more leathery, less shatter-prone pods into rape, would reduce the severity of the problem. As these two solutions do not appear imminent, growers are faced with a continuing problem. It is not known what influences the persistence of rape seed, nor what factors would minimise this persistence. General observations suggest that seed buried by ploughing will persist longer than seed left on or near to the soil surface. An understanding of the reasons for persistence will provide a basis for guidance on its minimisation.

8. RECOMMENDATIONS

1. Winter Oilseed Rape - Weed Competition Research is needed to identify when weed control is economic and when it is not. This work should concentrate on broad-leaved weeds, as this is where potential savings appear greatest. In addition, a simple system is needed to predict yield loss from weed assessments made in the autumn. These could be based on plant (weed) numbers, or on % ground cover of crop and weed, or a combination of the two. Current programmes have already identified the importance of crop vigour in determining the outcome of grass weed competition. No similar data is available for broad-leaved weeds. New research is required to study the effects of low doses of herbicides, on the competitive effects of the weeds.

2. Winter Oilseed Rape - Problem Weeds

Not all weed species are easily controlled in winter rape. There is a need to develop more reliable control measures for cleavers and 'Crucifer' weeds. Current herbicides are unreliable but could be improved by the addition of other products or formulating agents. This needs investigation.

3. Winter Oilseed Rape - Adverse Effects (apart from competition)

A number of other features relating to the effects of weeds on rape agronomy, such as potential crop contamination and disease carry over, need to be considered once competition thresholds have been generated. At present the rotational impact of weed control decisions in rape appears most important. However, this importance has not as yet been quantitatively assessed.

4. Spring Rape

This crop is well able to suppress weed competition and so herbicide-based weed control is rarely necessary. Additional herbicides for control of currently intransigent weeds would be welcome.

5. Linseed

This crop competes poorly with the more aggressive weeds and so herbicide treatments are needed to maintain yields. Research on weed control and crop tolerance is needed to identify other products that could be used safely and effectively in this crop, to control currently intransigent weeds.

6. Volunteer Oilseed Rape

The seedlings arising from seed shed at harvest are posing increasing problems both to the next rape crop and to other subsequent broad-leaved crops, where control in difficult. The length of persistence and factors affecting it are largely unknown, and could be studied relatively simply.

7. 'Minor uses'

The number of herbicides available for spring oilseed crops is limited. Current reviews of pesticides being conducted by MAFF may result in the withdrawal of some herbicides, making weed control even more difficult. As the costs of registration for these small acreage crops are much higher than any potential profits from the sale of the products, any development of new herbicides will have to be based on a collaborative approach involving manufacturers, government funded research organisations and growers.

9. REFERENCES

ANON (1983) Linseed for seed MAFF Booklet, **2286**, pp15.

ANON (1990) British Agrochemicals Association Annual Review and Handbook 1989/90, pp40.

BLACKSHAW, R.E., ANDERSON, G.W. & DEKKER, J. (1987) Interference of Sinapis arvensis L. and Chenopodium album L. in spring rapeseed (Brassica napus L.). Weed Research **27**, 207-213.

BOWERMAN, P. (1984) Comparison of harvesting methods of oilseed rape. Aspects of Applied Biology **6**, Agronomy, physiology, plant breeding and crop protection of oilseed rape, 157-165.

BOWERMAN, P. (1989) Weed control in winter oilseed rape - review of ADAS trials (1985-1987). Aspects of Applied Biology **23**, Production and protection of oilseed rape and other brassica crops, 219-226.

CONNOLLY, J. (1988) Experimental methods in plant competition research in crop-weed systems. Weed Research **28**, 431-436.

COVARELLI, G. & TEI, F. (1984) Competition entre tournesol et Sinapis arvensis a differents niveau d'infestation. 7th Colloque Internationale on Weed Biology, Ecology and Systematics (COLUMA/EWRS), 323-330.

COUSENS, R. (1985) A simple model relating yield loss to weed density. Annals of Applied Biology **107**, 239-252.

COUSENS, R.D, BRAIN, P., O'DONOVAN, J.T. & O'SULLIVAN, P.A. (1987) The use of biologically realistic equations to describe the effects of weed density and relative time of emergence on crop yield. Weed Science **35**, 720-725.

COUSENS, R.,FIRBANK, L.G., MORTIMER, A.M. & SMITH, R.G.R. (1988) Variability in the relationship between crop yield and weed density for winter wheat and Bromus sterilis. Journal of Applied Ecology **25**, 1033-1044.

CUSSANS, G.W. (1978) The problem of volunteer crops and some possible means of their control. Proceedings 1978 British Crop Protection Conference - Weeds, 915-921.

CUSSANS, G.W. (1991) Weed control strategies -- research progress. Proceedings of the First Annual Conference on Cereals R & D. Home - Grown Cereals Authority, 2.1 - 2.19.

CUSSANS, G.W., COUSENS, R.D.& WILSON, B.J. (1986) Thresholds for weed control - the concepts and their interpretation. Proceedings E.W.R.S. Symposium - Economic Weed Control, 253-260.

CUSSANS, G.W. & ROLPH, J. (1990) Herbmast--A herbicide selection system for winter wheat. Proceedings E.W.R.S. Symposium - Integrated Weed Management in Cereals, 451-457.

DAVIES, D.H.K. (1987a) Effect of herbicides on weed control and crop yield in winter oilseed rape in south-east Scotland. Proceedings British Crop Protection Conference - Weeds, 815-820.

DAVIES, D.H.K. (1987b) Evaluation of sulphonylurea herbicides for use in flax and linseed in south-east Scotland. Proceedings British Crop Protection Conference - Weeds, 815-820.

DAVIES, D.H.K. & RICHARDS, M.C. (1984) Trials with herbicides in flax (Linum usitatitissimum). Proceedings Crop Protection in Northern Britain, 234-239.

DAVIES, D.H.K., WALKER, K.C. & WHYTOCK, G.P. (1989) Herbicide use and yield response in winter oilseed rape in Scotland. Aspects of Applied Biology **23**, Production and protection of oilseed rape and other brassica crops, 227-235.

DAVIS, R.P., GARTHWAITE, D.G. & THOMAS, M.R. (1990) Pesticide usage survey: arable farm crops, 1988. M.A.F.F. Survey Report **78**, (reference booklet 578), pp56.

DE ST.REMY, E.A. & VANDEN BORN, W.H. (1989) How does the time of volunteer barley emergence affect spring rapeseed growth and yield? Abstracts Weed Science Society of America **29**, 57.

DE WIT, C.T. (1960) On competition. Versl. Landbouwk. Onderz. **66**, 1-82.

DIEPENBROCK, W. & LEAN, J. (1988) Quantitative effects of volunteer plants on glucosinolate content in double-low rapeseed (Brassica napus L.): a theoretical approach. Agronomie **8**, 373-377.

DINGEBAUER, G. (1990) Untersuchung zur tolerierbaren Verunkrautung in Winterraps-kulturen. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderh. **XII**, 315-328.

DIXON, F.L. & LUTMAN, P.J.W. (1991) The effects of drilling date on the growth and yield of sunflower (Helianthus annuus) in the U.K. Journal of Agricultural Science (in press).

DOVER, P.A., ROEBUCK, J.F. & WOOLLEY, E.W. (1987) Broadleaved weed control in linseed. Proceedings British Crop Protection Conference - Weeds, 829-836.

ENGLEMANN, R. von (1989) Unkrautbekämpfung in faserlein. Gesunde Pflanzen **41**, 174-175.

FIRBANK, L.G. & WATKINSON, A.R. (1985) On the analysis of competition within two-species mixtures of plants. Journal of Applied Ecology **22**, 503-518.

FRIESEN, G.H. (1986) Effect of weed interference on yield and quality of flax seed oil. Canadian Journal of Plant Science **66**, 1037-1040.

FRIESEN, L., MORRISON, I.N., MARSHALL, G. & ROTHER, W. (1990) Effects of volunteer wheat and barley on the growth and yield of flax. Canadian Journal of Plant Science **70**, 1115-1122.

FROUD-WILLIAMS, R.J. & CHANCELLOR, R.J. (1987) A survey of weeds of oilseed rape in central southern England. Weed Research **27**, 187-194.

GARRETT, H.J. & ORSON, J.H. (1989) Depth and date of emergence of volunteer oilseed rape (Brassica napus L.) and its control with herbicides used in peas, beans, potatoes and sugar beet. Proceedings British Crop Protection Conference - Weeds, 811-816.

GEROWITT, B. (1990) Ein Entscheidungsmodell zur Unkrautbekämpfung nach Schadensschwellen im Wintergetreide. Proceedings E.W.R.S. Symposium - Integrated Weed Management in Cereals, 467-474.

GEROWITT, B. & HEITEFUSS, R. (1990) Weed economic thresholds in cereals in the Federal Republic of Germany. Crop Protection **9**, 323-331.

GRÄPEL, H. & SCHILLER, R. (1988) Versuche zur Ermittlung wirtschaftlicher Schadensschwellen für die Unkrautbekämpfung in Winterraps und Möglichkeiten der praktischen Anwendung. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderh. **XI**, 147-153.

GUMMESSON, G (1985) Weed control in spring oilseeds. Proceedings 26th Swedish Weed Conference (Reports), 56-85.

HALLGREN, E. (1990) Time, stoppages, losses, moisture content in the combined material and proportion of screenings at different amounts of weeds in barley. Proceedings 31st Swedish Crop Protection Conference - Weeds and Weed Control (Reports), 125-138.

HARPER, J.L. (1977) Population Biology of Plants. Academic Press, London, New York, pp892.

ICKERINGILL, D. (1985) The use of cyanazine alone, in mixture and in sequence for weed control in oilseed rape. Proceedings British Crop Protection Conference - Weeds, 239-246.

JENSEN, P.K. (1987) Thresholds for weeds in spring oilseed rape. 4. Danske Plantevaernskonferenz - Ukrudt, 129-139.

JENSEN, H.A. (1990) Occurrence of weed seeds in samples of cereals and other field crops, examined during the period 1969-89. 7. Danske Plantevaernskonferenz - Ukrudt, 65-71.

JOHNSON, B.J. (1971) Effect of weed competition on sunflowers. Weed Science **19**, 378-380.

KAYSER, A. & HEITEFUSS, R. (1990) Influence of weeds on the infection of winter oilseed rape (Brassica napus L. var. oleifera Metzger) with fungal pathogens. Proc. I.O.B.C. Conference. Diseases, Pests, Weeds and Integrated Control in Oilseed Rape. Paderborn, (in press).

KING, J.M. & TURNER, M.T.F. (1989) A dimefuron/benazolin mixture for broad-leaved weed control in winter oilseed rape. Proceedings British Crop Protection Conference - Weeds, 859-864.

KLOSTERMYER, J. (1989) Competition by Stellaria media (L.) Vill and Matricaria inodora L. in oilseed winter rape (Brassica napus L. var.napus) and development of an empirical decision model for post-emergence weed control. PhD. Thesis Georg-August Universität, (Göttingen), pp85.

KÜST, G. (1989) Erarbeitung vorläufiger schadensschwellen und eines enscheidungsmodells zur unkrautbekämpfung im winterraps (Brassica napus L. var. napus) unter berücksichtigung der artspezifischen konkurrenz von unkräutern und ausfallgerste. PhD. Thesis Georg-August Universität, (Göttingen), pp82.

KÜST, G., HEITEFUSS, R. & WAHMHOFF, W. (1990) Ein vorläufiges Modell zur Unkrautbekämpfung nach Schadensschwellen im Winterraps. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderh. **XII**, 339-346.

KÜST, G., WAHMHOFF, W. & HEITEFUSS, R. (1988) Untersuchungen zur Erfassung der artspecifischen Koncurrenz ausgewählter Unkräuter in Winterraps als Grunlage für die Erarbeitung von Schadensschwellen. Mitteilungen aus der Biologischen Bundesanstalt für Land- und Forst- wirtschaft (245): 46 Deutsche Pflanzenschutz-Tagung, 192.

LUTMAN, P.J.W. (1984) The effects of weed competition on the growth and yield of oilseed rape. Aspects of Applied Biology **6**, Agronomy, physiology, plant breeding and crop protection of oilseed rape, 209-220.

LUTMAN, P.J.W. (1985) Effects of dalapon and TCA on the growth and yield of oilseed rape (Brassica napus). Annals of Applied Biology **107**, 515-527.

LUTMAN, P.J.W. (1989) Objectives of weed control in oilseed rape. Aspects of Applied Biology **23**, Production and protection of oilseed rape and other brassica crops, 199-210.

LUTMAN, P.J.W. & DIXON, F.L. (1985) The effect of the timing of control of grass weeds on the yield of oilseed rape. Proceedings British Crop Protection Conference - Weeds, 209-216.

LUTMAN, P.J.W. & DIXON, F.L. (1986) The effect of drilling date on competition between volunteer barley and oilseed rape. Proceedings E.W.R.S. Symposium, Economic Weed Control, 145-152.

LUTMAN, P.J.W. & DIXON, F.L. (1990) The competitive effect of volunteer barley (Hordeum vulgare) on the growth of oilseed rape (Brassica napus). Annals of Applied Biology **117**, 633-644.

LUTMAN, P.J.W. & DIXON, F.L. (1991) Weed competition in winter oilseed rape in the United Kingdom. I.O.B.C. Conference. Diseases, Weeds, Pests and Integrated Control in Oilseed Rape, Paderborn (in press)

MAHN, E. (1988) Changes in the structure of weed communities affected by agro-chemicals - what role does nitrogen play? Ecological Bulletins **39**, 71-73.

MARSHALL, G. MORRISON, I.N.,FRIESEN, L. & ROTTER, W. (1989) Effects of volunteer wheat and barley on the growth and yield of rapeseed. Canadian Journal of Plant Science. **69**, 445-453.

MAYES, A.J., MARSHALL, J. & HARRIS, R.I. (1989) Weed control in oilseed rape with a benazolin, clopyralid, dimefuron coformulation. Proceedings British Crop Protection Conference - Weeds, 865-870.

MELANDER, B. (1990) Yield loss in cereals, peas and rape due to competition from couch (Elymus repens). 7. Danske Plantevaernskonferenz - Ukrudt, 157-170.

MOSS, S.R. (1985) The effect of cultivation system and soil factors on the performance of herbicides against Alopecurus myosuroides. Annals of Applied Biology **107**, 253-262.

NIX, J. (1990) Farm Management Pocketbook. Wye College, Kent. pp211.

NUYKEN, W., HADEN, E., MENCK, B.H. & KLINGENSCHMITT, D. (1985) BAS 518 H - a new herbicide for weed control in cereals, rapeseed and sugarbeets. Proceedings British Crop Protection Conference - Weeds, 71-76.

OGILVY, S.E. (1989) The effects of severity and duration of volunteer barley competition on the yield of winter oilseed rape - a review of ADAS trials, 1986-87. Aspects of Applied Biology **23**, Production and protection of oilseed rape and other brassica crops, 237-246.

O'DONOVAN, J.T., KIRKLAND, K.J. & SHARMA, A.K. (1989) Canola yields and profitability, as influenced by volunteer wheat infestations. Canadian Journal of Plant Science **69**, 1235-1244.

ORSON, J.H. (1984) The control of volunteer cereals in winter oilseed rape. ADAS results harvest years 1982 and 1983. Aspects of Applied Biology **6**, Agronomy, physiology, plant breeding and crop protection of oilseed rape, 179-184.

PARISH, S. (1990) A review of non-chemical weed control techniques. Biological Agriculture & Horticulture **7**, 117-137.

POOLE, M.L. & GILL, G.S. (1987) The use of weed density - crop yield relationships for predicting yield losses in the field. Proceedings British Crop Protection Conference - Weeds, 945-954.

REGNAULT, Y. (1984) The control of grass weeds in oilseed rape in France. Aspects of Applied Biology **6**, Agronomy, physiology, plant breeding and crop protection of oilseed rape, 185-190.

REGNAULT, Y. & ADAM, C. (1989) Cahier technique colza - désherbage. Publication CETIOM, pp20.

ROEBUCK, J.F. & FLINT, C.E. (1985) A review of ADAS trials for recently introduced specific grass weed herbicides for winter oilseed rape and the effect on yield of the timing of removal of volunteer cereals. Proceedings British Crop Protection Conference - Weeds, 199-208.

ROUSH, M.L., RADOSEVICH, S.R., WAGNER, R.G., MAXWELL, B.D. & PETERSEN, T.D. (1989) A comparison of methods for measuring effects of density and proportion in plant competition experiments. Weed Science **37**, 268-275.

SANSOME, G. (1989) Effect of crop populations on the performance of herbicides in winter oilseed rape. Aspects of Applied Biology **23**, Production and protection of oilseed rape and other brassica crops, 257-262.

SAUR, R. & LÖCHER, F. (1986) Unkräuter als Wirtspflanzen von Sclerotinia sclerotiorum (Lib.) de Bary. Proceedings E.W.R.S. Symposium - Economic Weed Control, 225-232.

SCHWERIN, C.W. (1989) Auswirkung der Herbicidanwendung und Verunkrautung auf Laufkäfer (Col. Carabidae) im Winterraps. EWRS Newsletter (45), 17.

SHEPPARD, B.W., DAVIES, D.H.K., RICHARDS, M.C. & WHITING, A.J. (1989) Effects of weeds on cereal harvesting efficiency and grain quality, and the economic consequences of reduced weed control. Proceedings British Crop Protection Conference - Weeds, 961-966.

TURNER, J. (1987) Linseed Law - a Handbook for Growers and Advisers. BASF United Kingdom, pp356.

WAHMHOFF, W. (1990a) The use of economic thresholds over a three year period in cereal crop rotations and the effects on weed infestation two years later. Proceedings E.W.R.S. Symposium - Integrated Weed Management in Cereals, 323-330.

WAHMHOFF, W. (1990b) Unkrautbekämpfung im Winterraps - Auswertung von Herbizid versuchen aus den Jahren 1971 bis 1988. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderh. **XII**, 329-338.

WALKER, K.C., WHYTOCK, G.P. & DAVIES, D.H.K. (1990) Evaluation of yield response and financial benefits from weed control in oilseed rape in Scotland. Proceedings Crop Protection in Northern Britain, 301-306.

WARD, J.T. & TURNER, E.W. (1985) Annual grass and broad-leaved weed control in winter oilseed rape. Proceedings British Crop Protection Conference - Weeds, 223-230.

WHITEHEAD, R. & WRIGHT, H.C. (1989a) The incidence of weeds in winter oilseed rape in Great Britain. Aspects of Applied Biology **23**, Production and protection of oilseed rape and other brassica crops, 211-218.

WHITEHEAD, R. & WRIGHT, H.C. (1989b) The incidence of weeds in winter cereals in Great Britain. Proceedings British Crop Protection Conference - Weeds, 107-122.

WHYTOCK, G.P. & CARNEGIE, H.M. (1990) A survey of weeds in oilseed rape fields in north-east Scotland. Proceedings Crop Protection in Northern Britain, 307-312.

WILSON, B.J. & WRIGHT, K.J. (1990) Predicting the growth and competitive effects of annual weeds in wheat. Weed Research **30**, 201-212.